The impact of standards and fuel prices on vehicle fuel efficiency: an international panel analysis[*]

Theodoros Zachariadis[a] & Sofronis Clerides[b]

[a] Economics Research Centre, University of Cyprus, P.O. Box 20537, 1678 Nicosia, Cyprus
Tel. +357 22 892425, Fax +357 22 892426, E-mail: t.zachariadis@ucy.ac.cy

[b] Department of Economics, University of Cyprus, P.O. Box 20537, 1678 Nicosia, Cyprus

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 CO_2 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

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. 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]. Alternative 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. A second approach is to increase fuel

[*] For a more extensive version of this paper see [51].

[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).

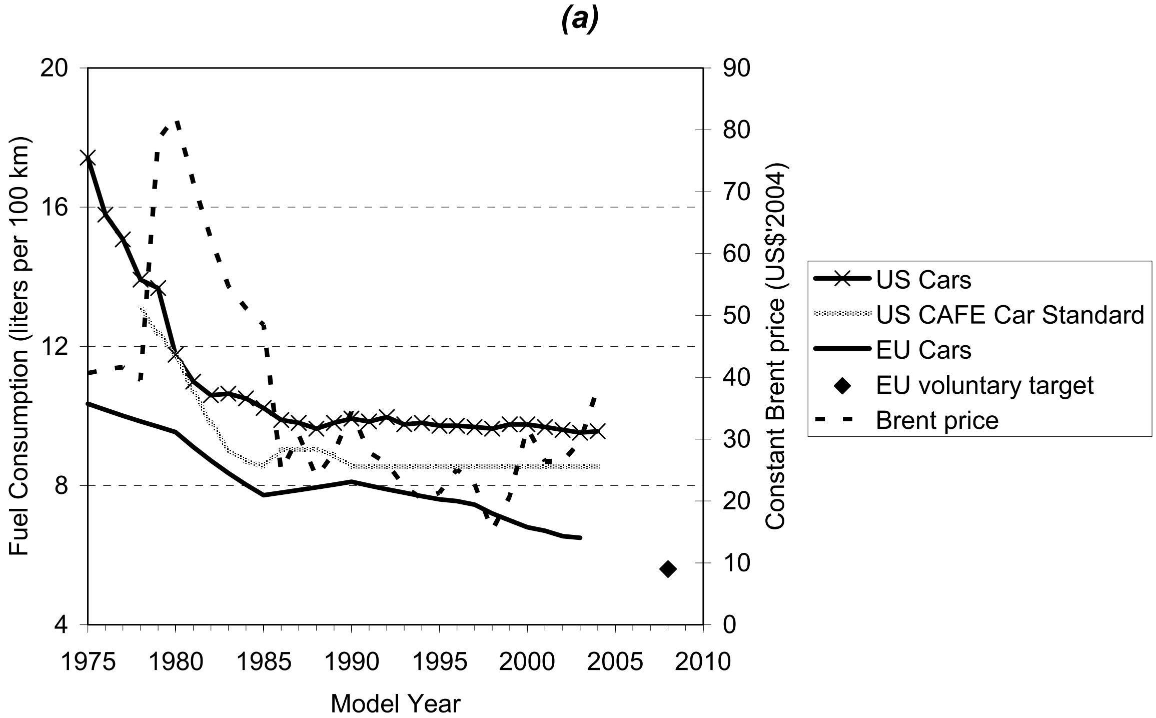
taxation in order to induce purchases of more efficient cars and discourage private car travel. Mandatory fuel economy standards have been in force in the United States since 1978 (although, with a small exception for light duty trucks, they have not been tightened since 1990). Other countries followed later, and currently Australia, Canada, China, the EU, Japan, Switzerland, South Korea and Taiwan implement some type of FE or CO_2 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. 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.

However, there are voices 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 and suggest that, if the CAFE system is to be retained, a number of improvements should be introduced [39, 43]. Other analysts reject the idea of any type of standard whatsoever [5, 38, 40, 46] and claim that increasing gasoline tax by a small amount would yield the same energy conservation effect with CAFE at significantly lower welfare costs.

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 CO_2 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 high [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 CO_2 g/km is mentioned for the year 2012 or later.



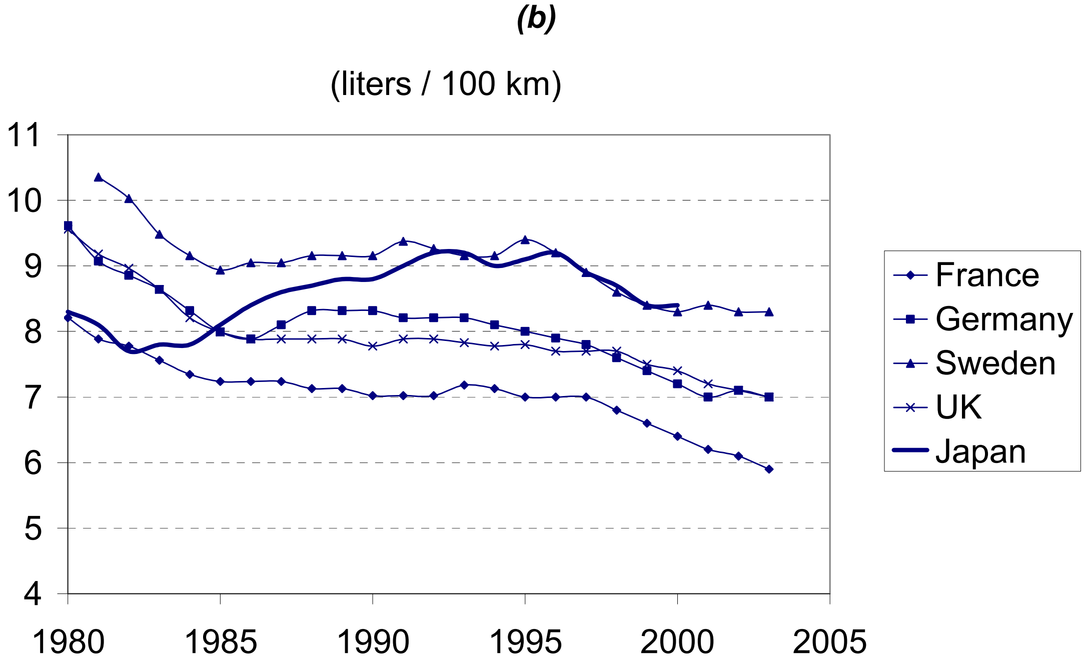


Figure 1: *(a)* Evolution of new-car fuel consumption in the US and the EU and the corresponding CAFE standard (for the US) and voluntary CO_2 target (for the EU). US data come from [32]; for compilation of EU data see [49]. The international oil price in real terms, taken from [8], is also shown. *(b)* New-car fuel consumption in Japan and four EU countries.

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], Johansson and Schipper [36], Storchmann [45], Greene [26], Gately [22] and Small and van Dender [44], but 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

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. Income may also significantly affect fuel economy, although the direction may not be *a priori* obvious. Existing studies [11, 18, 22, 36, 45] provide conflicting evidence. 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, 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 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.

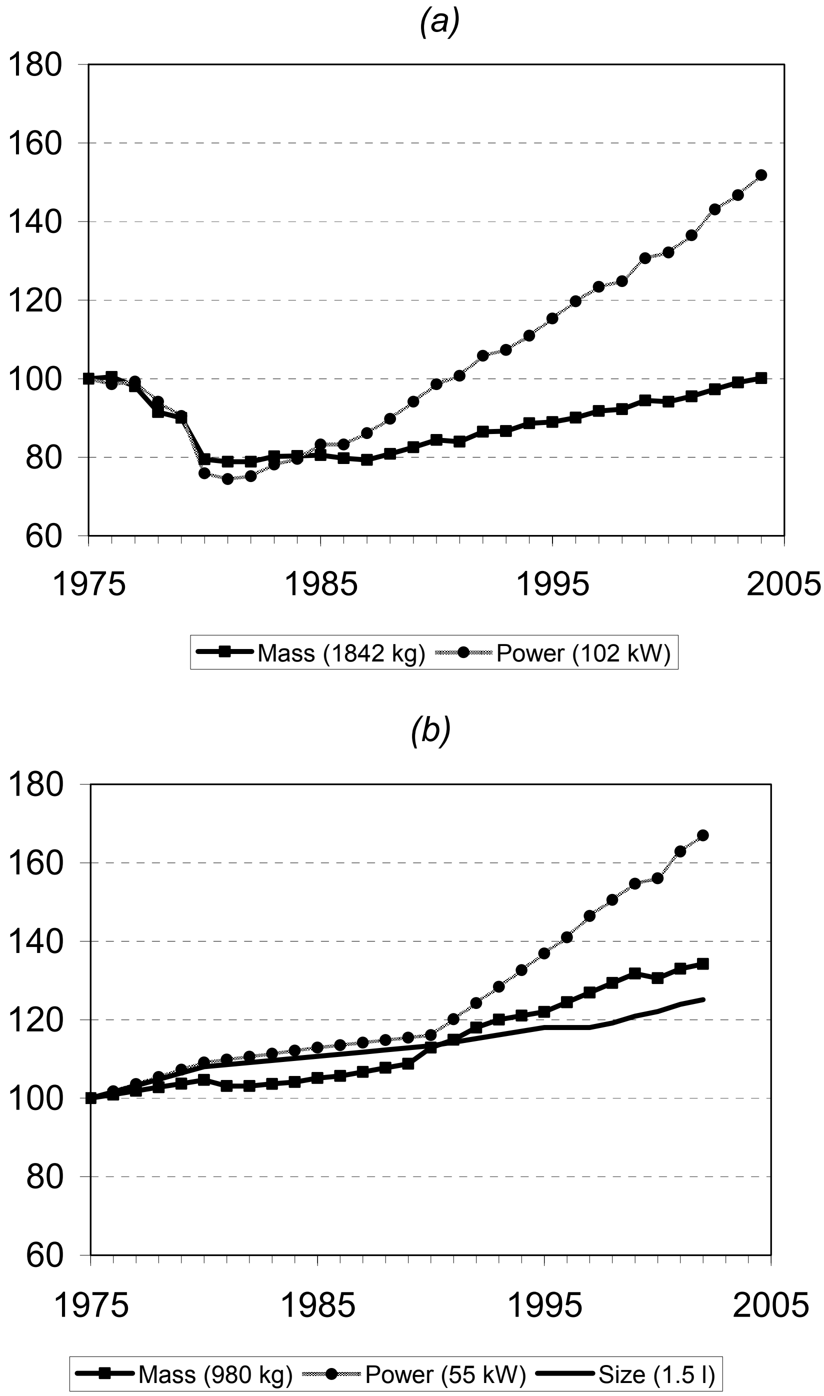


Figure 2: Evolution of new vehicle attributes (average vehicle mass, maximum engine power and average engine size) *(a)* in the US and *(b)* in Europe. In each case the attributes of year 1975 are the basis (1975=100), and legends provide the actual figures for the base year. See Figure 1 for description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

Technical progress is another important and controversial aspect. 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:

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

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 $(1-\lambda)$.

3. Data

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.

Country	*Vehicle category*	*Sample period*	*Type of standards*	*Enforcement type*	*First decision for the adoption of standards/targets*	*First year of implementation or first target year*
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 Web[2]); 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 Web[3]); the Japanese Automobile Manufacturers Association (JAMA)[4]; 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 CO_2 emission targets, some transformations were necessary in order to arrive at the common *STD* variable of equation (1); these are explained in detail in [51].

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 2. The model was estimated for the whole sample as well as for two sub-samples comprising North American and European data respectively, since these are the regions whose data dominate in the whole sample. The hypothesis of no second-order autocorrelation in the residuals, which is fundamental for the consistency of the Arellano–Bond estimator, cannot be rejected.

---

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

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

[4] See http://www.jama.org/statistics/motorvehicle/sales/mv_sales_size1.htm.

Table 2: Regression results for equation (1).

Countries	*Cross-sections*	*Sample size*	*λ*	*α 1*	*α 2,0*	*α 3*	*α 4*	*Autocorrel.*
All	20	339	0.709 ***	-0.001	-0.080 ***	0.135 ***	-0.004	0.636
			[20.270]	-[1.350]	-[6.580]	[2.490]	-[0.130]	
N. America	4	98	0.653 ***	0.000	-0.094 ***	0.236 *	-0.009	0.649
			[9.180]	[0.160]	-[3.180]	[1.770]	-[0.170]	
EU	13	193	0.780 ***	-0.001	-0.043 ***	0.219 ***	0.015	0.426
			[26.760]	-[1.000]	-[4.190]	[3.760]	[0.320]	

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 analysis. Finally, in all cases the deterministic time trend was found to be statistically insignificant.

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 [51]. 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.

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.

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. 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 CO_2/km is currently discussed for the year 2012 (a 25% decrease compared to about 160 g CO_2/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). Assessing the long-run effect of the two policies (tighter standards vs. higher fuel taxes) on total fuel consumption, we estimated [51] that the fuel savings from a 10% increase in CAFE would be equivalently attained through a fuel price increase of 36 US cents per gallon (at 2004 prices); this figure is the same with that of Austin and Dinan [5], who reached this result with a different method.

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

There are intense ongoing discussions in the EU regarding future CO_2 emission targets. Environmentalists and numerous analysts point to the need for adopting a 120 g CO_2/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 CO_2/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 consumption, or expanded availability of safety equipment and other amenities, which would make a car heavier and more fuel consuming. Increasing consumer awareness, 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 mean that there has been no autonomous technical progress in vehicle fuel economy over the last 30 years, but rather 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.

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.[5]

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 CO_2 emissions must be curtailed. 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 order to achieve its environmental goals. Apart from the questionable economic rationale behind already existing fuel taxes [42], the political acceptance of a considerably higher fuel tax is not given [41, 48]. 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

[5] 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.

type of FE standards for a substantial period of time. Using data from official sources, we built an unbalanced panel comprising 384 observations from 18 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. 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 observed in recent years; 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. 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 CO_2/km in the future. Thirdly, without higher fuel prices and/or tighter FE standards, one should not expect any marked improvements in fuel economy under 'business as usual' conditions. European policy makers might need to consider this issue carefully because some recent European studies tend to be optimistic in this respect.

Finally, we questioned whether raising fuel taxes leads indeed 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.

Acknowledgments

The first author has conducted his part of the research in the framework of a Marie Curie Fellowship that he has received from the European Community within its Sixth Framework Programme. Views expressed in this article and remaining errors or omissions are the sole responsibility of the authors.

References

1. F. An, A. Sauer, Comparison of passenger vehicle fuel economy and greenhouse gas emission standards around the world, Report prepared for the Pew Center on Global Climate Change, Arlington, VA, 2005.
2. T.W. Anderson, C. Hsiao, Formulation and estimation of dynamic models using panel data, J. Econometrics 18 (1982) 47–82.

3. M. Arellano, A note on the Anderson-Hsiao estimator for panel data. Econ. Letters 31 (1989) 337–341.

4. M. Arellano, S. Bond, Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. Rev. Econ. Stud. 58 (1991) 277–297.

5. D. Austin, T. Dinan, Clearing the air: The costs and consequences of higher CAFE standards and increased gasoline taxes, J. Environ. Econom. Management 50 (2005) 562–582.

6. Auto-Schweiz (Association of Swiss Vehicle Importers), 9. Berichterstattung im Rahmen der Energieverordnung über die Absenkung des spezifischen Treibstoff-Normverbrauchs von Personenwagen 2004, Bern, Switzerland, 2004 (in German and French). Also at http://www.auto-schweiz.ch/data/Bericht2004.pdf.

7. B.H. Baltagi, Econometric Analysis of Panel Data, John Wiley and Sons, 2001.

8. BP Statistical Review of World Energy, London, June 2005.

9. E. Bratberg, S. Tjøtta, T. Øines, Do voluntary international environmental agreements work?, J. Environ. Econom. Management 50 (2005) 583–597.

10. G.C. Chow, Tests of Equality between Sets of Coefficients in Two Linear Regressions, Econometrica 28 (1960) 591–605.

11. C.A. Dahl, Demand for Transportation Fuels: A Survey of Demand Elasticities and Their Components, J. Energy Lit. 1 (1995) 3–27.

12. S.C. Davis, S.W. Diegel, Transportation Energy Data Book: Edition 24, Report ORNL-6973, Oak Ridge National Laboratory, Oak Ridge, TN, 2004.

13. EC (European Commission), Commission recommendations on the reduction of CO_2 emissions from passenger cars, Official Journal of the European Communities, Nos L 40/49-13.2.99, L 100/57-20.4.2000 and L 100/55-20.4.2000. Also at http://europa.eu.int/comm/environment/co2/co2_agreements.htm

14. EC (European Commission), Monitoring of ACEA/JAMA/KAMA Commitment on CO2 Emission Reductions from Passenger Cars, Working Paper COM(2005) 269 final, Brussels, 2005. Also at http://europa.eu.int/comm/environment/co2/co2_monitoring.htm

15. ECMT (European Conference of Ministers of Transport), Monitoring of CO_2 Emissions from New Cars, Document No. CEMT/CM(2003)10, Paris, March 2003.

16. EEA (European Environment Agency) The European environment - State and outlook 2005, State of Environment report No 1/2005, Copenhagen. Also at http://reports.eea.eu.int/state_of_environment_report_2005_1/en/tab_content_RLR.

17. EIA (US Department of Energy, Energy Information Administration), Annual Energy Outlook 2006, DOE/EIA-0383(2006), Washington, DC, 2006.

18. M. Espey, Watching the fuel gauge: An international model of automobile fuel economy, Energy Econ. 18 (1996) 93–106.

19. Eurostat (European Statistical Service), Energy and Transport in Figures, Statistical pocketbook, Luxembourg, 2005.

20. Eurostat, NewCronos database. Available on CD-ROM and on the World Wide Web, Luxembourg, 2006.

21. L. Fulton, G. Eads, IEA/SMP Model Documentation and Reference Case Projection, Paris, France, 2004. Also at http://www.wbcsd.org.

22. D. Gately, Imperfect Price-Reversibility of U.S. Gasoline Demand: Asymmetric Responses to Price Increases and Declines, Energy J. 13 (1992) 179–207.

23. A. Glazer, C. Lave, How Regulations Can Succeed Where Taxes Do Not: An Examination of Automobile Fuel Efficiency, Working Paper Public Economics 9406002, EconWPA, 1994.

24. P. Goldberg, The effects of the Corporate Average Fuel Efficiency standards in the US, J. Ind. Econ. XLVI (1998) 1–33.

25. L.H. Goulder, R.C. Williams III, The substantial bias from ignoring general equilibrium effects in estimating excess burden, and a practical solution, J. Polit. Economy 111 (2003) 898–927.

26. D. Greene, CAFE or price? An analysis of the effects of federal fuel economy regulations and gasoline price on new car MPG, 1978-89, Energy J. 11 (1990) 37–57.

27. D. Greene, Why CAFE Worked Energy Policy 26 (1998) 595–613.

28. D.L. Greene, J.R. Kahn, R.C. Gibson, Fuel Economy Rebound Effect for U.S. Household Vehicles, Energy J. 20 (1999) 1–31.

29. D.L. Greene, J.-T. Liu, Automotive fuel economy improvements and consumers' surplus, Transp. Res.: Part A: Pol. Practice 22A (1988) 203–218.

30. D.L. Greene, P.D. Patterson, M. Singh, J. Li, Feebates, rebates and gas-guzzler taxes: a study of incentives for increased fuel economy, Energy Policy 33 (2005) 757–775.

31. J.M. Griffin, C.T. Schulman, Price Asymmetry in Energy Demand Models: A Proxy for Energy-Saving Technical Change? Energy J. 26 (2005) 1–21.

32. K.H. Hellmann, R.M. Heavenrich, Light-Duty Automotive Technology and Fuel Economy Trends: 1975 Through 2004, Report EPA420-R-04-001, US Environmental Protection Agency, Ann Arbor, Michigan, 2004. Also at http://www.epa.gov/otaq/fetrends.htm.

33. H. Huntington, A Note on Price Asymmetry as Induced Technical Change, Energy J. 27 (2006) 1–7.

34. IEA (International Energy Agency), Saving Oil and Reducing CO_2 Emissions in Transport – Options and Strategies, Paris, France, 2001.

35. IEA (International Energy Agency), Energy Prices and Taxes, Paris, France, 2005.

36. O. Johansson, L. Schipper, Measuring the long-run fuel demand of cars, J. Transp. Econ. Pol., September 1997, 277–292.

37. P. Kågeson, Reducing CO_2 Emissions from New Cars, Progress Report, European Federation for Transport and Environment, Brussels, 2005. Also at http://www.t-e.nu/Article90.html

38. A.N. Kleit, Impacts of long-range increases in the fuel economy (CAFE) standard, Econ. Inquiry 42 (2004) 279–294.
39. NRC (US National Research Council), Effectiveness and impact of corporate average fuel economy (CAFE) standards, National Academy of Sciences, Washington, DC, 2005.
40. I.W.H. Parry, C. Fischer, W. Harrington, Do Market Failures Justify Tightening Corporate Average Fuel Economy (CAFE) Standards? Resources for the Future, Washington, DC, 2005.
41. I.W.H. Parry, K.A. Small, Does Britain or the United States Have the Right Gasoline Tax? Discussion Paper 02-12 rev., Resources for the Future, Washington, DC, 2004.
42. I.W.H. Parry, M. Walls, W. Harrington, Automobile Externalities and Policies, Discussion Paper 06-26, Resources for the Future, Washington, DC, 2006.
43. P.R. Portney, I.W.H. Parry, H.P. Gruenspecht, W. Harrington, The Economics of Fuel Economy Standards, J. Econ. Perspect. 17 (2003) 203–217.
44. K.A. Small, K. VanDender, A Study to Evaluate the Effect of Reduced Greenhouse Gas Emissions on Vehicle Miles Traveled, Report prepared for the State of California Air Resources Board, California Environmental Protection Agency and the California Energy Commission, ARB Contract Number 02-336, Irvine, CA, 2005.
45. K. Storchmann, Long-Run Gasoline demand for passenger cars: the role of income distribution, Energy Econ. 27 (2005) 25–58.
46. S.G. Thorpe, Fuel economy standards, new vehicle sales, and average fuel efficiency, J. Regul. Econ. 11 (1997) 311–326.
47. WBCSD (World Business Council for Sustainable Development), Mobility 2030: Meeting the challenges to sustainability, Geneva, Switzerland, 2004.
48. S.E. West, R.C. Williams III, Empirical estimates for environmental policy making in a second-best setting, NBER Working Paper 10330, February 2004. Also at http://www.nber.org/papers/w10330
49. T. Zachariadis, On the baseline evolution of automobile fuel economy in Europe, Energy Policy 34 (2006) 1773–1785.
50. T. Zachariadis, S. Clerides, The effect of standards and fuel prices on automobile fuel economy: an international analysis. Proceedings of the 29th International Conference of the International Association for Energy Economics, Berlin, Germany, 2006.
51. S. Clerides, T. Zachariadis, Are Standards Effective in Improving Automobile Fuel Economy? Discussion Paper No. 06-06, Department of Economics, University of Cyprus. Available at http://www.econ.ucy.ac.cy/research/working_papers/2006/index.htm