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On the Role of Regulatory Standards: Specification and Some Empirical Evidence from Motor Vehicle Fuel Economy

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ABSTRACT

This paper proposes a simple model to evaluate the role of regulatory controls. It is formulated so as to enable drawing empirical conclusions on the basis of usual hypothesis tests. Three potential roles of standards are examined: they can act as penalties for non-compliant firms, as norms to which all firms converge, and as controls with cumulative impact over time. I test this specification focusing on automobile fuel economy (CAFE) standards that have been imposed in the US since 1978, using annual data from each major auto manufacturer. Results show that CAFE rules, functioning mainly as penalties, have been an important determinant of car fuel consumption. The hypothesis that standards acted also as norms is rejected. Finally, the automobile industry as a whole became less constrained by regulations over the years because of stagnating CAFE standards since 1990 and progress in vehicle technology.

Keywords: regulation; compliance; penalty; CAFE; automobile

JEL classification: L51; Q58

1. Introduction

The effect of regulatory standards has been studied extensively in the public economics literature, largely with focus on environmental regulations. There have been significant theoretical contributions (and some empirical demonstrations as well) on several related issues such as: the comparison between performance and design standards [2] or between price-based and quantity-based regulations [32]; the effectiveness of market mechanisms, e.g. emission permits, versus command-and-control standards [16]; or aspects of regulatory enforcement such as whether compliance can be maximized through targeting firms [17, 20] or self-reporting [29], how to define penalties for noncompliant firms [24] or whether to warn them before imposing fines [34]. Extending the investigation to health insurance markets, Finkelstein [9] examined the empirical evidence of the effect of binding minimum standards on the market for voluntary private health insurance for the elderly in the US.

In energy and environmental issues, the importance of fuel economy (FE) regulations for motor vehicles is a much debated topic because, among the various adverse side effects of transportation such as congestion, traffic accidents and local air pollution, energy and climate change related impacts are prominent. The share of transportation in total energy use and greenhouse gas emissions is increasing worldwide because demand for private mobility is still growing and automobile energy efficiency remains virtually stagnant. Advanced energy saving and low carbon-emitting technologies like fully electric vehicles or fuel cells are not expected to experience significant penetration rates very soon. It is therefore important to achieve considerable energy efficiency improvements for vehicles entering the market in the near future which will largely be powered by conventional engines and fuels.

One way to raise the fuel economy[1] of new cars is through standards, either mandatory or as a voluntary commitment of the automotive industry. A second way is to increase fuel taxation in order to induce purchases of more efficient cars and discourage private car travel. Mandatory FE standards (Corporate Average Fuel Economy – CAFE – standards) have been in force in the US since 1978. Other countries followed later, and currently Canada, Australia, Japan, the 15 old EU Member States, Switzerland, China, Taiwan and South Korea have implemented some type of standards. Although the adoption of standards has induced FE improvements, there are voices arguing against standards and favoring increases in fuel taxes instead because welfare impacts are estimated to be lower under the latter option.

In this policy context, FE regulations have been the subject of both theoretical and empirical exploration, mainly in the US. Several approaches have been used in the attempt to analyze the effects of standards on automobile fuel economy, from cross-section time series analyses [8, 22] to partial and general equilibrium models [1, 12, 26, 27, 35, 41]. A key feature in most of these analyses is the simulation of the

[1] The equivalent terms fuel economy (expressed in miles per gallon) and fuel consumption (expressed in liters per 100 kilometers) are linked by the following relationship: fuel consumption (l/100 km) = 235.2 / fuel economy (mpg).

decision-making process of automobile manufacturers: producers maximize profits or minimize costs depending, inter alia, on whether FE regulations represent a binding constraint for them or not. Extending the discussion to air pollutant emissions, Khazzoom [25] and Harrington [18] have explored potential linkages between fuel economy and vehicle emission regulations.

In a different field, studying the effects of government controls on UK firm dividends, Mayer and Pashardes [31] explored three ways that regulations may affect company behavior: they can act as penalty thresholds, as norms towards all firms converge, or as controls with cumulative impact over time. In this paper I adopt this framework for the study of motor vehicle fuel economy standards. I develop a simple theoretical model for new car fuel consumption that is general enough to accommodate all three aspects of standards mentioned above, in a way that enables testing these assumptions on empirical grounds with simple hypothesis tests. I then apply the model using firm level data of automobile sales in the US from 1975 to 2006.

In the context of automobile fuel economy, most studies employed cross-section time series analyses and did not include standards explicitly as an explanatory variable (see e.g. [8, 22, 40]), with the exception of Gately [10] and Small and van Dender [38] who used a regulatory variable in a time series context. [13] may be the only study applying a model that is similar to the first stages of this approach. The method proposed here, however, significantly extends that of Greene [13] as his objective was primarily to test the role of standards as constraints on some firms, which is only the first of the three potential roles of standards that I will explore here.

A feature of many models that have been designed to assess the effectiveness of CAFE rules is that they simulate decisions of firms, such as shifting their sales mix from (more profitable) bigger to smaller cars [26, 27], from cars to (less constrained by CAFE) light trucks [1, 35, 41], or from domestic to imported vehicles [12]. As such firm behavior cannot be captured explicitly by the model presented in this paper, the primary intention of the model is to explore the same issue from a different viewpoint. As I will explain in Section 2, examining regulations in this way has important implications for the evaluation of energy and environmental policies. Moreover, I will try to show at the end of this paper that the proposed model can be employed in other regulatory frameworks and thus can contribute to the empirical assessment of standards or other types of controls.

The next section provides a description of the three types of regulatory effects that I will explore. Section 3 presents the model specification. Section 4 describes how the theoretical model was adapted for the needs of the empirical analysis. Section 5 outlines the application of the model utilizing company level data from US automobile manufacturers and mentions potential policy implications of the results. Section 6 concludes and outlines possible extensions of the method so that it can be applied in other regulatory settings as well.

2. The different roles of regulations

As already mentioned, [30] explored three ways that regulations may affect company behavior: they can act as penalties, as norms, or as controls with cumulative impact. The following paragraphs will clarify each one of these concepts.

The penalty role is straightforward. For example, CAFE rules in the US foresee that each manufacturer whose fleet-average fuel economy figure is lower than the standard will pay as a fine 5.5 US$ per car sold per 0.1 mpg of shortfall. In the European Union (EU), manufacturers have voluntarily committed themselves to reducing the average amount of carbon dioxide (CO_2) emitted by new cars at 140 grams per kilometer by the year 2008, compared to the 1995 average of 185 g/km[2]. In this case there is no explicit penalty, but non-attainment of the target may force policy makers to make more stringent decisions in the future, and may also lead to some loss of reputation among the environmentally conscious public, so that it can be viewed as an implicit fine to be paid by the industry.

Secondly, standards may act as norms in the sense that firms which consistently perform better than required may find it more profitable to worsen their performance to some extent, provided that they still outperform the standard. Suppose that a specific manufacturer produces smaller-than-average cars and therefore its sales-weighted fuel economy is higher than the standard. Regulatory compliance offers this company a comparative advantage over those firms which are constrained by regulations and are forced to downsize and/or improve technically their products, or otherwise pay the fines due to non-compliance. Thus such a manufacturer may gradually shift its production towards bigger cars, whose production is generally more profitable than that of small cars[3]. This can be effected if compliant firms abstain from investing on fuel-saving technologies and put more emphasis on offering more powerful and comfortable automobiles. The estimates of Greene [13] provide some evidence from such firm behavior in the US as a result of CAFE regulations: a tighter standard seems to lead not only to a change in the mix of vehicles produced by a constrained firm so as to meet the standard, but also to increased consumer demand for less fuel efficient vehicles of unconstrained firms. Japanese auto producers were typical examples of unconstrained firms in the US market, particularly in the late 1970s and early 1980s when US manufacturers were considerably affected by CAFE regulations. Thorpe [41] explains in detail the theoretical background of this aspect, and his general equilibrium simulations provide similar evidence. However, the simulations depend critically on the magnitude of the substitution elasticities he uses, and in fact his sensitivity analysis shows indeterminate evidence about the real size of this effect in the US market.

Finally, the cumulative aspect of standards has been reported by Poterba [37] in the case of UK government controls on firm dividends during the 1970s. According to this, the effect of standards cumulates over time, and the value of the control variable

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[2] CO_2 emissions are proportional to fuel consumption, so that CO_2 emission standards are roughly equivalent to fuel economy standards.

[3] Sperling et al. [39] provide a review of evidence that larger cars are more profitable to the industry than smaller ones.

relates not only to the actually observed value of past years but also to its 'notional' value, i.e. the value that the variable would have taken in the absence of any standards. In our case, this hypothesis implies that fuel economy depends, apart from the standard, on the unconstrained fuel economy level that would satisfy consumer requirements; this in turn depends on market characteristics such as fuel prices, technological progress, and consumer preferences for vehicle size, top speed or maximum vehicle power.

A consequence of this hypothesis is that a 'catch-up' effect can occur if regulations are lifted. This may be particularly relevant in the automobile market: consumer preferences for ever bigger and more powerful cars might continuously shift upwards the 'notional' value of vehicle fuel consumption, thus putting continuously more burden on firms to meet the standards. Conversely, technical progress or other effects may decrease this notional value so that compliance may become easier over the years, even despite stricter regulations. Depending on the difference between notional and actual fuel consumption, an eventual abolition of standards might (or might not) lead to a sharp deterioration of fuel economy.

Examining these roles of standards has crucial implications for the assessment of regulatory energy and environmental policies and can provide *ex post* answers to questions such as: Were firms really constrained by specific regulations (i.e. did regulations indeed act as penalties)? Did standards have undesirable side effects (i.e. did they act as norms for compliant firms)? If regulations are relaxed or abandoned, how might firms respond (i.e. do standards have a cumulative impact)? Such questions can only be answered if these individual regulatory effects are modeled explicitly.

3. Theoretical specification

Suppose that a vehicle manufacturer produces cars with average fuel consumption (measured in liters per 100 kilometers) equal to F, while the optimal fuel consumption level of its vehicle fleet (i.e. the level that would maximize its profits) is F^*, with F^* depending on consumer preferences, retail fuel prices and other factors. Any deviation of actual fuel consumption from its market optimum incurs costs C_M to the firm. Assuming these costs to be quadratic in order to have a quite general specification that allows F to be greater or less than F^*, it follows that

$$C_M = \alpha_1 (F^* - F)^2 \qquad (1)$$

with $\alpha_1 \geq 0$.

Non-compliance with the FE standard F^R will also lead to costs C_R for the firm. As already mentioned, the fine to be paid by a non-compliant firm amounts to 5.5 US$ per car sold per 0.1 mpg of shortfall, which indicates a linear penalty function. In order, however, to account for additional indirect costs of non-compliance (such as bad publicity)[4], a more general quadratic function is allowed for C_R:

$$C_R = \alpha_0 (F - F^R)^2 \tag{2}$$

with $\alpha_0 \geq 0$. This formulation allows costs to occur both when $F > F^R$ and $F < F^R$. In other words, it includes both the 'penalty' and the 'norm' hypothesis for the standard as explained in the section 2. Since, however, we want to be able to test these two hypotheses separately, we can take $\alpha_0 = \alpha_2 + \alpha_3$ so that equation (2) becomes

$$C_R = (\alpha_2+\alpha_3)(F - F^R)^2 \tag{3}$$

where

$\alpha_2 > 0$ and $\alpha_3 = 0$ if $F > F^R$ (regulation acting as penalty for non-compliance)

$\alpha_2 = 0$ and $\alpha_3 > 0$ if $F < F^R$ (regulation acting as a norm)

The total costs to the firm will be $C = C_M + C_R$. From equations (1) and (3) we get

$$C = \alpha_1 (F^* - F)^2 + (\alpha_2+\alpha_3)(F - F^R)^2 \tag{4}$$

with α_2 and α_3 taking the values mentioned above.

Minimizing this cost function, i.e. setting $dC/dF = 0$, we get

$$2\alpha_1 (F - F^*) + 2(\alpha_2+\alpha_3)(F - F^R) = 0 \tag{5}$$

and, solving for F, we derive the simple fuel consumption model

$$F = (1 - \beta_2 - \beta_3) F^* + (\beta_2 + \beta_3) F^R \tag{6}$$

where $\beta_2 = \dfrac{\alpha_2}{\alpha_1+\alpha_2+\alpha_3}$ and $\beta_3 = \dfrac{\alpha_3}{\alpha_1+\alpha_2+\alpha_3}$. Following the above definitions of α_2 and α_3 we get

$$\beta_2 > 0 \text{ and } \beta_3 = 0 \text{ if } F > F^R \tag{6a}$$

$$\beta_2 = 0 \text{ and } \beta_3 > 0 \text{ if } F < F^R \tag{6b}$$

Thus equation (6) enables examining empirically three different assumptions:

– the 'penalty' hypothesis by simply testing $\beta_2 = 0$;
– the 'norm' hypothesis by testing $\beta_3 = 0$;
– the significance of standards: if $\beta_2 + \beta_3 = 0$ then standards become ineffective whereas if $\beta_2 + \beta_3 = 1$ standards are the sole determinants of FE levels.

In order to explore the cumulative role of standards on fuel economy, a specification is necessary that enables testing whether it is the actual or the 'notional' (i.e. unconstrained) past fuel economy values that influence current manufacturer decisions. For this purpose, suppose that 'notional' fuel consumption levels can be modeled with the following dynamic equation:

[4] See [13] for a justification of quadratic non-compliance costs. Recently an environmental group evaluated the fuel economy performance of auto manufacturers in Europe and published the results, praising the top-runners; see http://www.transportenvironment.org/Article250.html.

$$F_t^* = k_0 + k^* F_{t-1}^* + \sum_j k_j X_{jt} \tag{7}$$

where $k^* > 0$ and X_{jt} are exogenous variables that determine F_t^*. Reorganizing equation (6) and defining $\beta = \beta_2 + \beta_3$, we get

$$F^* - F = \beta\,(F^* - F^R) \tag{8}$$

Substituting (8) into (7) we get

$$F_t^* = k_0 + k^* \left(F_{t-1} + \beta(F_{t-1}^* - F_{t-1}^R)\right) + \sum_j k_j X_{jt} \tag{9}$$

or $F_t^* = k_0 + k^* F_{t-1} + k(F_{t-1}^* - F_{t-1}^R) + \sum_j k_j X_{jt}$ (10)

with $k = k^* \beta$.

This formulation shows that in each year the unconstrained fuel consumption F_t^* depends on the actual lagged fuel consumption F_{t-1} and the extent to which the firm was constrained by the standard in the previous year (expressed by the term $F_{t-1}^* - F_{t-1}^R$). As both k^* and β are positive, k is also positive and since it is reasonable to expect that $F_{t-1}^* - F_{t-1}^R > 0$, this difference has an increasing effect on current 'notional' fuel consumption.

Substituting (10) into (6) we get

$$F_t = (1 - \beta_2 - \beta_3)\left(k_0 + k^* F_{t-1} + k(F_{t-1}^* - F_{t-1}^R) + \sum_j k_j X_{jt}\right) + (\beta_2 + \beta_3) F_t^R \tag{11}$$

where $\beta_3 = 0$ if $F > F^R$ and $\beta_2 = 0$ if $F < F^R$.

This means for example that if F_{t-1}^* increased because of consumer preferences for more powerful cars or due to low fuel prices, then the distance of F^* from a given standard has grown in the past year, i.e. the manufacturer became more constrained in order to attain the standard. This in turn tends to increase current actual fuel consumption levels and put additional burden to the firm. If such an effect is confirmed empirically (something that can be tested by checking the hypothesis $k=0$ in the above equation), it means that a 'catch-up' effect (i.e. a fast increase in actual fuel consumption) should be expected once the standard is abolished. In case the standard continues to be in force but is not tightened (i.e. F^R remains constant over the years), an eventual continuous increase of F_{t-1}^* will further constrain the firm and make it more difficult to meet the standard.

4. Empirical strategy

An estimable model of equation (11) is the following[5]:

$$F_t = (1-\beta_2 D_2 - \beta_3 D_3)\left(k_0 + k^* F_{t-1} + k(F_{t-1}^* - F_{t-1}^R) + \sum_j k_j X_{jt} \right) + (\beta_2 D_2 + \beta_3 D_3) F_t^R + \varepsilon_t \quad (12)$$

where ε_t is an error term with the usual properties and D_2, D_3 are dummy variables for which:

- $D_2 = 0$ if $F<F^R$ or if F_t^R does not exist (i.e. for all years before the implementation of standards) and $D_2 = 1$ in all other cases;
- $D_3 = 0$ if $F \geq F^R$ or if F_t^R does not exist and $D_3 = 1$ in all other cases.

The unconstrained fuel consumption level F^* is given by equation (7):

$$F_t^* = k_0 + k^* F_t^* + \sum_j k_j X_{jt} + \xi_t \quad (13)$$

with ξ_t an i.i.d. error term.

For periods when standards do not exist, i.e. there is no F^R, F_t is equal to F_t^* and one can estimate k_0, k^* and k_j from equation (13) and use these estimates to estimate equation (12) for the period with standards.

During periods when FE standards are in force, F_{t-1}^* is unobserved. In order to overcome this problem and reach a tractable specification, one can replace the term $(F_{t-1}^* - F_{t-1}^R)$ in equation (12) with a period-specific dummy. From the significance and the magnitude of these time effects one can then make inferences on the value of k as will be shown in the empirical demonstration below.

Thus the empirical strategy involves two steps: a) selection of appropriate exogenous regressors X_j; b) estimation of F from equation (12). These steps will now be described.

Considering the selection of variables X_j, it is reasonable to assume that the 'optimal' fuel economy level F^*, which would materialize if no regulations were in place, is primarily determined by consumer preferences. Consumer choice will in turn depend on per capita income, current and lagged fuel prices and the overall technological level of the firm which determines how consumer preferences for acceleration, top speed, safety, comfort etc. can be met by models that the firm makes available to the market.

Although major vehicle attributes such as engine size, engine maximum power output, top vehicle speed, vehicle mass and acceleration are routinely available data sets for each auto manufacturer, they may be of little use for describing vehicle technology. First, none of these features alone can sufficiently describe the technological level: it is difficult to find any clear linkage between advances e.g. in a vehicle's rolling and aerodynamic resistance (which are crucial for fuel economy) and

[5] In the following equations I have omitted the firm-specific indicator *i* to facilitate presentation.

any one of the above attributes. Second, all of them (plus others derived from them such as the power-to-mass ratio of vehicles) depend on consumer income and fuel prices. To give some examples: a richer population would prefer bigger and more powerful cars; high fuel prices would encourage consumers to trade off some performance for greater fuel economy and hence lower operating costs; and a greater power-to-mass ratio, which may indicate technological advances due to the use of lightweight materials in modern cars, may partly be an effect of fuel prices that have induced this technical progress. Therefore, including one or more vehicle attributes in the list of regressors X_j would lead to endogeneity problems.

Hence it seems wiser to capture the evolution of firm-specific vehicle technology over time through the period-specific dummy that replaces the term $(F_{t-1}^{*} - F_{t-1}^{R})$. Obviously this dummy will account, apart from technical progress, for the composite effect of various other factors such as changing consumer preferences that are not related to income, or increased public awareness (if any) for environmental problems.

Using a maximum lag order of 3 for fuel prices, which is consistent with stated consumer preferences[6] and with the time it may take for manufacturers to adjust their product offerings in order to account for changing consumer demand induced by fuel prices, equation (13) can thus be written as follows:

$$F_t^{*} = k_0 + k^{*} F_{t-1}^{*} + \sum_{l=0}^{3} \left(k_{1l} p_{t-l} \right) + k_2 PCGDP_t + \xi_t \tag{14}$$

where p is real gasoline price per liter and $PCGDP$ is real per capita GDP. Substituting the exogenous X_j regressors in equation (12) and substituting also the period-specific dummy Y_t for the expression $(F_{t-1}^{*} - F_{t-1}^{R})$ as mentioned above we get

$$\begin{aligned} F_t = {} & (1 - \beta_2 D_2 - \beta_3 D_3) \left(k_0 + k^{*} F_{t-1} + kY_t + \sum_{l=0}^{3} \left(k_{1l} p_{t-l} \right) + k_2 PCGDP_t \right) + \\ & + (\beta_2 D_2 + \beta_3 D_3) F_t^{R} + \varepsilon_t \end{aligned} \tag{15}$$

5. Application with US data

5.1. Data description

In the United States, CAFE standards were adopted in 1975 when the ‘Energy Policy Conservation Act’ was enacted into law by Congress[7]. Specific values of standards were enforced starting with model year 1978 for cars and model year 1982 for light duty trucks. The penalty for failing to meet CAFE standards is currently US$5.50 for each tenth of mpg beyond the standard times the total sales volume of vehicles manufactured in a given model year. Since 1975, FE data have been collected for

[6] For example, [13] cites a study which finds that consumers form their expectations about future gasoline prices based on trends over the last sixteen months.

[7] See http://www.nhtsa.dot.gov/cars/rules/cafe/overview.htm.

every manufacturer's fleet and each model year along with several attributes of all individual vehicles such as mass, engine size, type of transmission, number of valves per cylinder etc. The US National Highway Traffic Safety Administration (NHTSA) is responsible for establishing and amending the standards, while the US Environmental Protection Agency (EPA) is responsible for calculating the average fuel economy for each manufacturer. The EPA maintains a comprehensive database and publishes aggregate and detailed information every year. For the analysis described here I used the latest publication [19], which contains data for model years 1975 through 2006. The Agency reports aggregate as well as manufacturer-specific data, distinguishing 8 major automobile manufacturer groups that accounted together for more than 95% of sales of model year 2006 vehicles (DaimlerChrysler, Ford, General Motors, Honda, Hyundai-Kia, Nissan, Toyota and Volkswagen), and a ninth category comprising data of all other firms.

Data are available for the following vehicle categories: passenger cars, station wagons, vans, sport utility vehicles and pickups. Passenger cars and wagons constitute the 'car' group for which CAFE standards were first implemented in 1978, while the latter three categories make up the 'truck' group with its own standards that started in 1982. The 'car' group is quite homogenous, constrained by the same FE standard each year and forming an almost balanced panel of 277 observations (the panel is not perfectly balanced because there are no data for Hyundai-Kia vehicles for years 1975–1985). Conversely, the 'truck' group is heterogeneous: it consists of quite different vehicle types, with some of the vehicles being used as passenger cars and some for goods transport; moreover, it has many gaps in data so that 4 out of the 9 cross-sections (Honda, Hyundai-Kia, Volkswagen and other vehicles) have to be dropped from the sample because of too few observations, thus leaving a sample size of 160. Because of heterogeneity and small sample size of trucks, I based the analysis on the car sample only.

The CAFE legislation foresees that each year the standard for cars is applied separately for the domestically produced and the imported fleet of each manufacturer. Historically, the imported fleet of most manufacturers was more fuel efficient than the domestic one until the end of the 1990s, whereas differences in FE performance almost diminished afterwards[8]. The EPA has stopped using the 'domestic' and 'imported' classification in its reports, noting that: "As the automotive industry has become more transnational in nature, this type of vehicle classification has become less useful". Therefore, it reports data "by groups of manufacturers … to reflect the transnational and transregional nature of the automobile industry" [19, p. 79]. In the analysis presented here, the distinction between 'domestic' and 'imported' fleets would be even less useful since the model that I examine attempts to simulate each manufacturer's behavior; switching between different parts of the fleet of the same firm is part of this behavior to respond to regulatory constraints, so it would not be appropriate to examine 'domestic' and 'imported' fleets of the same firm separately. Another reason for using composite fleet data by manufacturer is that only the NHTSA reports separate 'domestic' and 'imported' FE data but does not report other

[8] See US NHTSA's report 'Summary of Fuel Economy Performance' at http://www.nhtsa.dot.gov/cars/rules/cafe/index.htm

vehicle attributes (e.g. engine power) of each fleet; moreover, the EPA provides a more consistent grouping of manufacturers during the entire period 1975–2006. For these reasons I used the composite (domestic + imported) EPA data.

The EPA reports two sets of FE information: ‘laboratory’ and ‘adjusted’ data. The ‘adjusted’ figures are reportedly closer to real-world vehicle fuel economy. For the purpose of this analysis, however, ‘laboratory’ readings are more appropriate since they are directly comparable with the corresponding CAFE standard, thus enabling the application of the model described in the previous section. Therefore, the ‘laboratory’ data set was employed in this analysis.

Firm-specific data in equation (15) are those for fleet-average fuel consumption and are plotted in Figure 1 for the ‘car’ vehicle group of each one of the nine manufacturers mentioned above. It is evident that in the early 1980s, among major manufacturers, Ford and General Motors were non-compliant, and could only satisfy the regulations by using credits earned by complying in some years to offset shortfalls in others. Others had to pay fines for exceeding the standard[9], while since 1990 there have been some occasions when some firms were penalized for noncompliance.

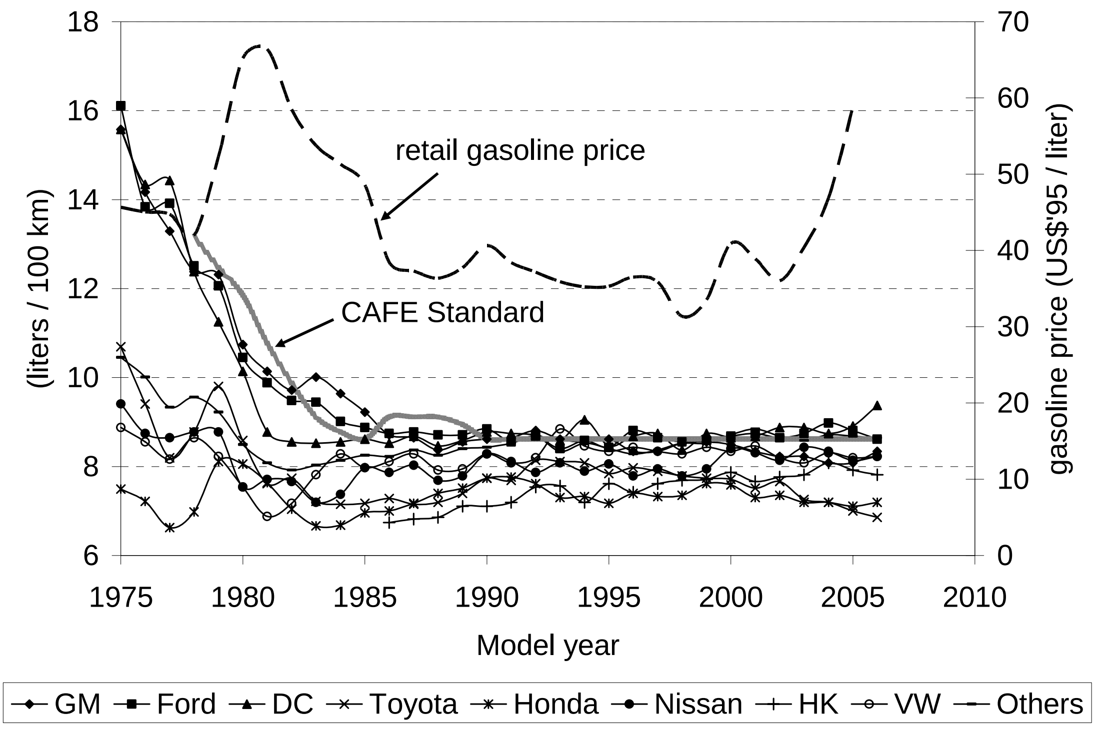

Figure 1: Data by automobile manufacturer group for cars of model years 1975–2006: fuel consumption (weighted average for domestic and imported fleet of each company), fuel prices and the corresponding CAFE standard. Source: [19]. Real gasoline prices come from [21] and [7]. GM, DC, HK and VW stand for General Motors, DaimlerChrysler, Hyundai-Kia and Volkswagen respectively.

[9] Most prominent examples of non-compliant forms were BMW (which is mixed with other firms in the ‘Others’ category of Figure 1) and Mercedes-Benz (which is currently part of the DaimlerChrysler group).

Per capita GDP was derived from data on population and total GDP (in 2000 US dollars) from the US Bureau of Economic Analysis[10]. Real gasoline prices were taken from the International Energy Agency [21] and the US Department of Energy [7].

5.2. Final specification and results

The time effect kY_t of equation (15), which has replaced the term $(F_{t-1}^{*} - F_{t-1}^{R})$, has to be firm-specific because the unconstrained FE level F_{t-1}^{*} differs for each firm. However, using 32 period-specific dummies (for years 1975 through 2006) for each cross-section in a sample with 9 cross-sections only causes collinearity problems. Therefore, I split the 1975–2006 period in three parts: the pre-standard period (1975–1977), the period when standards were becoming continuously tighter (1978–1989) and the period with stagnant CAFE standard (1990–2006). For the two latter periods I constructed dummy variables *D7889* and *D9006* respectively, which take the value of unity during the corresponding period and the value of zero in all other years. For light trucks the corresponding periods were 1982–1995 and 1996–2006. Using these dummies with cross-section specific coefficients in the model one may approach the manufacturers' decision making process avoiding at the same time collinearity problems. Thus, transforming equation (15) as explained above and adding the cross-section identifier *i* where necessary, the model to be estimated becomes:

$$F_{it} = (1 - \beta_2 D_{i2} - \beta_3 D_{i3})\left(k_0 + k^{*} F_{i,t-1} + \delta_{i1} D7889 + \delta_{i2} D9006 + \sum_{l=0}^{3} \left(k_{1l} p_{t-l}\right) + k_2 PCGDP_{it} \right) + \\ + (\beta_2 D_{i2} + \beta_3 D_{i3}) F_t^{R} + \varepsilon_t \qquad (16)$$

To estimate this model, I produced a system of 9 equations for the car model, one for each cross-section. As the equations are not simultaneous but have partly common exogenous regressors, I estimated this system using Zellner's Seemingly Unrelated Regression (SUR) method [44] which allows for contemporaneously correlated errors across the equations.

Table 1 reports the results. Parameter β_2 comes out as significant and takes the value of 0.37. The lagged endogenous and some lagged price variables are also significant, with the overall price effect being about –0.13[11]. Conversely, β_3 has a low value (0.02) and is not significant. The income effect is also very small and insignificant. In line with the model description in section 2, the implications of this result are that:

- CAFE standards seem to have played a major role in determining the fuel economy of cars in the US since their implementation, but were not an absolutely binding constraint: the hypothesis $\beta_2 + \beta_3 = 1$ is rejected at the 1% significance level[12]. Market forces and fuel prices have also affected fuel economy.

[10] Data are available on the World Wide Web at http://www.bea.gov.

[11] The low value of some coefficients in absolute terms (e.g. k_{11}) should not be directly interpreted as a very low impact of prices: variables do not enter as logarithms in the equation, hence these coefficients should not be mistaken for elasticities.

[12] In fact some auto firms, mainly Japanese manufacturers, could relatively easily fulfil the CAFE requirements throughout the 1978–2006 period, as is evident from Figure 1.

Regulations have been effective because of the penalties they imposed to non-compliant firms.

- If the model is a good approximation of reality, it seems that standards have not acted as norms for complying firms: auto manufacturers that consistently produced more fuel efficient cars than what was required by CAFE did not significantly shift their sales towards less efficient cars. The hypothesis of deterioration of fuel economy as a negative side effect of CAFE implementation is not confirmed.
- After controlling for fuel prices and regulations, per capita income did not significantly affect new-car fuel economy. Although this may be a surprising finding, it is not very different from earlier evidence. Dahl [5], based on US data, estimated a mostly negative impact of income on fuel consumption. This result was confirmed by [22] for their panel of 12 OECD countries. [8], with data from 8 OECD countries, found income to be insignificant for fuel consumption, while [10] did not even include income among the explanatory variables. On the other hand, [40] found a small but significant and positive income elasticity in his panel of 90 countries, which included data from several low-income world regions[13]. The diversity of these findings implies that it is not simple to interpret the income effect: on the one hand, cars that consume more fuel may be associated with high income consumers buying bigger and more luxurious cars; on the other hand older and technologically least advanced cars, driven by low-income people, may be the greatest gas guzzlers. While the first observation points to a positive effect of income on fuel consumption, the latter one indicates a negative income effect. As these contrasting impacts may cancel each other out, it should not be surprising that the aggregate income effect is not significant in this context.

Firm-specific time effects are significant in the model but do not display a common trend: some of them are increasing and some decreasing over time. Recall that in the empirical formulation of section 3 this effect was used in order to represent the term $k(F_{t-1}^{*} - F_{t-1}^{R})$ of the theoretical specification. The significance of this effect seems to confirm that in each year actual fuel consumption depends on the actual lagged fuel consumption F_{t-1} and the extent to which the firm was constrained by the standard in the previous year – see equation (11). As income and fuel prices have been explicitly included in equation (16), the time effect expresses the composite impact of changing consumer attitude towards valuing fuel economy, and changes in the firms' technological level. The relevant evidence, however, shows that consumers do not value fuel economy highly in their purchase decisions [3], and this has remained essentially unchanged over the years [28]. Therefore, the hypothesis of increasing or decreasing consumer awareness cannot be supported, hence the changing time effects should primarily be attributed to technical progress and its interaction with the regulations.

An increasing effect over time shows that a firm may have been more constrained by regulations in the most recent period (1990–2006), despite the fact that standards were not tightened after 1990. A reason for this may be consumer demand for bigger and

[13] All these findings refer to fleet-average and not new-car fuel consumption.

more powerful cars, which has outweighed technological advances that have improved vehicle fuel economy. Conversely, a decreasing effect over time seems to indicate that a firm has gradually adjusted its production and technological level in such a way that it can fulfil both consumer preferences and regulatory requirements. Exploiting the stagnation of CAFE standards since 1990 and technical progress in modern cars, these firms were able to accommodate for increasing comfort and safety preferences without sacrificing fuel economy. In the first case, the 'notional' market-based FE level F^* approaches the level mandated by the CAFE standard F^R; in the second case F^* moves further away from F^R.

On a closer inspection, however, time effects are almost invariant over time and similar across firms. In fact, Wald tests in every individual firm show that δ_1 is not significantly different from δ_2 in any firm. Most importantly, the joint hypothesis that all time coefficients are equal (i.e. $\delta_{1,DC} = \delta_{2,DC} = \delta_{1,GM} = \delta_{2,GM} = \ldots$) cannot be rejected ($p$-value is 0.40). This finding indicates that throughout the whole period 'with standards), i.e. post-1978, the burden that manufacturers faced in complying with regulations was essentially the same every year.

Table 1: Regression results.

		Coefficient	(std. error)	Observations	Adjusted R^2
	β_2	0.373 **	(0.146)		
	β_3	0.023	(0.026)		
	k_0	0.194	(1.466)		
	k^*	0.830 ***	(0.027)		
	k_{10}	0.004	(0.006)		
	k_{11}	-0.034 ***	(0.010)		
	k_{12}	0.021 **	(0.009)		
	k_{13}	0.005	(0.007)		
	k_2	0.010	(0.008)		
Time effects:					
DaimlerChrysler	δ_1	1.038 *	(0.533)	32	0.919
	δ_2	1.249 **	(0.507)		
Ford	δ_1	1.195 **	(0.531)	32	0.928
	δ_2	1.223 **	(0.502)		
General Motors	δ_1	1.274 **	(0.524)	32	0.960
	δ_2	1.175 **	(0.497)		
Honda	δ_1	1.118 **	(0.513)	32	0.081
	δ_2	1.036 **	(0.495)		
Hyundai-Kia	δ_1	1.006 **	(0.500)	21	0.418
	δ_2	1.117 **	(0.491)		
Nissan	δ_1	1.110 **	(0.518)	32	0.120
	δ_2	1.165 **	(0.496)		
Toyota	δ_1	1.088 **	(0.523)	32	0.405
	δ_2	1.082 **	(0.501)		
Volkswagen	δ_1	1.160 **	(0.515)	32	0.289
	δ_2	1.202 **	(0.497)		
Other	δ_1	1.210 **	(0.514)	32	0.781
	δ_2	1.250 **	(0.492)		
Total observations:		277			

Notes: See equation (16) for explanation of coefficients. *, ** and *** denote significance at 10%, 5% and 1% level respectively.

Since time effects turned out to be equal across firms, it is necessary to explore this issue in more detail. Therefore, I further divided the 1975–2006 period and estimated a model without firm-specific time effects – see equation (17) below[14]. I split the

[14] A model like equation (17) but with cross-section-specific time dummies could not be estimated because of collinearity problems.

1975–2006 period in five instead of three sub-periods: without CAFE standard (1975–1977), with rising standard and high oil prices (1978–1985), with partly rising standard and low oil prices (1986–1989), with stagnant standard and low oil prices (1990–1999) and with stagnant standard and higher oil prices (2000–2006). The rationale behind that split was to examine whether the burden on the industry overall increased or decreased during the 1990s when standards were not tightened at all and oil prices were low.

$$F_{it} = (1-\beta_2 D_{i2} - \beta_3 D_{i3}) \cdot$$
$$\left(k^* F_{i,t-1} + \delta_1 D7577 + \delta_2 D7885 + \delta_3 D8689 + \delta_4 D9099 + \delta_5 D0006 + \sum_{l=0}^{3} \left(k_{1l} p_{t-l} \right) + k_2 PCGDP_{it} \right) +$$
$$+ (\beta_2 D_{i2} + \beta_3 D_{i3}) F_t^R + \varepsilon_{it} \qquad (17)$$

Table 2 reports the results. Except for the pre-standard period 1975–1977, time effects are significant and have been falling under these specifications. This implies that, for the automobile industry as a whole, technical progress over the years has been important in continuously reducing the burden that standards have put on companies. Even in times of low oil prices (1986–1989 and 1990–1999) and despite consumer purchases of ever more powerful cars (see Figure 2), the degree of constraint on manufacturers seems to have decreased somewhat. Recall that low fuel prices and preference for more powerful cars tend to increase the 'notional' market-based fuel consumption F^* and thus to bring it further away from the regulatory standard F^R. Therefore, results show that during the 1990s technological advances helped the automotive industry to avoid being put in greater pressure from the co-existence of CAFE standards and higher values of F^*.[15] This is in line with what Sperling et al. [38, p. 12] note: "Technological innovation dampens the cost of complying with new regulations".

After 2000, however, the time effect was essentially the same as in 1990–1999: despite somewhat rising fuel prices, the burden on the industry was not reduced further. This may indicate that there are limits to what technology can achieve, when vehicles become ever bigger and more powerful[16].

Conclusions for the estimates of other parameters from equation (17) remain essentially the same as those based on equation (16).

[15] Obviously, if standards had been tightened during the 1990s, i.e. F^R had become lower, it would be reasonable to expect that the burden on the industry would have increased, perhaps pushing it towards more advanced technological solutions or changes in the vehicle sales mix in order to comply with CAFE requirements.

[16] A close examination of the temporal evolution of two efficiency indicators, the power-to-mass ratio and the ton-mpg metric for each manufacturer (see [19]), shows a fairly steady annual efficiency improvement from the early 1980s to 2006 and does not reveal any substantial changes after 2000. However, as mentioned in section 4, none of these two indicators can sufficiently capture all technological advances in automobiles, therefore they are not reported here for the sake of brevity.

Table 2: Regression results for the model without firm-specific time effects.

	Coefficient		(std. error)
β_2	0.569	***	(0.147)
β_3	0.007		(0.034)
k^*	0.827	***	(0.030)
k_{10}	-0.001		(0.006)
k_{11}	-0.034	***	(0.010)
k_{12}	0.020	**	(0.009)
k_{13}	0.000		(0.007)
k_2	0.011		(0.014)
δ_1	1.809		(1.971)
δ_2	1.658	**	(0.807)
δ_3	1.490	*	(0.759)
δ_4	1.450	*	(0.747)
δ_5	1.453	*	(0.815)

	Observations	Adjusted R^2
DaimlerChrysler	32	0.903
Ford	32	0.915
General Motors	32	0.951
Honda	32	0.061
Hyundai-Kia	21	0.156
Nissan	32	0.023
Toyota	32	0.336
Volkswagen	32	0.190
Other	32	0.740
Total observations	277	

Notes: See equation (17) for explanation of coefficients. *, ** and *** denote significance at 10%, 5% and 1% level respectively.

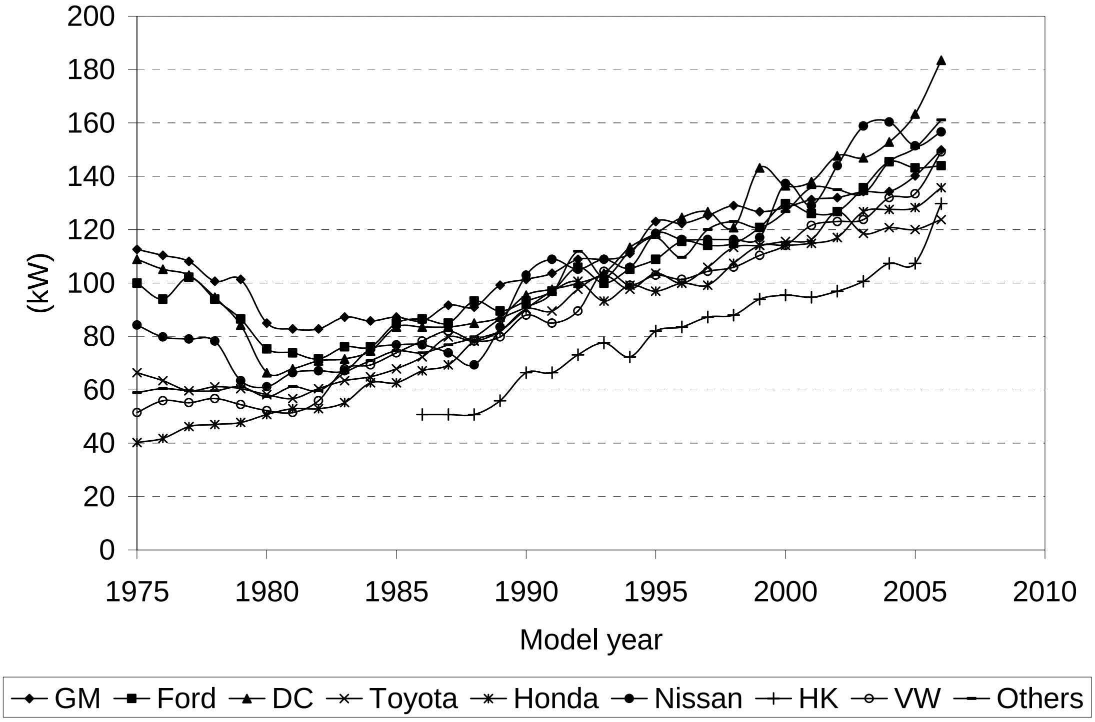

Figure 2: Average sales-weighted engine power output of vehicles in the US market, 1975–2006. See Figure 1 for explanation of data source and abbreviations.

5.3. Implications for public policy

The results reported above are in line with those of other studies. The finding that CAFE standards have been significant (but not the only) determinants of new-car fuel economy since the late 1970s confirms results of Greene [13], Small and van Dender [37] and Clerides and Zachariadis [4], each one of whom employed a different type of model. Conversely, Gately [10] did not identify a significant effect of standards but, as [4] explain, this may have been a result of the sample that was available to him during that period.

Furthermore, the low and insignificant value of β_3 shows that a shift towards less efficient cars may not have taken place among manufacturers who complied with CAFE rules, thereby rejecting the hypothesis that there was such a negative side effect of CAFE. This finding somewhat contradicts those of Greene [13] and Thorpe [41]. However, Greene's sample, which is similar to the one I used here, included data from model years 1978–1989, whereas the sample in this paper covers the 1975–2006 period. As regards Thorpe's result, as mentioned in the section 2, it is sensitive to the elasticities of substitution he assumes. On the other hand, the model proposed here does not account for the possibility of a manufacturer to shift sales from cars to light duty trucks. Therefore, the insignificance of β_3 cannot completely rule out that a 'norm' effect has taken place. Many analysts have suggested revising the current CAFE system in order to avoid such undesirable impacts. [33] and [36] provide some solutions that, though not perfect, might help overcome those problems, such as: allowing for differentiation of standards based on vehicle attributes, enabling the use of tradable FE permits among manufacturers, demanding uniform percentage increases in fuel economy for all companies, or tightening standards of light trucks .

The two slightly different models that have been tested here – equations (16) and (17) – indicate that CAFE standards may have gradually become less restrictive for the auto industry, despite consumers' desire for more powerful and comfortable cars. As the models account explicitly for income, price and regulatory effects, this result must be attributed to technological advances in vehicle engines and accessories and to the fact that standards have not been tightened since 1990. It might be possible to conclude that, to some extent, the CAFE program has induced considerable improvements in automobile technology by forcing manufacturers to satisfy market expectations and efficiency regulations at the same time[17]. Obviously, this does not necessarily imply that CAFE has been the most cost-effective way to attain these improvements, but only that, *ceteris paribus*, these would not have appeared to that extent in the absence of regulations and in a world of low oil prices.

Another policy implication of declining time effects in equation (17) is that, although the results confirm that fuel economy depends on its 'notional' market-optimal value, a 'catch-up' effect becomes less likely than it was in the 1980s and the early 1990s. In other words, if CAFE standards were lifted today, new cars sold in the market would become less efficient than under the CAFE regime, but this effect would not be very pronounced. This has to be attributed to technical progress again, which is largely irreversible: as soon as more efficient engines and vehicle accessories (e.g. tyres, lightweight materials etc.) are embedded in the production process, they will most probably remain even under very low energy prices and in the absence of efficiency standards that caused their development in the first place [15, 42]. CAFE standards have become somewhat easier to meet in the last years, largely because they have not been tightened since 1990, so that even their abolition might not cause much deterioration in new car fuel efficiency – although it would not cause an efficiency improvement either.

Evidently, there are caveats in this study too. First, the analysis uses annual average data at firm level; micro data from individual companies, not available to the author, would constitute a richer and more diverse sample that might produce more insight into the issues discussed here. Second, the specification employed does not account for the provision of CAFE to allow companies that over-comply in one year to transfer credits to the next or previous 3 years. At least two US manufacturers (Ford and GM) made some use of these credits in 1983–1985. However, credit transfer was not used extensively by other major manufacturers and during the post-1985 period, so that omitting this effect should not alter the overall policy conclusions. Finally, the model covers a homogenous vehicle group only (cars and wagons) and hence cannot account for eventual shifts from cars to light trucks in company sales. After 1990, light truck sales increased continuously, reaching half of all new vehicle sales in year

[17] As Sperling et al. [38, pp. 12-13] note, "New regulations that improve vehicle safety and environmental and energy performance also impose additional costs. But these additional costs are not permanent nor cumulative. As with any new products or technologies, with time and experience engineers learn to design the products to use less space, operate more efficiently, use less material, and facilitate manufacturing. They also learn to build factories in ways that reduce manufacturing cost".

2003 [19]. However, this important effect can be clearly attributed to the less stringent CAFE standards for light trucks and not to an eventual role of standards acting as norms. Therefore, applying a more complex model that would consider firm behavior as regards fuel economy of cars and light trucks at the same time would probably not add much to the regulatory assessment discussed here.

A final word must be said about Europe. Currently there is an intense discussion about setting standards to restrain energy use and CO_2 emissions in Europe as well. However, an agreement of the automotive industry with the European Commission (the European Union's executive body) to reduce car CO_2 emissions does not require that fuel consumption figures are reported for each manufacturer separately [6]. As a result, the European, Japanese and Korean automobile manufacturer associations publish annual fuel consumption and CO_2 emission data of their EU car sales as averages over all their individual member companies. This is a feature of the agreement that has been criticized by many analysts for lack of transparency [23, 43]. Because of this, the model presented in this paper cannot be applied to European data. An important aspect of the agreement in Europe is that it is voluntary, so that it would be particularly interesting to examine what role it has played in the evolution of car FE and explore potential differences from the effect of mandatory CAFE standards in the US. In the absence of appropriate data, however, this analysis cannot be performed.

6. Conclusion and outlook

The role of regulatory standards and the response of citizens and firms affected by them have been explored theoretically and empirically in various degrees. Usually, theoretical analyses involved sophisticated model formulations originating from microeconomic or game theory, which could not be tested on empirical grounds. The model I proposed in this paper has a theoretical background but is quite simple and formulated in such a way that enables drawing empirical conclusions on the basis of usual hypothesis tests. The model specification allows to explore three potential roles of standards: they can act as penalties for non-compliant firms, as norms to which all firms (both complying and non-complying) converge, and as controls with cumulative impact on firm behavior over time.

I tested this specification focusing on the issue of motor vehicle fuel economy (CAFE) standards that have been imposed in the US since 1978. I used data on fuel consumption and average vehicle attributes from 9 automobile manufacturer groups for the period 1975–2006. The results are in line with most findings of previous studies: CAFE rules, acting mainly as penalties for non-compliant companies, have been a very important (though not the sole) determinant of car fuel consumption in the US since their implementation; consumer preferences, fuel prices and technology have also affected the overall picture. The assumption that standards acted also as norms was not confirmed. Finally, testing for the cumulative impact of CAFE revealed that each firm has remained almost equally constrained over the years; for the industry as a whole it seems that the unconstrained market-optimal FE level gradually approached the level imposed by the standards. This shows that, due to stagnating CAFE standards since 1990 and technological progress, lifting CAFE regulations today might worsen vehicle fuel economy but this effect would not be very pronounced unless consumer preferences cause a dramatic increase in average car size and power.

Finally, it is worth noting that an application of the same model to other regulatory fields is quite straightforward, provided that the control variable is continuous and the regulation addresses directly that variable. In fact, as already mentioned, a similar formulation was used in [31] to explore the role of government controls on UK firm dividends. To employ the model, one needs to identify the control variable (e.g. percentage increase in distributed dividends, energy efficiency, emissions of a pollutant, concentration of a toxic element in wastewater, content of a specific substance in a food or drink etc.), the corresponding standard and some exogenous variables that affect the unconstrained value of the control variable (F^* in the notation of equation (16)). However, in order to accommodate more complex or less straightforward regulations such as the minimum standards on health insurance coverage analyzed in [9] or the safety standards examined in [30], different formulations would be necessary.

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