



Are Standards Effective in Improving Automobile Fuel Economy?

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ABSTRACT

There is an intense debate over whether fuel economy standards or fuel taxation is the more appropriate policy instrument to raise fuel economy and reduce CO₂ emissions of cars. The aim of this paper is to analyze the impact of standards and fuel prices in new car fuel economy with the aid of cross-section time series analysis of data from 18 countries. We employ a dynamic specification of new car fuel consumption as a function of fuel prices, standards and per capita income. Results are used to address policy questions that are currently in the center of discussions worldwide: to what extent the implementation of fuel economy standards has yielded fuel savings; how much fuel prices should rise in order to increase fuel economy without tightening standards; and whether autonomous fuel economy improvements should be expected in the absence of regulations or fiscal policy instruments.

Keywords: CAFE; fuel tax; greenhouse gases; rebound effect; regulation; technical progress

JEL classification: Q4; Q5

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1. Introduction

The share of transportation in total energy consumption and greenhouse gas (GHG) emissions is increasing, particularly in OECD countries, because of continuous growth in total vehicle kilometers traveled and stagnancy in automobile energy efficiency. This comes in sharp contrast to GHG mitigation achievements in other sectors like power generation and industrial processes. In the European Union (EU), for example, the transport sector almost completely cancels out other progress towards meeting the 8% GHG reduction target under the Kyoto protocol [16]. With the exception of biofuels, which are regarded as CO₂-neutral and whose production is gradually increasing and encouraged by legislation in some world regions, other fuel/engine combinations are still not mature for mass production and even commercially available hybrid powertrains are experiencing quite slow penetration rates. It therefore becomes imperative for OECD countries to succeed in improving the fuel economy (FE)¹ of conventional gasoline- and diesel-fueled passenger cars if they are to ensure progress in limiting GHG emissions and meeting their Kyoto commitments (where applicable).

One way to raise the fuel economy of new cars is through FE standards, either mandatory or as a voluntary commitment of the automotive industry. An FE standard is usually expressed as the minimum sales-weighted average fuel economy for the new-car fleet entering the market in a given year. A second approach towards improving FE is to increase fuel taxation in order to induce purchases of more efficient cars and discourage private car travel. Mandatory fuel economy standards have been in force in the United States since 1978 (although, with a small exception for light duty trucks, they have not been tightened since 1990). Other countries followed later, and currently Australia, Canada, China, the EU, Japan, Switzerland, South Korea and Taiwan implement some type of FE or CO₂ standard.

It is generally acknowledged that the adoption of standards has induced fuel economy improvements, or at least it has ensured that the fuel economy of new cars will not deteriorate despite consumer preferences for extra energy-consuming amenities and safety features. This seems to be confirmed by observing the evolution of fuel economy over time and its close relation to the existence of standards or voluntary targets; Figure 1 shows this relationship for the US and the EU. Post-1982 FE improvements are particularly noteworthy because fuel prices decreased sharply after 1982, so that these improvements cannot be attributed to high fuel prices.

Supporters of standards cite the myopic behavior of both consumers and producers and conclude that FE regulations may be more successful than fuel taxes. For example, Glazer and Lave [23] argue that, despite higher fuel prices, both consumers and manufacturers may prefer to wait until uncertainty about technology or gasoline prices is resolved before making purchase decisions or undertaking costly research on more efficient cars respectively. Hence, even if an increase in the price of gasoline has powerful effects, those effects may be delayed and regulation may have a more immediate impact.

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

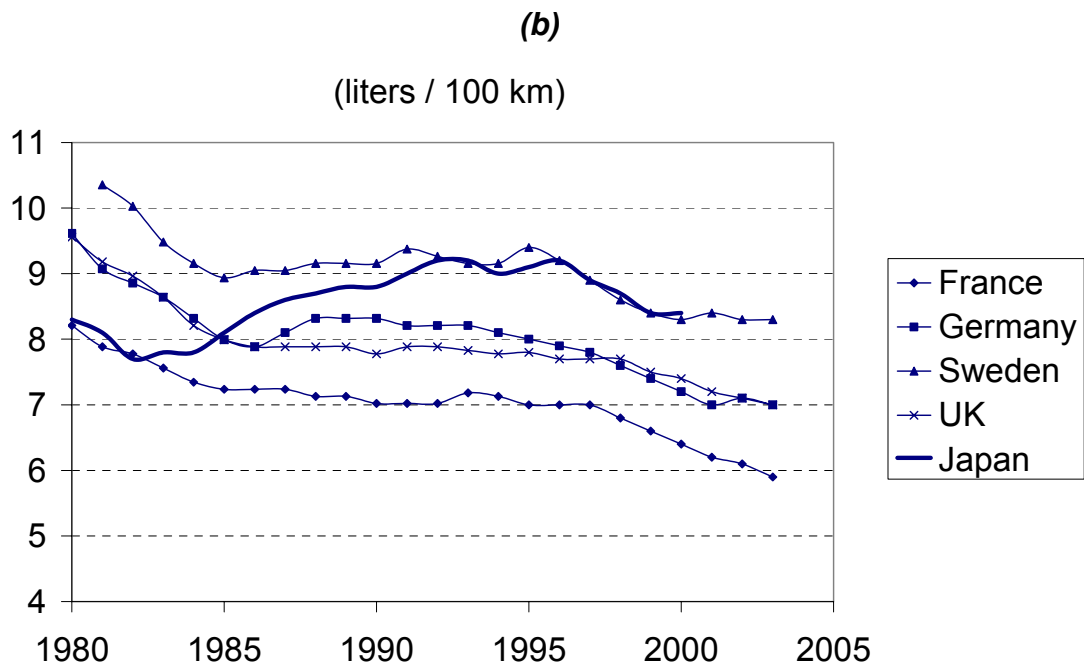
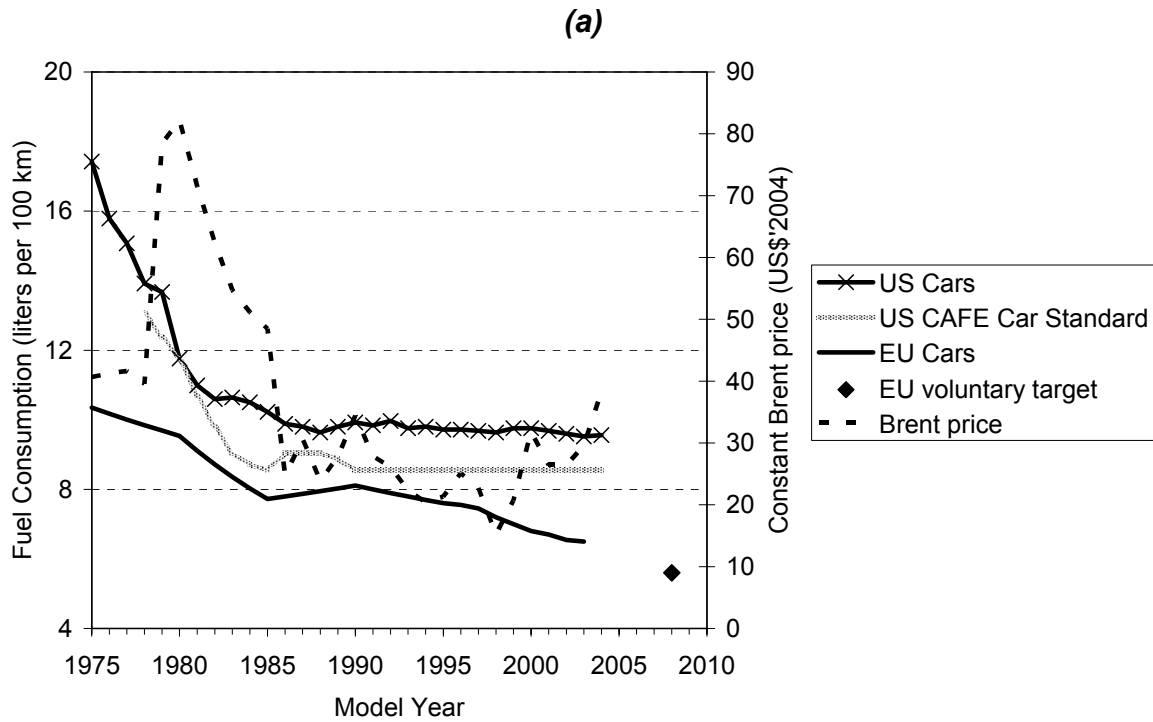


Figure 1: (a) Evolution of new-car fuel consumption in the US and the EU and the corresponding CAFE standard (for the US) and voluntary CO₂ target (for the EU). US data come from [32]; for compilation of EU data see [49]. The international oil price in real terms, taken from [8], is also shown. (b) New-car fuel consumption in Japan and four EU countries.

A similar argument for standards is provided by [27] and [30], who claim that standards are effective because of failures in the market for fuel economy. They cite several studies reporting that consumers are myopic, i.e. they undervalue the potential cost savings of fuel efficient cars, so that higher fuel prices would have a smaller impact on fuel economy than regulations. Modeling studies such as [24] and [29], which did not find strong evidence for or against standards in terms of their welfare impact, can also be cited as results favoring FE regulations. [24] found also that a high gasoline tax (of the order of 80 US cents per gallon), which is unlikely to be accepted in the US, would be required to yield the same fuel saving benefit as CAFE standards.

However, there are voices in the US (where most of the experience has been gathered) arguing against standards and favoring increases in fuel taxes instead. Among opponents of FE regulations, some analysts express doubts whether the current type of Corporate Average Fuel Economy (CAFE) standards are appropriate. For example, NRC [39] and Portney et al. [43] suggest that, if the CAFE system is to be retained, a number of improvements should be introduced such as: enabling the use of tradable FE permits among manufacturers, revising the distinction between cars and light trucks, removing distinctions between domestic and imported vehicle fleets, or allowing for differentiation of standards based on vehicle attributes.

Other analysts reject the idea of any type of standard whatsoever. Thorpe [46], for instance, applied a general equilibrium model and found that CAFE actually reduces fuel economy as it shifts automobile sales towards less efficient vehicles. Kleit [38] estimated that increasing gasoline tax by 11 US cents per gallon would yield the same energy conservation effect with raising the current CAFE standards by 3 mpg, at significantly lower welfare costs. Austin and Dinan [5] reached a similar conclusion, and Parry et al. [40] found that tightening the standards would raise welfare only under severe consumer myopia, i.e. if consumers greatly undervalue fuel savings. [5], [38] and [42] have also countered the argument of market failures (which is mentioned by supporters of standards), noting that consumers are very well informed about automobile fuel costs because of ample information on both new car fuel economy and fuel prices, so that it is unlikely for this market to be inefficient.

There is also currently an intense debate on fuel economy regulations in the EU. In a voluntary agreement with the European Commission in the late 1990s [13], the automobile industry made a commitment that by 2008/2009 the average (sales-weighted) new passenger car will emit 140 grams of CO₂ per kilometer, compared to the 1995 average of 185 g/km. As the deadline approaches and this target will most probably not be met [37, 49], discussions among stakeholders have become intensive again. In Europe, however, the question is not whether to impose higher fuel taxes or standards as fuel taxation is already quite high: in 2003, excise taxes alone accounted on average for about 60% and 50% of the retail price of gasoline and automotive diesel oil respectively [19]. EU-wide discussions focus on whether the automotive industry's commitment should be expanded in the future and whether a mandatory standard should be imposed: a target of 120 CO₂ g/km is mentioned for the year 2012 or later.

In view of these and similar discussions around the world, the aim of this paper is to analyze the impact of FE standards and fuel prices on new car fuel economy with the aid of time series analysis of data from several countries worldwide. Similar work was previously

undertaken by Espey [18], who addressed fleet-wide fuel consumption using data from 8 OECD countries from 1975 to 1990. Only the US had FE standards during that period and even these standards correlated closely with the time trend because standards had been rising fairly steadily until 1990. Therefore the impact of the FE standard in that work could not be separated from the overall time trend that may represent technical progress or other change.

Johansson and Schipper [36] conducted a similar analysis with cross-section time series models including 12 OECD countries for the period 1973–1992, but using again fleet-average FE as the dependent variable and without addressing standards explicitly. Using country-specific time trends, the authors found that FE improvements had been much faster in the US than in any other country since 1978, but they were reluctant to attribute all the improvement to the CAFE program. Storchmann [45] also employed a pooled model to estimate fleet-average fuel consumption using several explanatory variables such as private income, population density, urbanization rates, fuel prices and automobile costs. He focused on the effect of income distribution on worldwide gasoline demand and did not address the issue of FE standards.

Greene [26] tackled the same question using a different methodology. He modeled the automobile manufacturers' decision-making process and concluded that CAFE standards played a greater role than fuel prices in improving new-car FE levels in the US. Data came from the US only and, as in [18], involved a period of monotonously rising standards.

Gately [22] tested equations of fleet-average FE as a function of prices and CAFE standards, allowing for potentially asymmetric price elasticities in US gasoline consumption. He found that standards were not statistically significant and gasoline prices alone (with lags of up to 10 years) could sufficiently explain the evolution of FE over the years. The effect of standards, however, is diluted when fleet-average FE is the dependent variable because of slow vehicle retirement rates. In order to account properly for the effect of standards, not only the current value of the standard but a sufficient number of lags of the standard variable has to be included. If Gately [22] had longer time series available in order to include the lagged effect of standards in his model his results might have been different.

Small and van Dender [44] include a CAFE variable in their analysis, which turns out to be significant for determining fuel economy. However, as their main concern is the extent of the rebound effect, i.e. how much vehicle travel will increase if fuel economy decreases, they only use the CAFE variable (defined as the difference between regulated and 'desired' fuel economy levels) in order to derive more stable estimates of the rebound effect.

This paper extends previous analyses in several ways. First, it addresses new-car (instead of fleet-averaged) fuel economy, which is a variable that is easier to follow and is not compounded by assumptions on vehicle turnover rates. Second, it includes US data from 1975 to 2004, thus enriching the sample with periods of rising as well as falling oil prices and rising as well as stagnant CAFE standards. Third, it includes data from several world regions (North America, Europe, Japan and Australia); thereby it extends the discussion beyond the US and places results in the context of ongoing policy discussions worldwide.

The international analysis presented here has to rely on reduced form time series relationships as it cannot employ micro level data on the producer's side. The voluntary agreement that is in place in the EU does not include any requirements for individual automobile manufacturers, hence it is not possible to analyze this issue in Europe on the basis of

simulations of a firm's behavior (such as many of the studies mentioned above). Nonetheless, the wide international and temporal coverage of the sample yields interesting and policy-relevant results.

2. Methodology

As mentioned in the literature review above, using fleet-average FE as the dependent variable complicates the analysis because this is a derived quantity influenced both by new-car fuel economy and the rate at which new cars enter the market. Fleet-average FE changes very slowly, hence it becomes difficult to discern the potential impact of a standard or a new technology; this was also the result of estimations of [18] and [36]. Conversely, fuel prices affect fuel consumption of both new and old cars, in the latter case through changes in vehicle utilization (i.e. distance traveled) or maintenance levels. This wider and direct impact of prices may conceal the influence of other factors and hence, as explained in the previous section, the effect of tighter FE standards or technical progress can only be identified if lagged values of the corresponding variables are included. Therefore, in order to examine the impact of FE standards without using a large number of lagged variables that may lead to a considerable loss of degrees of freedom, it is preferable to use new-car FE as a dependent variable.

It is reasonable to include fuel prices and FE standards as explanatory variables as these may be the two most important mechanisms that induce FE improvements. High fuel prices push consumers to purchase more fuel efficient cars and thus indirectly give manufacturers an incentive to increase vehicle efficiency. FE standards or voluntary targets encourage (or force) manufacturers to introduce efficient cars and to make them attractive to their customers, while they may also increase consumer awareness of fuel economy issues. It is important to include lagged prices in the model and perhaps also lagged FE standards as producers will need to gradually adjust their vehicles to meet future FE requirements.

Income may also significantly affect fuel economy, although the direction may not be a priori obvious. Existing studies provide conflicting evidence. Dahl [11], based on US data, estimates a mostly negative impact of income on fuel consumption. This result is confirmed by [36] for their panel of 12 OECD countries. Others studies like [18], with data from 8 OECD countries, find income to be insignificant for fuel consumption, or do not even include income among the explanatory variables [22]. On the other hand, [45] finds a small but significant and positive income elasticity in his panel of 90 countries, which includes data from several low-income world regions². The diversity of these findings implies that it is not simple to interpret the income effect: cars that consume more fuel may be bigger and more luxurious (positive income effect) or older and not technologically advanced (negative effect).

In physical terms, fuel consumption depends on the forces exerted on a vehicle while it is driven (inertia, rolling resistance and aerodynamic drag), the thermal efficiency of its engine and the mechanical efficiency of its power transmission system. Observable variables that could partly reflect these physical factors are the average mass or engine size and the

² All these findings refer to fleet-average and not new-car fuel consumption.

maximum engine power of new cars, or the share of diesel cars in annual sales. Each variable, however, can only explain some of these effects on fuel consumption, so that none of them may be appropriate for our model. Besides these variables may be themselves a result of tighter FE standards, high fuel prices or technical progress rather than a cause of improved fuel economy; this means that they should not be treated as exogenous in the model. Therefore, it may be simpler and more appropriate to include a deterministic time trend in the model instead of these individual variables, which also exhibit an almost monotonous increase over time as shown in Figure 2.

Technical progress is another important and controversial aspect. There are, for example, different views as to whether price elasticities of energy demand are asymmetric (with price increases having a stronger impact than decreases) or this apparent asymmetry is just the composite effect of symmetric price elasticities and price-induced technical change ([31, 33]). In the context of this study, the inclusion of prices and FE standards means that price-induced and regulation-induced technical progress is captured by these two variables. In order to allow for the additional possibility of ‘autonomous’ fuel economy improvements, it is appropriate to use a deterministic time trend in the model. This means that the time trend is intended to capture this kind of technical progress as well as changes in consumer preferences as outlined in the previous paragraph – to the extent that they are not related to income.

Having selected the major explanatory variables, we applied the dynamic panel model described in equation (1). The autoregressive formulation of the dependent variable, applied also in [18] and [36], enables the identification of both short-run and long-run effects and is therefore useful for policy simulations:

$$FC_{i,t} = \lambda FC_{i,t-1} + \alpha_1 t + \sum_{j=0}^L \alpha_{2,j} p_{i,t-j} + \alpha_3 STD_{i,t} + \alpha_4 INC_{i,t} + \nu_i + \varepsilon_{i,t} \quad (1)$$

where indices i and t denote cross-section (country) and time respectively.

All variables are expressed in natural logarithms. FC is average sales-weighted fuel consumption of new cars in liters per 100 kilometers (l/100 km), λ is the autoregressive coefficient of the dependent variable, α_1 is the time trend coefficient, p is real gasoline price expressed in Euros at 1995 prices per liter, STD is the level of the country-specific FE standard of that year, expressed in l/100 km, INC is real per capita GDP expressed in Euros at 1995 prices, and ε is a residual term that is independently and normally distributed with zero mean and constant variance. To account for lagged price effects, we selected a maximum lag length of $L=5$ to allow for the possibility that consumer decisions on the fuel consumption of their new car are affected by price fluctuations over the last 5 years. In such a model the short-run effect of each variable is given by the values of the corresponding coefficients α_2 through α_4 , while the long-run effect is given by the corresponding coefficients divided by $(1-\lambda)$.

There are several reasons why such a model should include country effects, ν_i ; national particularities in vehicle fuel consumption that persist over the years will affect model estimation. Examples include population density and urbanization rates, which influence average automobile size and hence fuel consumption [45]; vehicle taxes and how these increase progressively for bigger cars [18, 36]; and the price ratio of diesel fuel to gasoline per country, which has a direct impact on the share of diesel car sales.

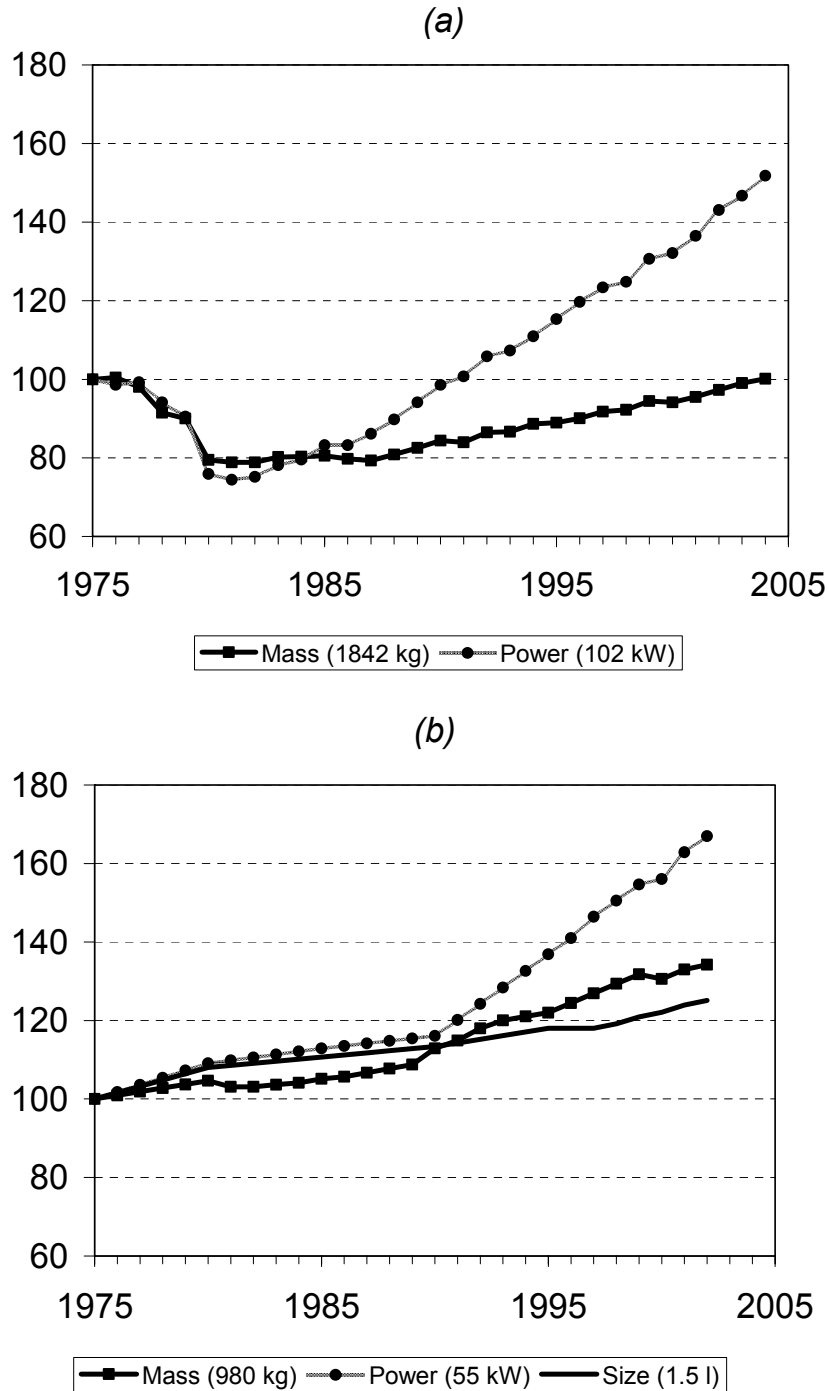


Figure 2: Evolution of new vehicle attributes (average vehicle mass, maximum engine power and average engine size) (a) in the US and (b) in Europe. In each case the attributes of year 1975 are the basis (1975=100), and legends provide the actual figures for the base year. See Figure 1 for description of data sources.

Before arriving at a model that uses the *STD* variable as shown in equation (1), we considered alternative ways to formulate the variable that describes FE standards. One could argue that, instead of using $STD_{i,t}$ one should use the standard of a few years ahead since FE standards will mainly influence forward-looking decisions of manufacturers who gradually adjust the

fuel economy of cars they introduce in the market depending on the level of FE standards that will be in force in the near future. We addressed this possibility by defining the year-by-year *STD* variable (as described in the Appendix) in a way that already incorporates this forward-looking behavior because of the assumption that *STD* evolves each year in order to gradually approach a future standard or target. We therefore considered it more appropriate to use $STD_{i,t}$ in the model.

Bratberg et al. [9] used a ‘difference in difference’ estimator to assess the effectiveness of international environmental agreements: for each country they compared the change of the dependent variable over time (before and after the implementation of the agreement) with the corresponding evolution of the variable in a country that has not implemented this agreement. In our case, however, this was not possible because we could not find fuel consumption data for countries that have not implemented FE standards or targets; section 3 provides more information on data availability. We therefore relied on the usual expression of the *STD* variable in levels as shown in equation (1).

An alternative way to address the effect of standards would be to express the *STD* variable as a difference between the value of the FE standard in a given year and the observed FE level one year before (or with a different lag/lead combination). This approach might be justified because, theoretically, average new-car fuel consumption should be lower than or equal to the level of the corresponding standard in each year. In practice, however, average fuel consumption levels may be different because of the way that standards are implemented. In the US, for example, average fuel economy of Japanese cars was always higher than the corresponding CAFE standard, so that fuel economy averaged across cars from all manufacturers was higher than the standard although American and European manufacturers had to strive to reach the standard. In the EU, the CO₂ target value (which is voluntary in any case) applies to Europe-wide automobile sales, so that in some countries with bigger cars and lower diesel sales (e.g. Sweden) average CO₂ emissions are always higher than the target, while in other countries (e.g. France or Spain) emissions are consistently lower than the European average target. For these reasons this approach too had to be rejected as inappropriate.

3. Data

For the variables included in equation (1), data were obtained from official national and international sources. New-car fuel consumption is not routinely recorded in many countries, and in most cases it was only after the implementation of some FE standards that this variable started being systematically measured in countries with regulations in place. There are, however, OECD countries where such information has been gathered since the late 1970s, primarily through initiatives of the International Energy Agency (IEA) with the aid of data collected from automobile manufacturers.

We were able to construct consistent time series for 18 countries. We thus built an unbalanced panel consisting of 20 cross-sections: the US (cars and light duty trucks separately), Canada (cars and light duty trucks separately), Australia, Japan, Switzerland and 13 EU countries – 384 observations in total. Table 1 provides more details of this panel.

Table 1: Overview of the sample used in the study.

<i>Country</i>	<i>Vehicle category</i>	<i>Sample period</i>	<i>Type of standards</i>	<i>Enforcement type</i>	<i>First decision for the adoption of standards/targets</i>	<i>First year of implementation or first target year</i>
Australia	Cars	1978-2002	FE	Voluntary	1978	1978
Austria	Cars	1980-2003	CO ₂	Voluntary	1998	2008
Belgium	Cars	1980-2003	CO ₂	Voluntary	1998	2008
Canada	Cars	1980-2003	FE	Voluntary	1976	1980
Canada	Light duty trucks	1980-2003	FE	Voluntary	1982	1990
Denmark	Cars	1995-2003	CO ₂	Voluntary	1998	2008
France	Cars	1980-2003	CO ₂	Voluntary	1998	2008
Germany	Cars	1980-2003	CO ₂	Voluntary	1998	2008
Ireland	Cars	1995-2003	CO ₂	Voluntary	1998	2008
Italy	Cars	1980-2003	CO ₂	Voluntary	1998	2008
Japan	Cars	1980-2000	FE	Mandatory	1995	2010
Luxembourg	Cars	1995-2003	CO ₂	Voluntary	1998	2008
Netherlands	Cars	1995-2003	CO ₂	Voluntary	1998	2008
Portugal	Cars	1995-2003	CO ₂	Voluntary	1998	2008
Spain	Cars	1995-2003	CO ₂	Voluntary	1998	2008
Sweden	Cars	1981-2003	CO ₂	Voluntary	1998	2008
Switzerland	Cars	1996-2004	FE	Voluntary	2002	2008
United Kingdom	Cars	1980-2003	CO ₂	Voluntary	1998	2008
United States	Cars	1975-2004	FE	Mandatory	1975	1978
United States	Light duty trucks	1975-2004	FE	Mandatory	1975	1982

We used information from the US Environmental Protection Agency [32] and the US Transportation Energy Data Book [12]; the IEA (see e.g. [34]; and additional material that is available on the World Wide Web³); the European Commission ([14] and similar earlier documents reporting for years 1995-2004); the European Conference of Ministers of Transport [15]; Natural Resources Canada (various publications available on the World Wide Web⁴); the Japanese Automobile Manufacturers Association (JAMA)⁵; the Association of Swiss Vehicle Importers [6]; and an international study [1]. Data on real GDP per capita were obtained by the EU Statistical Service [20] and fuel prices from the IEA [35].

Since some countries enforce FE standards while EU Member States apply CO₂ emission targets, some transformations are necessary in order to arrive at the common *STD* variable of equation (1). We therefore converted all standards expressed in mpg to l/100 km and transformed the targets expressed in grams of CO₂ per km to liters of gasoline equivalent per 100 km by applying the commonly used conversion factor of 23.7 [14]. Moreover, the experimental method used to determine FE has changed twice in Europe since the mid-1990s: once in 1997, where a cold start phase was added to the test cycle, and once in 2001, where an idling period on engine start up was removed from the test [15]. We applied appropriate correction factors in order to obtain consistent time series of FE data in those countries where earlier data were available. A detailed description of the approach we followed in order to arrive at a meaningful time series for the *STD* variable is provided in the Appendix.

4. Results

Estimation of the dynamic model of equation (1) has to be treated with care. The presence of a lagged dependent variable among the regressors means that not only the OLS estimator but also the usual ‘within’ estimator is biased and inconsistent because the lagged endogenous variable is correlated to the error term [7]. One solution to this problem is to apply a two-stage least squares (2SLS) estimation, differencing the data and employing as an instrumental variable the level of the endogenous variable two periods lagged [2, 3]; [36] have applied this technique. Arellano and Bond [4] have proposed a generalized method of moments (GMM) procedure that is more efficient than the Anderson and Hsiao [2] estimator because it utilizes many more instruments by taking advantage of the orthogonality conditions that exist between lagged levels of the dependent variable and the disturbance term. We used this GMM estimator and report results in Table 2⁶. The model was estimated for the whole sample as well as for two sub-samples comprising North American and European data respectively,

³ See e.g. IEA’s Energy Information Centre focusing on transport:
http://www.iea.org/Textbase/subjectqueries/keyresult.asp?KEYWORD_ID=4121.

⁴ See e.g. http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/handbook_tran_ca.cfm?attr=0.

⁵ See http://www.jama.org/statistics/motorvehicle/sales/mv_sales_size1.htm.

⁶ We also performed estimations based on OLS, the ‘Within’ estimator with OLS and the ‘Within’ estimator with two stage least squares. As the GMM procedure is clearly superior to these methods for the reasons mentioned above, we do not report their results for the sake of brevity.

since these are the regions whose data dominate in the whole sample. In all cases we report heteroskedasticity and serial correlation consistent standard errors. The hypothesis of no second-order autocorrelation in the residuals, which is fundamental for the consistency of the Arellano–Bond estimator, cannot be rejected.

Table 2: Regression results for equation (1).

Countries	Cross-sections	Sample size	λ	α_1	$\alpha_{2,0}$	α_3	α_4	Autocorrel.
All	20	339	0.709 *** [20.270]	-0.001 [-1.350]	-0.080 *** [-6.580]	0.135 *** [2.490]	-0.004 [-0.130]	0.636
N. America	4	98	0.653 *** [9.180]	0.000 [0.160]	-0.094 *** [-3.180]	0.236 * [1.770]	-0.009 [-0.170]	0.649
EU	13	193	0.780 *** [26.760]	-0.001 [-1.000]	-0.043 *** [-4.190]	0.219 *** [3.760]	0.015 [0.320]	0.426

Notes: See text for explanation of coefficients. Estimation was carried out with the Arellano and Bond [4] GMM procedure. *t*-statistics, calculated with heteroskedasticity and serial correlation robust standard errors, are shown in brackets. *, ** and *** denote significance at 10%, 5% and 1% level respectively. The last column reports the probability of the Arellano-Bond test for second order serial correlation of the residuals.

Out of the five price lags included in equation (1) only current prices (lag order zero) were found to be significant, both in the whole sample and in the American and European subsets; this suggests that any longer term effects are captured by the autoregressive endogenous term. The autoregressive coefficient λ varies between 0.65 (for North America) and 0.78 (for Europe). This implies that between 22% and 35% of the long-term adjustment of fuel consumption due to prices, income and standards takes place in the first year. This quite high adjustment rate is expected because new-car FE is the dependent variable; in contrast, [18], using fleet-average FE, found a 6% annual adjustment.

The dynamic model allows us to distinguish between short-run and long-run effects. The short-run effects of standards and fuel prices are significant and range from 0.14 to 0.24 and from -0.04 to -0.09 respectively. Per capita income turns out to be insignificant in this equation, for the whole sample as well as for the American and European subsets. Long-term impacts of FE standards (i.e. the short-run coefficients divided by $1-\lambda$) vary between 0.46 (for the whole sample) and 0.99 (for North America), whereas long-term price effects range from -0.20 (for Europe) to -0.28 (for the whole sample). For US data alone (not shown in Table 2), the long-term price elasticity is estimated at -0.29 , compared to the value of -0.22 that Austin and Dinan [5] found on the basis of partial equilibrium analysis⁷. Finally, in all cases the deterministic time trend was found to be statistically insignificant and very close to zero.

⁷ The elasticity that [5] found is positive because it refers to the effect on fuel economy, whereas we use fuel consumption as a variable; see also footnote 1.

5. Policy implications

The results from our econometric model can be used to provide answers to some policy questions which are at the center of related discussions worldwide.

Do fuel economy standards make a difference?

Table 2 shows that FE standards enter significantly in equation (1), with coefficients that are higher (in absolute terms) than those of fuel prices, in the whole sample as well as in the North American and European sub-samples. This is already an indication that standards have indeed made a difference in the evolution of automobile fuel consumption.

In order to further examine whether the adoption of standards has been crucial for FE developments, we split the sample in ‘pre-standard’ and ‘with standards’ sub-samples for those cross-sections with available data. This is not possible with US data as the whole post-1975 period is under the ‘with standards’ regime (see Appendix for more explanations). Such a separation is possible, however, in Japan and 7 European countries (Austria, Belgium, France, Germany, Italy, Sweden and the UK), where available data cover the ‘pre-standard’ period 1980-1994 and the ‘with standards’ period from 1995 onwards (170 observations in total). Figure 1b shows the evolution of new-car fuel consumption in some of these countries; European countries not illustrated in this Figure experienced a very similar evolution.

Since data in these 8 countries can be split into periods with and without standards, it makes sense to test whether the adoption of standards should be viewed as a structural change in the data series. For the ‘pre-standard’ and ‘with standards’ periods as well as for the entire period, we re-estimated equation (1) minus the *STD* variable (since this is constant throughout the pre-standard period). We conducted these two regressions jointly for the 7 EU countries and Japan. We performed a Wald test and a Chow [10] test in order to examine the stability of the estimated coefficients. The null hypothesis of these tests is that of coefficient stability, meaning that there is no structural break in the series. Following the notation of equation (1), the null hypothesis of the Wald test is:

$$H_0: \lambda_{pre} = \lambda; \alpha_{1pre} = \alpha_1; \alpha_{2,0pre} = \alpha_{2,0}; \alpha_{4pre} = \alpha_4$$

where the *pre* index denotes the estimated coefficient for the pre-standard sample.

The Wald test for H_0 gave a $\chi^2(4)$ -statistic of 95.99, which corresponds to a *p*-value of 0.000 for the 8-country sample. Furthermore, the Chow test gave an F-statistic of 3.071, which, for 170 observations and 4 parameters, yields a *p*-value of 0.019. The rejection of the null hypothesis by both tests indicates a structural break in 1995: pre-1995 coefficients are different from those estimated for the whole sample period. We had reached a similar conclusion in an earlier paper [50], where we had also tested for a structural break in simple equations including an intercept, a time trend and post-1995 dummies for both the intercept and trend.

The above results seem to provide a clear indication that the adoption of FE regulations or similar voluntary targets has indeed made a difference in the evolution of automobile fuel economy over the years, and also to the evolution of total automobile fuel consumption. If it had not been for FE standards, average new-car fuel consumption would not have improved at the rates that have been observed in Europe and Japan in recent years, and this would most probably have happened in the US as well. Furthermore, bearing in mind the overall increase in vehicle kilometers traveled during the last decades, total fuel consumption would also have been considerably higher in the absence of standards.⁸ This finding does not imply that there are no better alternatives to FE standards but just that, *ceteris paribus*, fuel economy and total fuel use would have been worse without them.

What would be the equivalent fuel price increase of tighter fuel economy standards?

As already mentioned, the results in Table 2 indicate that the *STD* coefficient is higher in absolute terms than the price coefficients. In America, the absolute ratio of the *STD* coefficient to the price coefficient is 2.5; in Europe the corresponding ratio is 5.1. This means e.g. that a 20% lower (i.e. tighter) fuel consumption standard (expressed in liters per 100 km) might yield the same improvements in new-car fuel consumption as an increase in retail fuel prices of 50% in America and 102% in Europe. This implies that in Europe, where a target of new-car 120 g CO₂/km is currently discussed for the year 2012 (a 25% decrease compared to about 160 g CO₂/km realized in the year 2004), if standards are not to be tightened then retail fuel prices might have to double in order to have an equivalent effect.

Similarly, an increase of the current CAFE car standard of 27.5 mpg by 3 mpg, which is a 10% reduction in liters per 100 km, would be equivalent to increasing the gasoline price relative to the average US price in 2004 by 45 US cents per gallon (in 2004 prices). This price rise is higher than that of [38], who estimated an increase by 11 cents per gallon to yield the same FE benefits as a 3 mpg higher CAFE standard, and closer to that of [5], who estimated that 30–36 cents per gallon would be equally effective with an increase of the CAFE standard by 3.8 mpg. It should be noted, however, that these two studies also take into account the long-run impacts on gasoline demand: a tighter standard might induce more driving (the so called rebound effect) and hence would save less fuel than expected, whereas higher fuel prices would discourage driving of all cars and would thus yield additional fuel savings. Hence our estimates are consistent with those from the aforementioned studies.

What would be the long-run effect of the two policies (tighter standards vs. higher fuel taxes) on total fuel consumption? To provide a rough assessment, it is reasonable to assume a rebound effect of 20%, i.e. that the total distance traveled annually by a car increases by 2% for every 10% improvement in fuel economy [27, 28], so that the overall effect of a 10% tighter standard on fuel consumption would come down to

⁸ Greene [14] argues that the CAFE program has saved hundreds of billions of gallons of fuel in the US since 1980.

8%⁹. Over a period of 10-15 years (when most cars would have been replaced by the new fuel efficient ones) such a standard would yield total fuel savings of approximately 8%. Based on the results of Table 2 and the above mentioned ratio of *STD* coefficient to price coefficients, the same fuel savings could be equivalently attained through a fuel price increase of 20% or 36 US cents per gallon (at 2004 prices); obviously this is a lower increase than in the case where we ignored the rebound effect. Alternatively, ignoring the coefficients of Table 2 and assuming instead a long-run price elasticity of total gasoline consumption of -0.39 like Austin and Dinan [5] did, the 8% reduction in fuel use would require a 20.5% increase in fuel prices, or 37 cents per gallon – almost the same amount as that of our calculations based on equation (1).

How might new-car fuel economy evolve without stricter standards and at today's fuel prices?

As mentioned above, there are intense ongoing discussions in the EU regarding future CO₂ emission targets. Environmentalists and numerous analysts point to the need for adopting a 120 g CO₂/km new-car mandatory target for the year 2012 or later, instead of the current voluntary industry commitment (which is unlikely to be fulfilled) to achieve 140 g CO₂/km by 2008/2009. On the other hand, several European long-term energy and transport models assume that automobile fuel economy will continue to improve at fast rates (similar to those observed in Europe between 1995 and 2003) even without post-2010 FE regulations (see e.g. the review in [49]).

Observing the results for coefficient α_1 in Table 2, it is evident that the deterministic time trend of equation (2) is insignificant and almost zero, in the whole sample and in the American and European sub-samples alike. Note that this time trend is intended to capture the composite effect of 'autonomous' technical progress, i.e. progress that is not induced by high energy prices nor by FE standards, and other factors that are not explicitly addressed by the explanatory variables. Examples of such factors are changing consumer preferences in favor of diesel cars, which would reduce average fuel consumption¹⁰, or expanded availability of safety equipment and other amenities (e.g. air conditioning systems, electrically controlled items) even in small cars, which would make a car heavier and more fuel consuming. Increasing consumer awareness for climate change, if any, would eventually be included in this time trend too.

Bearing this in mind, the observation that the time trend in equation (1) is almost zero does not necessarily mean that there has been no autonomous technical progress in

⁹ However, [44] estimate that the rebound effect diminishes as private income rises and find a long-run rebound effect of 10% for California.

¹⁰ As already mentioned, the sharp increase of diesel sales in Europe after 1995 should not be entirely attributed to the industry's commitment for more fuel efficient cars. For example, environmental regulations that require significant cuts in particulate emissions from diesel vehicles have induced technological breakthroughs in the design of diesel engines that a) have made diesel cars more attractive to consumers (e.g. achieving low noise levels and fast acceleration rates that are similar or even better than their gasoline counterparts) and b) have partly improved fuel economy as well.

vehicle fuel economy over the last 30 years. A more plausible interpretation is that automotive technology advances in other fields and changing consumer preferences towards safer and more comfortable cars have canceled out any autonomous technical progress achieved during this period.

The major policy implication of such a result is that, without stricter FE standards and at fuel prices around or below \$40–50 (in 2004 prices) per barrel, one should not expect any marked FE improvements in the future in the absence of major technological breakthroughs or an economic recession. Although this finding is not reflected in many European studies (which tend to be optimistic), it is in line with the assumptions made in an international study of the World Business Council on Sustainable Development jointly with the International Energy Agency [21, 47]. In America this assumption of almost zero autonomous improvement is already reflected in official US studies [17].

Are taxes always the most efficient measure?

From an economic point of view, an externality is tackled most effectively by imposing an appropriate tax and letting the market work. As mentioned in the introductory section, according to some analysts consumer myopia is a reason that may render fuel taxation inefficient. Analyses like [5], [38] and others refute this finding and estimate that raising fuel taxes causes much lower welfare costs than regulatory options such as imposing FE standards. However, even if these studies are better representations of reality, they employ a partial equilibrium framework and do not account for the effects on those economic sectors that use fuel as an intermediate good, which may be significantly affected by e.g. a 20% increase in retail gasoline prices. Available general equilibrium analyses address the impact of one policy only: either that of tighter standards [46] or that of higher fuel taxes (a possible application of [25]). In the absence of comparisons of the cost of policies on the whole economy, the conclusion that raising fuel taxes is a clearly superior option may have to be treated with caution.¹¹

Furthermore, an analyst should not overlook political aspects. The analysis of costs and benefits from tighter FE standards has mainly been performed in the US up to now, but the European scene is quite different. The European Union has decided to fulfill its commitment under the Kyoto protocol, which means that ever increasing transport CO₂ emissions must be curtailed. This is a political decision that has been taken irrespective of estimates on the external costs of transport energy consumption. In this context, if the EU is to restrain greenhouse gas emissions from transport, it is highly unlikely that any country would be willing to double automotive fuel prices in

¹¹ Parry and Small [41] note that a higher gasoline tax in the US would hardly have any effect on production costs because only a very small fraction of gasoline is used for medium and heavy trucks. This argument obviously does not hold for Europe, where a higher fuel tax should be applied to gasoline and diesel alike as both fuels are used by private cars. This means that all enterprises using transportation fuel as an intermediate production input would be affected.

order to achieve its environmental goals. Apart from the questionable economic rationale behind already existing fuel taxes¹², the political acceptance of a considerably higher fuel tax is not given¹³. This means that, no matter how accurate the welfare calculations are, the political economy of higher taxes cannot be ignored as it may prove to be decisive for the success of policy measures. Therefore, while in the US a combination of higher gasoline taxes with an improved CAFE program may be a prudent solution, in Europe mandatory or voluntary standards may be the only way to proceed.

6. Conclusions

To our knowledge, this study is the first one that attempts to explore econometrically the impact of automobile fuel economy regulations around the world and to compare it with the effect of fuel prices, including all countries that have implemented some type of FE standards for a substantial period of time. Using data from official sources, we built an unbalanced panel comprising 384 observations from the US, Canada, Australia, Japan, Switzerland and 13 EU countries spanning a period between 1975 and 2003. We specified a reduced form dynamic panel model of FE and used the Arellano–Bond GMM estimator to obtain consistent and unbiased estimates of the parameters of interest. Average annual fuel consumption of new cars was the dependent variable, and explanatory variables were lagged gasoline prices, the FE standard or target and real GDP per capita. Estimating the model for the whole sample and also for North American and European data separately, we found that the impact of a FE standard on new-car fuel consumption is more pronounced than that of a rise in fuel prices, which in principle should have been expected as standards (mandatory or voluntary) represent binding commitments for the automotive industry.

Based on these estimates, we addressed three important and topical policy issues. Firstly, there seems to be sufficient evidence that if there were no FE standards or targets in force, new-car fuel consumption would not have improved at the rates that have been observed in Europe and Japan in recent years (or it may have even deteriorated), and this would most probably have happened in the US as well; as a result, transportation energy use would have increased more rapidly. Secondly, in order to avoid tightening FE standards by 10% in the US, one would have to raise fuel prices by 20% (or 36 US cents per gallon at 2004 prices) in order to attain the same fuel savings, taking into account the rebound effect. In Europe, if standards are not to be tightened then retail fuel prices might have to double in order to attain the currently discussed target of 120 g CO₂/km in the future. Thirdly, without higher fuel prices and/or tighter FE standards, one should not expect any marked improvements in fuel

¹² Parry et al. [42] note that “...The externality rationale for higher fuel taxes, or more stringent fuel economy standards, may well have come and gone.” (p. 30) and favor user charges per mile driven.

¹³ [41] provides examples of public opposition to higher fuel taxes in the US and the UK, and West and Williams [48] note that “...the practical relevance of any result on optimal gasoline taxes is limited by political constraints; the existing tax in the U.S. is far below what almost any economic analysis would indicate as the optimum” (p. 18).

economy under ‘business as usual’ conditions. Potential fuel savings due to autonomous technical progress in the past have been counterbalanced by changes in consumer preferences towards safer and more comfortable cars, and there is no reason to believe why this trend should not continue in the future in the absence of impressive technological breakthroughs or an economic recession. European policy makers might need to consider this issue carefully because some recent European studies tend to be optimistic in this respect.

Finally, we attempted to provide some explanations as regards the question why raising fuel taxes may not lead to the economically most efficient solution. In the US tighter FE standards and higher gasoline taxes need to be carefully examined against their welfare impact, and a combination of both policy options should not be excluded. Conversely, it is hardly possible to increase fuel taxes in Europe because of their already high levels. Moreover, as a tax increase would have to apply to both gasoline and diesel fuel in Europe, the effect of such a measure in the whole European economy has to be considered with great care.

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APPENDIX: Treating fuel consumption standards in a time series context

a) Non-continuous standards

In a time series model the standard variable (*STD* in equations (1) and (2)) should also be available as a time series. This is straightforward in the case of the US CAFE standards and the Canadian fuel consumption targets, where a FE standard or target value is officially provided for each year's new-car fleet. In the cases of Australia, Europe and Japan, however, standards or voluntary commitments are provided as a target value in a given future year (e.g. 8.2 l/100 km in 2000 for Australia, 140 g CO₂/km in 2008 for the EU). To transform such a target to a usable *STD* variable, we assumed:

- a linear change between two target values (if FE targets had been adopted 2 or more times during the sample period)
- or a linear change between the average observed FE value of a reference year and the target value; that was the case for Japan and the EU countries. For example, we obtained values of the *STD* variable for years 1996-2004 by making a linear interpolation between the EU-wide average value of 185 g CO₂/km in the reference year 1995 [14]¹⁴, and the target value of 140 g CO₂/km for 2008.

b) Distinguishing between 'pre-standard' and 'with standards' periods in the sample

In each country, a FE regulation or voluntary agreement was introduced for the first time in a given year, specifying standards or targets that would begin to apply some years later. The introduction of such a regulation may (or may not) be associated with a structural break in automobile FE time series. In order to reflect this reality in a time series model, one should take care in assigning meaningful annual values to the *STD* variable and distinguishing between 'pre-standard' and 'with standards' periods. To this end we proceeded for each country as follows:

- Australia: The first voluntary code of practice for improving car FE was established by the Australian Federal Chamber of Automotive Industries (FCAI) in 1978, setting targets for years 1983 and 1987. A second and a third voluntary agreement followed, with the latest one calling for a reduction in new-car fuel consumption by 2010 [1]. Since Australian data in our sample start in 1978, the whole period 1978-2003 is a 'with standards' period, and we assigned values to the *STD* variable according to the interpolation described in the previous section.

¹⁴ The 185 g/km figure refers to cars produced by European and US manufacturers only, whose sales constitute 80-85% of EU automobile sales and should therefore be considered as representative of the EU car market. See common report by the European Commission and the European Automobile Manufacturers Association [14] on data from year 2003, as well as similar reports for earlier years available at http://europa.eu.int/comm/environment/co2/co2_monitoring.htm.

- Canada: Voluntary Company Average Fuel Consumption (CAFC) targets were introduced in 1976 for new passenger cars, taking effect from 1980 onwards. Corresponding target values for light trucks took effect in 1990. As data are available since 1980, the whole sample period has to be treated as a ‘with standards’ regime.
- European Union: the voluntary agreements between the European Commission and the automotive industry organizations were finalized in 1998-1999, but discussions started several years before, so it is not surprising that the agreements contain CO₂ emission targets that are compared to the reference values of model year 1995. Hence it is appropriate in this case to regard 1995 as a turning point: from 1996 onwards we applied a value for *STD* variable according to the linear interpolation described above.
- Japan: weight-specific new-car FE standards for year 2010 were set in the mid-1990s, requiring that in 2010 average fuel consumption should be 19% lower than in 1995 [1]¹⁵. Here again, 1995 seems to be the appropriate turning point with regard to fuel economy, and interpolation was used similarly with Australian and EU data.
- Switzerland: a voluntary agreement similar to the EU one was established, but with different implementation dates [6]. Since, however, the Swiss car market is greatly influenced by the much larger EU market, the whole sample of Swiss data, which starts in 1996, should be treated as being in a ‘with standards’ period.
- United States: CAFE standards were adopted already in 1975 when the ‘Energy Policy Conservation Act’ was enacted into law by Congress [26]¹⁶. This means that the whole post-1975 period should be viewed as a uniform ‘period under standards’, both for cars and light trucks. The *STD* variable takes the value of the corresponding CAFE standard in each year. For those years that are in the ‘with standards’ period but no CAFE standard was in force yet (1975-1977 for cars), it would not be correct to assign *STD* the value of the 1978 CAFE standard, as this would imply that the 1978 standard was already in place in 1975 and was not tightened until 1978. Therefore, in order to reflect the fact that the 1975 regulations took effect immediately, we assigned *STD* a linearly interpolated value between observed 1975 FE and 1978 CAFE standard. We did the same for the 1975-1981 period for light trucks.

¹⁵ 2005 is the target year for diesel vehicles, but these are a small fraction of the Japanese car stock.

¹⁶ See also <http://www.nhtsa.dot.gov/cars/rules/cape/overview.htm>.