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Transportation Fuel Use, Technology and Standards:

The Role of Credibility and Expectations

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Abstract

There is a debate among policy analysts about whether fuel taxes alone are the most effective policy to reduce fuel use by motorists, or whether to also use mandatory standards for fuel efficiency. A problem with a policy mandating fuel economy standards is the “rebound effect,” whereby owners with more efficient vehicles increase vehicle usage. If an important part of negative externalities from transport are associated with vehicle kilometers (accidents, congestion, road wear) rather than fuel consumption, the rebound effect increases negative externalities. Taxes and standards should be mutually supportive because fuel taxes often meet political resistance. Over time, fuel efficiency standards can reduce political resistance to fuel taxes. Thus, by raising fuel efficiency standards now, politicians may be able to pursue higher fuel tax paths in the future. Another argument in support of fuel efficiency standards and similar policies is that standards to a greater extent than taxes can be announced in advance and still be credible and change the behavior of inventors, firms, and other agents in society. A further argument is that standards can be used with greater force and commitment through international coordination.

This paper—a product of the Sustainable Rural and Urban Development Team, Development Research Group—is part of a larger effort in the department to mainstream research on climate change. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at eske@cicero.uio.no.

Transportation fuel use, technology and standards:
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Gunnar S. Eskeland, Torben K. Mideksa[1]

ACRONYM LIST

CAFÉ	Corporate Average Fuel Economy
IEA	International Energy Agency
LRMC	Long Run Marginal Cost Curve
MPG	Miles per Gallon
R & D	Research and Development
SRMC	Short Run Marginal Cost Curve

[1] CICERO Center for Internatinoal Climate and Environmental Research, Oslo. Eskeland was a consultant to the World Bank at the time of preparing this paper. We thank the World Bank for financial support, and Ariel Dinar, Tobias Persson, Zmarak Shalizi, an anonymous referee and participants at the EAERE conference in Gothenburg, 2008 for valued comments and suggestions. Comments are welcome: eske@cicero.uio.no.

I. Introduction

Energy and energy consumption are a public policy issue for many reasons. One reason is that there are negative externalities related to energy consumption (such as emissions of local air pollutants or global greenhouse gases). Policy instruments to address such problems will to a great extent attempt to reduce fuel consumption even if they are not addressed with fuel taxes, as when one uses tradable quotas or emission taxes. To this extent the arguments here apply. Another is that energy consumption might be a sensible and practical way of charging for some public service, like provision of road space, to limit congestion and accidents, etc. A third reason is that government may be concerned that scenarios of energy shortage are given too little attention in private markets. These types of issues give government reason to apply policy instruments to reduce energy consumption. This paper examines the question of how to use efficiency standards and/or fuel taxes for such purposes, and uses the example of vehicular fuel use as the concrete model.

This paper takes for granted that security of the energy supply and greenhouse gas emission reductions are major public goals that can underpin strategies to conserve petroleum use. Both of these goals have, from the perspective of the objectives themselves, important dimensions of time and uncertainty. If the oil supply in the future becomes more costly, is the government currently playing a role in helping to reduce oil consumption *now*? Today's world market prices could reflect future expected scarcity, and markets may also allow for valuation of scenarios that are less likely, and offer insurance. Similarly, for greenhouse gas emissions, should one take steps towards conservation now, under the belief that emission costs in the future will be high? The present study accepts that the answer to both questions could be yes. First, current prices may not fully reflect future scarcity, and the issue of insurance may be different between a country or a group of countries and (smaller) individual agents[2]. Second, in particular through their effect on

[2] Hotelling's famous model for exhaustible resources imply that oil prices should increase with the real rate of interest, making oil savings at any time worth the same ex ante. But assumptions are important, and exhaustible resources could be harvested more like open access fisheries, with present prices too low to reflect future scarcity. For Carbon dioxide emissions, more obviously than for oil, a property rights regime has not been established generally and firmly, and low emission prices applying in many contexts likely fail to express expected future scarcity premia.

capital decisions, such as car efficiency and related research, present policies may change our future ability to deal with energy scarcity and/or emission reduction requirements.

From the basic welfare economics point of view, it appears as if fuel efficiency standards are not required if externalities relate to fuel consumption. A fuel tax asks consumers to reduce fuel consumption by optimally combining reduced demand for the energy service (vehicle miles) *and* improved fuel efficiency. Therefore the government would have little reason to make use of a fuel efficiency standard, which singles out improved fuel efficiency as a solution. Arguments in favor of the efficiency standard could be that producers or consumers fail to focus sufficiently on fuel efficiency improvements due to how expectations are formed or how the future is discounted, and thus we shall allow these considerations as we discuss the case for combinations of standards and taxes.

The improvements in fuel efficiency that follow from either fuel taxes or fuel efficiency standards include technological change, which may be far-reaching and radical depending on the general policy setting. Currently we deal with this question in a very basic way by simply assuming that producers can make cars more efficient for a cost, in response to these two instruments. Technological change responds to many factors (most of which we abstract from), an important one being expectations. Since expected fuel prices is a question of importance for technological change, we address the question of whether fuel economy standards could affect expectations and technological change differently than fuel taxes and announcements about future fuel taxes.[3]

Oil price shocks beginning in the 1970s left negative and memorable consequences for importing countries forcing them to seek ways to reduce their dependency on imported oil. Reducing energy dependency became an important policy objective of the United States, the European Union, and a host of other countries. Many countries have opted to diversify

[3]Apart from these narrow questions regarding these two instruments, technological change is not dealt with in this paper.

their energy portfolios and reduce reliance on imported oil. Through the 1980s and 1990s, concerns declined[4]. Dependency was lower, and so were oil prices.

Taxes have kept prices from dropping for products such as gasoline and diesel in many countries. In some cases this has been in lieu of environmental objectives and road user charges, however equally as important are the general fiscal objectives. In the past couple of decades, a consensus has been building among scientists that consumption of fuel, more specifically the release of anthropogenic carbon dioxide to the atmosphere, has been the primary factor behind the increase in temperature and climate change. Responsible policies required countries to once again reduce consumption of fossil fuel for dual purposes of energy supply security and greenhouse gas emission reductions.

Reducing carbon dioxide emissions and enhancing energy security have been the primary factors driving countries to reduce their oil consumption. Most countries throughout the world (though there are exceptions among oil exporting countries) take some measures to conserve energy through gasoline taxes and/or mandated increases in fuel efficiency standards.

Across the world, there are alternative policies in place to help reduce gasoline consumption (See, among others, Schipper et al, 1999). Policy makers in the United States, the European Union, China, etc. use both mandated fuel efficiency standards as well as fuel taxes[5]. One important argument in favor of fuel efficiency standards is based on the assumption that car buyers, and private individuals in particular, care very little about future savings in fuel consumption. In economists' terms, people discount the benefit from expected fuel savings at a higher rate than what is socially optimal. If they do, they do not offer car makers enough of a premium for more efficient cars, thus car makers and inventors have suboptimal incentives to build (and invent) more efficient cars. This

[4] In fact, according to IEA data, in OECD, government research on energy technology almost halved between 1985 and 2000 (Alfsen and Eskeland, 2007).

[5] We shall use the term fuel taxes, in part because our point is a general one about a variable input with negative external effects, and due to the illustration we make about vehicles and transport, we should think about 'fuel' as gasoline and diesel. The terms 'car' and 'vehicles' carry the more general meaning of 'machine'. The terms fuel economy standards and fuel efficiency standards are used interchangeably.

question is an important one, and it is separate from the question of whether fuels are taxed so as to internalize the negative externalities due to fuel consumption.

Many economists argue that a gasoline tax is an effective policy instrument if the objective is to reduce gasoline consumption, and that when fuel taxes are used, there is no need for fuel efficiency standards. It could very well be, of course, that consumers discount future fuel savings 'too heavily' because they are financially constrained. Without this, justifying government intervening with fuel economy standards to force consumers to buy cars that are more efficient (and, by assumption, either more expensive or less interesting in one quality dimension or another) is difficult.

We argue that the 'competition' between fuel economy standards and fuel taxes is falsely created in the literature. Representative views in the literature are reflected by Crandall (1992): "As a practical matter, the current policy choice for reducing fuel consumption or carbon emissions is between CAFE and fuel tax" or CBO (2004) "This issue briefly focuses on the economic costs of CAFE standards and compares them with the costs of a gasoline tax that would reduce gasoline consumption by the same amount." We shall argue here, in contrast, that mandated standards are compliments, to be used together.

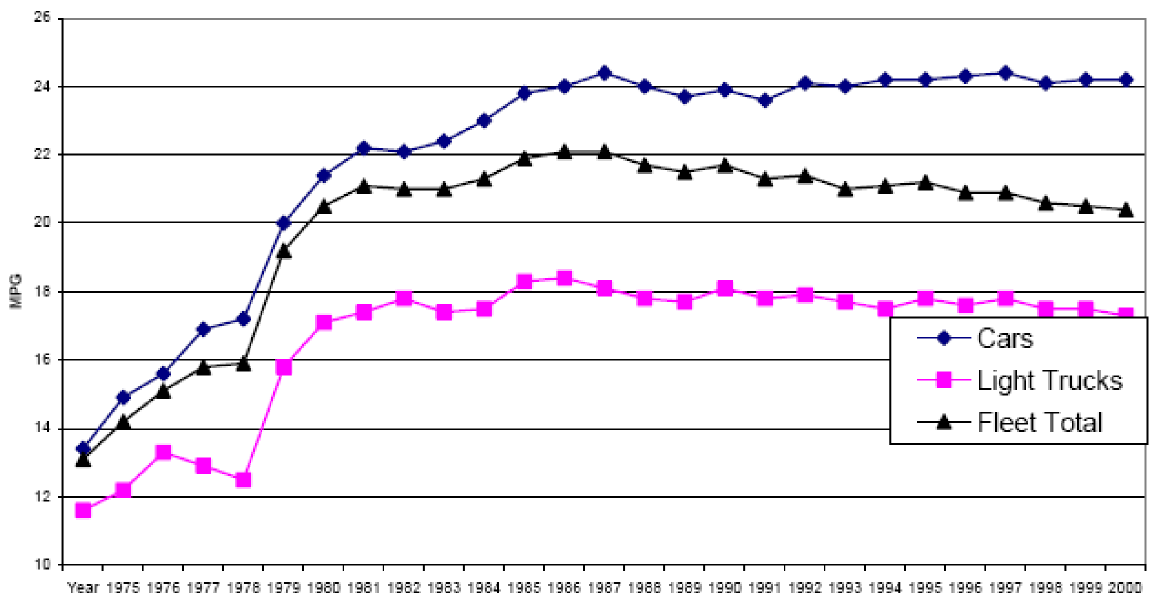
The remainder of the paper is organized as follows. Section III presents a review of the literature following a historical overview in section II of mandated increases in the fuel economy. In section IV, a simple model is presented as to analyze the joint use of the two policies. General implications are drawn from the models and we conclude the paper with some final remarks.

II. Brief History of Standards

The pattern of fuel economy standards and gas taxes are an important indicator of the policy process over time. Fuel economy standards have increased over time just as gasoline taxes have in many countries.

The 1973-74 oil embargoes and its consequence on oil prices have led United States policy makers to consider the automobile fuel efficiency within their economy. According to Bamberger (2003), new cars' average fuel economy, as measured by miles per gallon (MPG), had fallen from 14.8 in 1967 to 12.9 in 1974. Thus, in 1975 the Corporate Average Fuel Economy (CAFE) Standard for passenger cars was enacted. The program required manufacturers that sell more than 10,000 autos per year to comply with the mandated CAFE standards[6] or face a fine of $55 per car-MPG fine.[7].

Figure1: Fuel Economy of New vehicles



Source: Gerard and Lave (2003)

The above figure illustrates the average fuel economy for passenger car's and light duty trucks within the United States between 1975 through 2000. Throughout this period, light duty trucks (which include vans and sport utility vehicles, SUVs) have been under more generous (lax) fuel standards than cars. Their increased share in the market, which has reached 50% of total sales, is seen by the fact that the fleet's total fuel economy is declining though within the two subcategories it has been fairly stable since the mid-1980s.

[6] See Kleit (2004).

[7] Economists will appreciate the feature that cars can be sold that are more or less efficient than the standard, as long as the average complies with the standard. Corporations that sell mostly luxury cars have not had the benefit of this averaging, facing a barrier that probably combines politics and administrative feasibility.

As noted by Crandall and Graham (1989), sky rocketing oil prices, partly caused by the Iranian revolution, had provided sufficient incentives for automobile producers to improve their fuel economy standards, so that all three of the major United States car producers exceeded the mandates by wide margins. However, the decline in oil price in 1981 lead to decreasing fuel efficiency, and the mandated fuel economy standards again became binding.

Countries have different fuel economy standards. An and Sauer (2004) reported that increasingly many countries have raised the fuel economy standard over time. By and large, Japan has the highest fuel economy standards compared to the rest of the world. The United States has the lowest, along with Canada, Australia and China, all of which have lower (i.e. more lax) standards than the European Union (figure 2)[8]. Figure 2 also displays an important feature of fuel economy standards: they may develop over time according to a preannounced schedule. If automakers can be made to believe that the schedule will be implemented and enforced, then the credibility of such a plan may imply that these standards have an edge over fuel taxes in terms of sending longer term signals, and thus more powerful incentives to invest and innovate.

On average, the United States' federal gas tax rates have been increasing, except for the decline in the late 1980s. Federal taxes have initially been levied for revenue generating reasons. However, increasing recognition of the negative externalities associated with gas provided additional rationale for taxing gasoline.

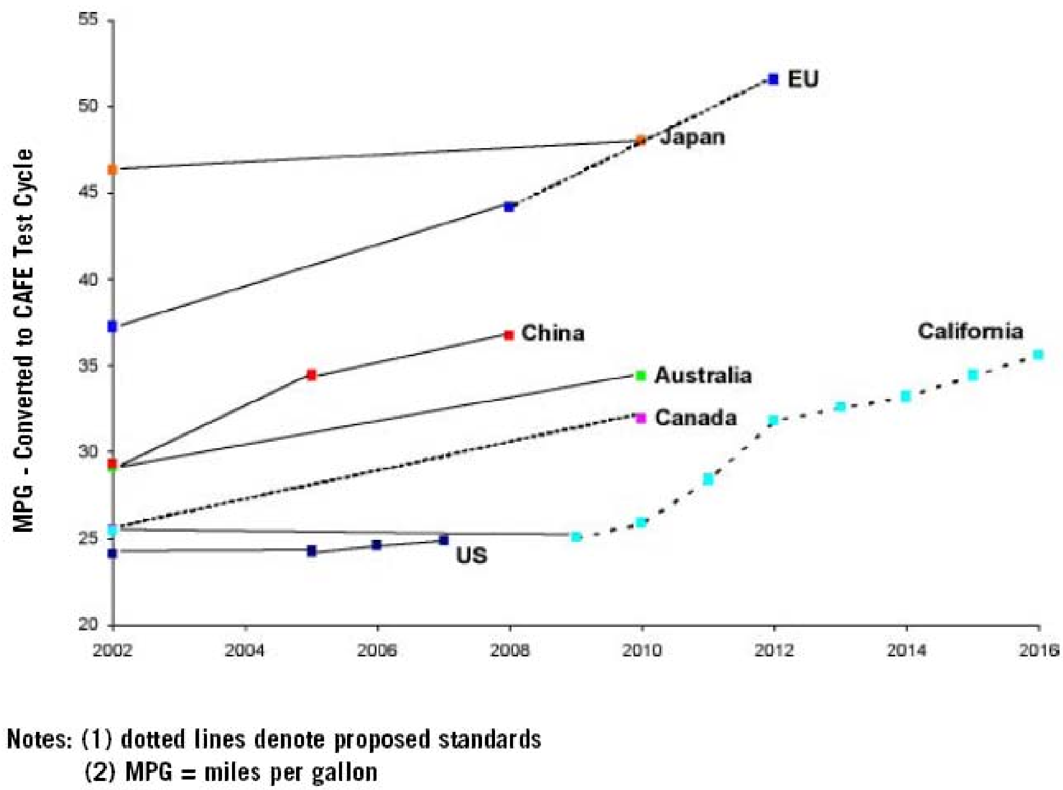
Practical illustration shows that fuel taxes and standards often work together, rather than as competing instruments. From the mid–1980s, in the United States, we have seen that both have increased (not shown)[9]. As long as mandated fuel economy standards and gas tax rates are 'discretely' chosen by policy makers, policy makers have been using both instruments as compliments to each other instead of an alternative to each other. The fact that almost all research focuses on the comparison between technology standards and gas

[8] see also Zachariadis (2006)

[9] According to CBO (2003) federal gasoline tax started in 1932. United States gas taxes are low by international standards, see Parry and Small (2005).

tax is somewhat paradoxical given how fuel economy standards are used in many countries, including Australia, Canada, China, Japan, the United States and the European Union.

Figure 2: Comparison of Fuel Economy Standards across Countries



Source: An and Sauer (2004).

The Challenges Ahead

As incomes grow, car ownership rates can safely be expected to expand. Moreover, since space at home and in the workplace are normal goods, urban densities will decline, unless changes in prices and other conditions counter this trend.[10]. This puts great demands on investment in transport infrastructure, makes it increasingly costly to defend or expand the share of public transport, and to manage externalities due transport. As a result, the policy objectives of greenhouse gas emission reductions and of energy security results in a need for long term management of fossil fuel use in transport, perhaps by using policy

[10] See Alain Bertaud and Stephen Malpezzi (2003). Transport is generally found to be a normal good. Private cars often are luxury goods (in the narrow sense of income elasticities exceeding one) at least at low to moderate income levels, and – then – so is travel by personal vehicles.

instruments such as energy efficiency standards in addition to instruments such as gasoline and diesel taxes.

In general, private cars are normal goods in the sense that car ownership rates are increasing with income, as is the use of private cars. In addition, people (or nations) tend to buy less fuel efficient cars at higher income levels (illustrations of these stylized facts are given in annex figures A1 through A7, merely meant to illustrate empirical associations, rather than implying causality). The explanation for this phenomenon is typically found in the fact that income growth allows people to seek other quality dimensions in cars, and that these may correlate with low fuel efficiency. Cars with more space, acceleration, carrying capacity and comfort may be – ceteris paribus – also less fuel efficient. Such a pattern is illustrated in the data by showing that the average weight per car is higher in countries with higher average incomes. Finally, it is also found that people buy more efficient cars in countries with higher fuel prices. Thus, in broad, cross-country averages, presumptions along the lines of 'homo economicus' are not contradicted.

In sum, when population and incomes grow, there will be more and greater vehicles on the road, and in welfare terms this is of course an agreeable development. Such growth has, however, implications for fuel use, and the management of the externalities demands long-term perspectives.

III. Review of the Literature

There are two strands of research that has focused on fuel economy standards. One type of research has been geared towards understanding the relative merits of fuel economy standards relative to fuel taxes. The other strand, on the other hand, focused on the efficiency of standards in light of different market failures.[11]

[11]Lower fuel consumption would make an the economy less dependent on energy, and on trade with regions that might be politically unstable and some times very hostile to the US. In fact, the 1973-1974 Arab oil embargoes had been the main driving force for the 1975 fuel efficiency standard mandate. As concerns on

Economics researchers have focused on whether mandated fuel economy standards or gasoline taxes are most suited to reduce gasoline consumption. The public policy issue is that greenhouse gas emissions as well as national oil dependence can be seen as unpriced consequences of fuel consumption, or *negative externalities*. These externalities in principle are best *internalized* with a fuel tax at the appropriate level, thus making the fuel user take these effects into account when consuming fuel. A fuel efficiency standard addresses fuel consumption in a less flexible, more constrained way, since it makes cars more fuel efficient, but fails to give incentives to drive less.

Fuel efficiency standards are thus not the best instrument choice from basic principles, and arguments in their favor typically include a few twists with appeal from the real world. One twist is that consumers, and also auto manufacturers, fail to fully value the fuel savings that an efficient car offers for the future; due to myopia or other reasons (we deal with these issues below). Another is that fuel taxes transfer money to governments in addition to internalizing the externality, and unless the transfer is seen as valuable to tax payers, fuel taxes will meet greater political resistance than standards (Parry et al, 2007, give a well rounded treatment, and the basic point was observed by Buchanan and Tullock, (1975)..

Austin and Dinan (2005) and the CBO (2003) analyze the cost effectiveness of either raising CAFE standards or increasing the federal gasoline tax. After careful analysis, both studies conclude that the current CAFÉ design is not cost effective when compared with the gas tax.

Crandall (1992) and also Kleit (2004) document that the welfare costs of reducing consumption with fuel economy standards are higher than when comparable reductions are

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climate change grow, lower fuel consumption is intended also to reduce the emission of CO2 to the atmosphere.

achieved with taxes.[12] This fits well with basic theory. It establishes that unless one accepts and incorporates effects such as myopia and excessive discounting, fuel efficiency standards will be a costly way of reducing consumption relative to fuel taxes. This is illustrated well by Fischer et al.(2007) who develop a general model to analyze increases in fuel economy standards, allowing for alternative assumptions about how consumers value fuel efficiency. Those assumptions allow tighter efficiency standards to bring anything from moderate welfare gains to substantial welfare losses, based on damage costs estimates from the USA (i.e. a cost benefit analysis, rather than comparison with tax).

Gerard and Lave (2003), in contrast, argue that there is a huge gap between social and private willingness to pay for oil conservation. The source of this mismatch is not due to lack of information or traditional sources of market failure as they argue that "…we argue that CAFE is justified even for rational, well-informed consumers, since there are social benefits of fuel conservation that private decision makers do not internalize."

One argument in favor of a mandated increase in fuel efficiency concerns a particular aspect of household decisions, perhaps to be regarded as market failure. These arguments (see National Academy of Sciences (1991), and Haussmann (1979)), are based on empirical studies indicating that low-income households use higher discount rates when they value future fuel savings. Accordingly, consumers discount the benefit of energy conservation at a higher rate than what a society would desire, and fuel economy standards can address this.[13]

Another argument for mandated fuel standards in relation to gasoline taxes concerns equity and public finance. According to this argument, uniform gasoline taxes are more painful to

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[12] See also Charles River Associates (1991) for details of the calculation of costs.

[13] The empirical estimate from Espey and Nair (2005) suggests that there are cases with no evidence of excessive discounting. Generally, the research testing the hypothesis of market failure through excessive discounting is not rich, neither providing clear results on the empirical phenomenon nor in terms of policy implications.

the poor than to the rich, while fuel economy standards selectively penalize those who buy new cars only (in fact, David Harrison and others have pointed out, regulations that make new cars more expensive can give owners of old cars capital gains, though perhaps transitory). Nevertheless, while gasoline taxes transfer money from the private sector to government and this may be argued to be regressive, there are important counterarguments. First, there are compensatory ways to transfer money back to the private sector, including some that are better at targeting the poor than are gasoline subsidies. Second, there is an important insight from public finance that raising money for the public sector is costly, but worthwhile to analyze in a general equilibrium context. While ‘green taxes’ such as gasoline taxes may indeed provide opportunities for ‘double dividends’ (reduce pollution *and* raise revenue) the literature points to the importance of the pre-existing tax structure, and that a second dividend depends on exactly which other taxes are reduced when green taxes are increased (Goulder et al, 1999, Parry et al. 2007).

A mandated increase in the fuel efficiency standard is a long run policy since they only apply to new vehicles entering the active fleet. Over the long term, improvements in energy efficiency, such as through higher technology standards reduce the cost of trips through the reduction of fuel consumption. As long as trips are not completely inelastic in demand (as long as the demand elasticity for trips is not zero), consumers respond to more efficient cars by raising their consumption of trips. Therefore, everything else equal, a mandated increase in fuel efficiency raises the number of miles driven. This effect is known as the rebound effect in the literature (see our model, below). As a result of the decreased effect on the price of trips, or miles, one can thus see a rise in congestion and traffic fatalities, etc. (CB, 2003), Fischer et al., 2007, Crandall and Graham, 1989, Noland 2004)[14], as well as - potentially - a reduction in labor supply (West and Williams, 2005). This is the basis of our proposition to view standards and fuel taxes jointly.

[14] Yun (2002) argues this effect is weak

IV. A Simple Model of Fuel Efficiency and Demand

Both car ownership and use are sensitive to pricing and thus gasoline taxes, diesel taxes, and car taxes. Cars can be taxed both in terms of the purchase decision (Denmark and Norway have car taxes in excess of 100%), and thus people may buy different cars depending on tax levels and tax structure. Norway applies taxes to cars increasing in their weight, horse powers, CO_2 emissions and other parameters, and the United States applies both fuel efficiency standards (though with some unattractive consequences of poor design) and a gas guzzler tax for vehicles with the highest certified consumption per mile.

It is well argued in the literature that the best way to limit the consumption of a commodity such as gasoline or diesel is with the price instrument and taxation[15]. In the following theoretical section, we carefully look into this argument, and also examine the consequences of fuel efficiency standards. We shall retain unchallenged throughout the paper, the validity of the argument that fuel taxes are very important policy instruments, but recognize that additional instruments to fuel taxes may be desirable. We examine the case for fuel efficiency standards in that context. In brief, our arguments rest on fuel taxes and expected fuel taxes being lower than desirable from the perspective of a social planner (alternatively, producers and consumers fail to value sufficiently highly expected future fuel savings). In these cases, fuel saving instruments, such as fuel efficiency standards or subsidies to Research and Development (R&D) are used as supplementary instruments. Their function is in part to reduce future average fuel dependency, thereby making lower fuel use and higher fuel taxes politically feasible and thus expected.

We use the terminology of cars and fuel efficiency to illustrate, though the following arguments apply to capital equipment embodying energy use more generally[16]. The assumption is that there is a trade off between fixed costs and variable (energy) costs,

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[15] See for instance Portney (2002)'s report on the Academy of Sciences review of the fuel efficiency standards in the United States, and Charles River Associates, 1991. Eskeland and Feyzioglu, 1997, demonstrates that an attempt to reduce driving in Mexico with a rationing scheme proved not only to be costly as compared to a tax, but counterproductive. Affirming those results, see also Davis, 2008.

[16] There are different models in the literature: Goldberg (1998), Austin and Dinan (2005), Kleit (2004), Kwoka (1983) or Fischer, Harrington and Parry(2007). The one applied here generates the key results while remaining very simple.

represented by a function $x = f(q,k)$, where x is a quantity of energy services rendered through the use of the equipment. In the case of cars, x is vehicle miles driven, q is gallons of gasoline, and k is capital. In simple terms, we assume that with everything else equal, one can get more mileage out of the capital equipment by investing more. We shall simplify further by assuming that the function f takes the form $f(q,k) = q \cdot e(k)$, so that

(1) $$x = q \cdot e(k),$$

Where e is fuel efficiency (in miles per gallon), and k is the cost of the car. We assume that the derivative of efficiency with respect to k is positive, $e_k > 0$ and that its second derivative is nonnegative $e_{kk} \geq 0$. For the moment, we shall assume that the demand for miles driven, is given, so that we may view the decision maker (a consumer choosing what car to purchase, for instance) as minimizing costs given the miles the consumer wants to drive. Let us assume that the costs of holding capital equipment k for a year are δ. The parameter δ represents the sum of the discount rate and the depreciation of the capital equipment, so δ could be 0.2 if the discount rate (or interest rate) is ten percent and the car is depreciated over ten years. We may now write the consumer's costs, where the cost of gasoline in dollars per gallon is the sum of the marginal cost of production and the gasoline tax, as

(2) $$c(q,k) = (p+t)q + \delta k.$$

The consumer's problem can now be described as choosing q and k such as to minimize costs while making sure the consumer gets the desired miles. Equivalently, we describe the consumer as maximizing services, or miles driven, for a given budget[17]. The Lagrangian of the consumer's maximization problem can be written as:

(3) $$L = q \cdot e(k) - \lambda\left[(\delta + t_k)k + \left(p + t_q\right)q\right]$$

[17] This form makes the transition easier when we later introduce a demand function.

Where t_k is a car tax.

This yields the following first order conditions for the consumer's optimum

(4) $$e-\lambda\left(p+t_q\right)=0,$$

(5) $$qe_k-\lambda\left(\delta+t_k\right)=0.$$

We eliminate λ, to obtain efficiency as a function of fuel consumption.

(6) $$e=qe_k\,\frac{p+t_q}{\delta+t_k}.$$

Using (1), we can describe optimal fuel efficiency as a function of miles driven, prices, and the fuel efficiency function:

(7) $$e=\sqrt{xe_k\,\frac{p+t_q}{\delta+t_k}}.$$

We can see that energy efficiency is higher when the cost of capital is lower. The higher the fuel prices, the higher is the boost to fuel efficiency given by better capital equipment e_k. Finally, energy efficiency is higher when demand is higher for the derived energy services, miles driven, in the given example.

Introducing a demand function with constant utility of income, we obtain in addition the first order condition representing optimal consumption of vehicle miles:

(8) $$d(x)=\frac{p+t_q}{e},$$

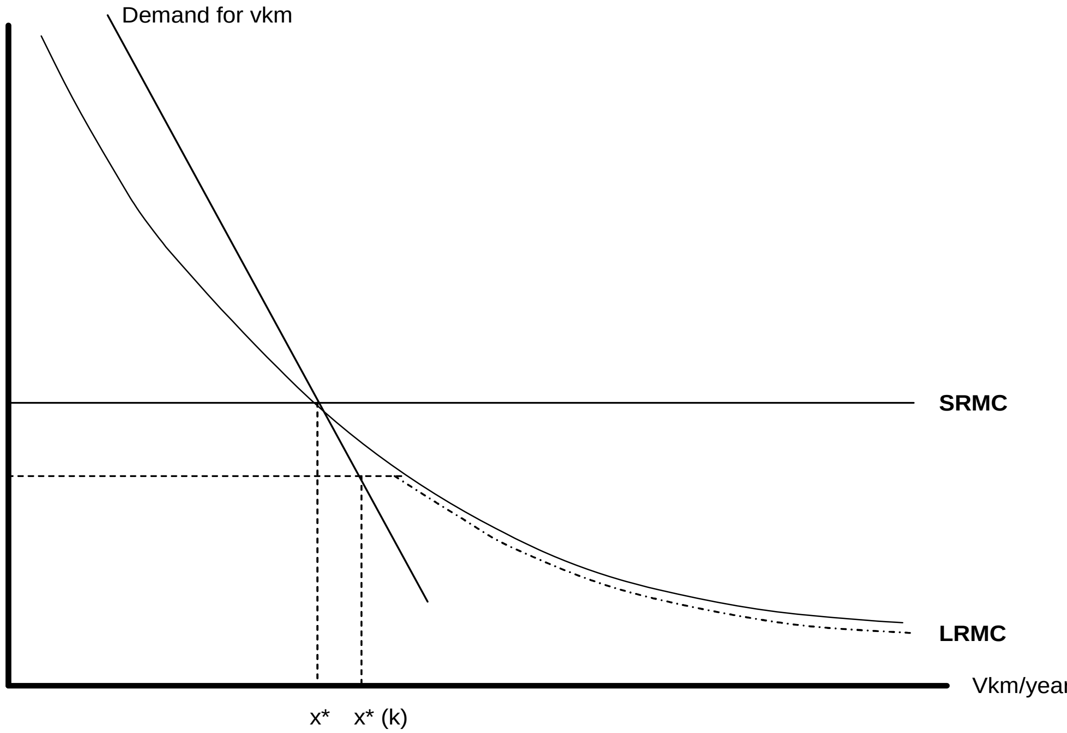
Where $d(x)$ is the cost at which *x* miles are demanded, and the right hand side expression is the short run marginal costs. Similarly, we will have, at the time period when capital equipment is adjusted to current prices:

(9) $$d(x) = \frac{\delta + t_k}{qe_k}.$$

Thus, when the consumer is not only in short-term equilibrium (assumedly always), but also in long-term equilibrium, short-run marginal costs and long-run marginal costs are the same. More interesting, perhaps, is that the consumer always has a horizontal short-run marginal cost curve, where the level represents the efficiency parameter of current capital equipment. In the long term, assuming that current consumption and current prices represent expectations for the future as well, the consumer can choose capital equipment fitting those prices and annual mileage, so that the long-run marginal cost curve lies above the short-run marginal cost curve for lower distances, and below for higher distances. For the system to be stable, the demand curve cuts both of these marginal cost curves from above, as illustrated in figure 3.

The long-run marginal cost curve (LRMC) for miles driven, in the case of cars) will be declining in quantity, when higher energy efficiency can be chosen if demand for services is high. When a consumer invests in equipment (a car, for instance), fuel efficiency is selected to ensure intersection between the demand curve *d(x)* and LRMC (based on expectations). The short-run marginal cost curve SRMC that is thereby chosen then intersects the two curves in the same point.

Figure 3: Long run marginal costs are downward sloping since fuel efficiency is increasing in vehicle kilometres. A fuel efficiency standard raises demand for vkm.



A fuel efficiency standard and the rebound effect

A fuel efficiency standard, assuming it is binding, takes the choice of fuel efficiency out of the hands of the consumer[18]. Thus, we may study its effect on the shorter-term utilization decision. Differentiating (8) w. r. t. *k*, the capital that raises fuel efficiency, we have

$$(10) \qquad \frac{\partial d(x)}{\partial x}\frac{dx}{d\bar{k}} = \frac{-e_k(p+t_q)}{e^2},$$

[18] Zachariades (2006) provides an account of developments in fuel efficiency in Europe and the USA, including the role of the Corporate Average Fuel Efficiency standards. The effectiveness of the fuel efficency standards in reducing the average consumption in the US was jeopardized by the lax standards for large, heavy vehicles (SUVs), which zoomed in popularity over more than 20 years, to take 50% of the market. Even this effect could probably have been prevented, or at least limited, if the good principle of averaging fuel economy performance across car models in the enforcement of standards had applied also across the boundary between SUVs and others.

Using (10), we may solve for the percentage change in miles driven, where $\varepsilon_{x,p} = \frac{1}{\frac{\partial d(x)}{\partial x}\frac{x}{d(x)}}$ is the elasticity of miles driven with respect to price, to (11).

(11) $$\frac{dx}{xd\bar{k}} = -\varepsilon_{x,p}\frac{e_k}{e}$$, or

(12) $$\frac{dx/x}{d\bar{k}}\frac{e}{e_k} = -\varepsilon_{x,p}$$

In (12), the left hand side is the proportionate change in miles associated with a proportionate increase in fuel efficiency. It is intuitive that demand increases by the elasticity of demand for miles with respect to fuel price, since a percentage change in the fuel efficiency standard changes short run marginal costs in exactly the same way as does a percentage change in fuel prices. This is, in terms of vehicle miles driven, what is called the rebound effect. Thus, as long as the price elasticity is bound to be negative; there will be a rebound in terms of increased travel to fuel efficiency improvements, as here with a standard.

In terms of miles traveled, the rebound effect can be seen in figure 3, above, by assuming that the consumer's short-run marginal cost curve is shifted downward by regulatory fiat. The left hand part of the long-run marginal cost curve is leveled from above[19].

We can now calculate the change in fuel demand; it combines the improvement in fuel efficiency with the increased demand for miles. We solve (1) for *q*, and differentiate with respect to *k*:

(13) $$\frac{dq}{d\bar{k}} = \frac{\frac{dx}{d\bar{k}}\cdot e - e}{e^2}$$, which can be rearranged to

[19] With an eye to empirical research, many studies refer to or report estimates indicating 'low' demand elasticities for transportation services, or for transportation fuels. Nevertheless, it should be noted, a selection of studies that include longer term, as here with car purchases and characteristics, render demand elasticities in the higher end of this general population of studies. Eskeland and Feyzioglu, incorporating car purchases, yield price elasticities of demand for gasoline between -.8 and -1,25, depending on model formulation.

(14) $$\frac{dq/q}{d\bar{k}}\frac{e}{e_k} = -(\varepsilon_{x,p} + 1)$$

Thus, the fuel efficiency standard translates the increase in miles driven into an increase in fuel demand if and only if the price elasticity of energy services, miles driven in our case, is lower than minus one (or higher than one in absolute value). If the elasticity of demand for miles does not exceed one in absolute value, fuel consumption *q* is reduced even though there is a rebound effect in terms of miles driven.

We may finally develop the relationship between the various elasticities with respect to gasoline price that follows from the identity

(15) $$x = q(p) \cdot e(p)$$

Where we have suppressed *k*. Taking the logarithm on both sides, we find

(16) $$\varepsilon_{x,p} = \varepsilon_{q,p} + \varepsilon_{e,p}$$

In the short term, when fuel efficiency does not adjust ($\varepsilon_{e,p} = 0$), the price elasticity of elasticity of fuel demand $\varepsilon_{q,p}$ equals the price elasticity of travel demand $\varepsilon_{x,p}$. In the longer run, however,

(17) $$\varepsilon_{q,p} = \varepsilon_{x,p} - \varepsilon_{e,p},$$

The gasoline demand elasticity $\varepsilon_{q,p}$ is the travel demand elasticity $\varepsilon_{x,p}$ *augmented by* the elasticity of efficiency with respect to fuel prices (the two first elasticities are negative, and the last is positive). We may notice that the possibility for a rebound from the short-term response to the long-term response is possible, but a rebound to a gasoline price increase is not possible even in the long term, since the long-run marginal cost curve is shifted outwards by a price increase.

Observations

- A rebound effect in terms of increased demand for energy services (miles driven), is always present when a fuel efficiency standard raises fuel efficiency (assuming it is binding);
- The rebound effect can raise *fuel demand* when the demand elasticity of miles driven, with respect to costs, is greater than one in absolute value;
- The rebound effect can be limited or eliminated by an accompanying increase in fuel taxes;
- The sensitivity of fuel efficiency implies that the effect of fuel price changes on fuel demand are greater in the long term than in the short term if and only if the demand elasticity for energy services does not exceed one in absolute value (not shown).

Externalities related to vehicle miles, apart from those related to gasoline consumption

It should be mentioned that there are several types of (negative) externalities related to vehicle use, and only some of them are related to fuel consumption. As has also been done in the literature (see, for instance, Parry, Fischer and Harrington, 2007), let us tentatively categorize externalities as follows: those related to fuel use include emissions of local air pollutants and greenhouse gases. Also, if there are unpriced concerns about fuel security, these should be included as fuel related. Let us denote the sum of fuel consumption related externalities by $D^q = d^q \cdot q$, so they are assumed proportional to fuel consumption. Those related to vehicle miles include accidents, noise, road wear and congestion, $D^x = d^x \cdot x$. Now, we can use equations (11) and (13) to develop the change in external damages, $D = D^q + D^x$ in response to a raised fuel efficiency standard:

(18) $$dD = d^q \cdot \left[-q \frac{e_k}{e} (\varepsilon_{x,p} + 1) \right] + d^x \cdot \left[-x \frac{e_k}{e} (\varepsilon_{x,p}) \right]$$

where the terms in the brackets represent *dq* and *dx*, respectively. Fuel related damages fall as a response to the tightened standards unless it is the case that the travel demand is very elastic, exceeding 1 in absolute value. Thus, the fuel related externalities will, in most cases, be reduced. The externalities related to miles driven, in contrast, will increase, since the sign in the content of the second brackets will always be positive (there is always a rebound in demand for miles, since mileage related private marginal costs are reduced). It follows from this that if damages related to miles driven are significant compared to damages related to fuel consumption, tightened fuel efficiency standards will likely increase *total* negative externalities.

The table below summarizes some studies of externalities from transport that distinguish externalities related to fuel use from those related to miles traveled. It appears from these that two important categories of externalities related to miles driven, accidents and congestion, easily can be far greater than the other externalities. This represents an a priori warning against programs that raise fuel efficiency standards without simultaneously raising fuel taxes (see below).

Comparison of Externalities Associated with Fuel consumption and with miles driven

	Externality Due to		
	Fuel Consumption***	VKM***	Ratio
Parry, Fischer, and Harrington (2004)*	11	2.5	4
ECON(2003)** Cars	0.03	0.31	10
ECON(2003)** Goods Transport	0.04	0.20	5
Schreyer et al. (2004)*	26.5	50	2
Parry and Small(2005)*	5	17	3

*Measured in Cents per mile. **Measured in Øre per kilometre. *** See text for categorization of externalities. Across the studies reported here, there are important differences in terms of the externalities included.

A fuel efficiency standard: how it relates to fuel taxation[20]

The model of optimal fuel efficiency and the possibility of a rebound effect alerts us to the fact that based on first principles there is nothing better than fuel taxation to reduce fuel consumption, or to reduce externalities that relate to fuel use, such as CO2 emissions (with a tax base properly scaled by fuel types).[21]

In part because the use of fuel taxes as a policy instrument often is politically constrained (Hammer et al, 2004, Buchanan and Tullock, 1974), it may be instructive to examine the use of fuel efficiency standards in combination with or as an alternative to fuel taxes. In figure 4, below, we have demonstrated how the use of a fuel tax increase Δt initially shifts the short run marginal cost curve sharply upwards (to $srmc(\Delta t, k)$, but the shift is less sharp after the consumer has also adjusted the car's efficiency ($srmc(\Delta t, k(\Delta t))$), according to the new long run marginal cost curve ($lrmc(\Delta t)$. In fact, when fuel efficiency adjusts, there is a slight 'rebound' in *vm* from *a* to *b* relative to the initial contraction from *x** to *a*, but *vm=b* is still lower than its original value *x**. Fuel consumption has unequivocally contracted, since the consumer adjusts to the long run marginal cost curve, which has shifted outwards (not shown).

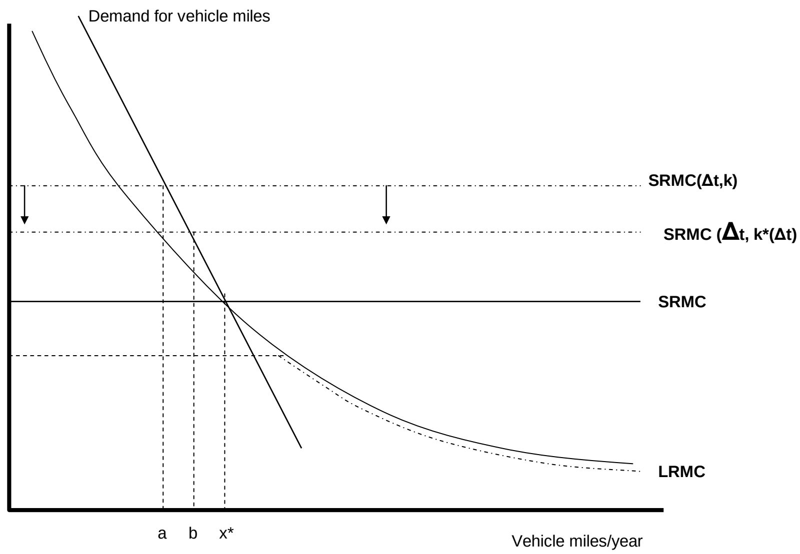
Now consider, in contrast, a fuel economy standard (the lower dotted horizontal line). The standard has shifted down the long run marginal cost curve except when *vm* levels are

[20] Accidents are very important amongst external costs of transport, and it should first be noticed that accidents can be responsive to many factors more well targeted than with crude instruments such as fuel taxes and fuel efficiency standards. In table 1, we have assumed that accidents such as damages external to the driver are related to miles driven. Kopits and Cropper (2005) analyse accidents worldwide. An important debate, however, is whether policies for fuel efficiency reduce a car's resilience towards crashes (thus increasing the accident internal damage to the owner) while perhaps at the same time reducing external damages through impacts in crashes on others (pedestrians, other cars). We leave this topic without entering its details, by noticing that other instruments should be considered for this particular type of damage. Gordon et al (2007) analyse opportunities for fuel efficiency improvements that do not increase accidents.

[21] An identical argument applies in theory for emission taxes in the case of other pollutants (these emissions are typically less strictly proportionally linked to fuel consumption): there is nothing better than emission taxes based on first principles. But for practical reasons, combinations of emission standards and fuel taxes can work well in that case. An important difference between the two cases is that fuel consumption is easily taxed in a cumulative fashion (the tax is applied in a linear fashion, and you pay a tax on your total consumption), whereas for emissions of pollutants, the 'taxman' can easily get a measure of your emission rate (per gallon or per mile), but cannot easily combine this with a measure of your cumulative gasoline consumption or vehicle utilization). See Eskeland, 1994.

high (where *lrmc* is unchanged), and *vm* increases due to the rebound effect. Given the higher efficiency, if the standard were complemented with a fuel tax, at any level lower than Δt, the tax increase would be less painful to consumers than without the standard (since fuel efficiency is higher). To bring *vm* to the same level *b*, however, the tax level would reach exactly the level Δt, so that the standard is nonbinding. To see this, consider the contrary case that the standard would still be binding. If so, fuel efficiency is 'too high' for the Δt tax-including fuel price, so short run marginal costs fail to be high enough to bring consumption down to *b*.

Figure 4: The determination of equilibrium fuel efficiency with a fuel tax increase Δt where $a \equiv x^*(\Delta t, \bar{k})$ and $b \equiv x^*(\Delta t, k^*)$



Fuel efficiency standards and tax increases in a practical political setting

The important insight from this model is mostly a practical one related to political feasibility. One can imagine that there is political resistance (and a sensible one) to high or rapidly increasing fuel taxes in a setting where people depend on fuel, partly because there is a stock of fuel inefficient cars. In such a case, if an externality related to fuel use requires accelerated policy reform, then fuel efficiency standards can accelerate the transformation of the vehicle stock towards a more efficient one. This improvement in the vehicle stock will, over time, also make higher fuel taxes feasible.

To illustrate this, it can be seen from (2) that the tax-including gasoline price times quantity $(p+t_q)q$ enters the consumer's budget constraint, and that by Roy's identity the effect on utility for the consumer of a small increase in the tax is

$$\frac{\partial v}{\partial t_q} = -q\frac{\partial v}{\partial I} = -\frac{x}{e}\frac{\partial v}{\partial I}, \qquad (18)$$

i.e. the marginal utility of income times miles divided by efficiency. Thus, if the effect on the consumer by a tax increase is a measure of political resistance, then the more efficient the car, the smaller the resistance (unless if miles demanded is price elastic beyond 1 in absolute value, see above).

The possibility that the fuel taxes and standards work together in a dynamic political setting is indicated by the argument of Hammar et al. 2004, and is easily illustrated by equation (18). At any point in time, if people own inefficient cars, *e* is low and given their travel needs *x*, they'll resist a tax increase with a fervor indicated by (18). Hammer et al. state (page 1): 'Not only do low taxes and thus low prices encourage high consumption, but high levels of consumption also lead to considerable pressure against raising taxes." If rational, they will also resist a plan for a future tax increase (if it could be announced in a credible fashion), even though a planned tax increase will give those a chance to adjust efficiency by planning to replace their car in the mean time. Thus, resistance to a present fuel tax increase will be somewhat lower or reduced for those families who soon plan to replace their cars.

Similarly, however, a fuel efficiency standard will immediately harm only those families that plan to replace their car (the fuel economy standard increases the costs of new cars).

For other families, the costs of more expensive cars lie in the future, and resistance is reduced, at least, by their discounting of this effect[22].

A possibility is that a tax increase meets excessive resistance and that a planned tax increase would not be credible. When credible, the car stock would begin increasing its efficiency (with the rate of replacement and growth) and resistance would decline, but if it is not credible, efficiency does not change, and resistance to the tax increase remains constant[23]. A related possibility is that a fuel efficiency standard would meet little resistance, and that it would start changing the vehicle stock towards a more efficient one, and that in the process, according to (18), the fuel tax increase could be passed over time.

In fact, if there is a future fuel cost increase, then the social costs of that increase are lower if it can be *expected*, lending support to anything that makes policy more strategic and predictable.

The possibility exists, thus, that the use of fuel efficiency standards and fuel taxes over time can make feasible not only a car stock that is more efficient than what fuel taxes could achieve alone, but that society would save on car use and use-dependent externalities because higher fuel taxes are made politically feasible with more efficient cars.

We should mention the important possibility, too, that in the course of such a combined program, society both employs more fuel efficient cars and economizes on their use while the (path of) fuel efficiency standards never become very constraining for consumers. The reason lies in the observation above, that the tax rate which eliminates the rebound effect indeed is the tax rate at which the efficiency standard is not binding. Thus, if one thinks of fuel efficiency standards as moving forward along a path mainly to make higher

[22] In fact, there will also be capital gains for used cars when regulations make new cars more expensive, and cars will, for this reason, live longer (Kahn, 1986), but we may distract from this in the present treatment.
[23] Those familiar with the literature will recognize the problem of time consistency, pointed out by Kydland and Prescott, 1977. If the planned tax increase could be made credible, for instance, by a rule agreed in an international treaty, the problem would be solved. The fuel efficiency standard, we surmize here, might work as a *commitment device*.

fuel taxes acceptable and thus credible, then the departure from first principles may indeed be minor, at least in the sense that the important role of the price instrument as a rationing device is retained.

Sunk costs in technology investments, fuel economy standards, and international coordination

We have shown the possibility that future fuel tax increases are discounted too heavily by consumers, either because consumers are myopic, liquidity constrained, or rationally expect that government cannot follow up on announced policies. Car makers and others who might invest in more efficient future car technology will, similarly, have too low incentives to do so, if they do not believe fuel taxes will be raised as announced (this argument is developed in greater detail in Montgomery and Smith, 2004, and Alfsen and Eskeland, 2007).

If investments in new and low-carbon technologies have a characteristic of sunk costs, then indeed it is the case that a technology developed to abate emissions of carbon – once it has been developed – will be marketed even if (fuel and) emission taxes turn out lower than those that had to be promised to stimulate its development. In other words, if the government promises you future fuel taxes at a certain level in order for you to develop a certain energy efficient technology, it could be rational for government to implement lower taxes than promised if and when you have succeeded. So, you will have taxes high enough to sell your goods, but not high enough to reward you fully for your past investment efforts. This reasoning, of course, raises doubts that expected taxes can provide the stimuli for technological change and other long term investments that are needed for challenges such as the global climate.

The question then arises whether commitment mechanisms exist, and it is possible to be very pessimistic about this. A consequence could be that the tax levels that need to be expected for the problem of global warming to be solved cannot be expected by rational consumers and producers. Within these contexts, however, one could argue that fuel economy standards set many years in advance can be credible. If a city could announce that buses for concessions from 2020 onwards would need to satisfy a certain fuel economy standard that is now almost inconceivable, perhaps it would not be credible. If a country or a group of countries announced the same, perhaps it could be credible. Indeed, California has been successful in pushing the car industry towards lower emission standards in terms of traditional (local) air pollutants. A list of tentative reasons for California's success should include: i) the California market is large enough to be attractive to car makers; ii) standards have been successful when set high, but realistically; iii) California does not have its own car industry, so political resistance from industry has been modest; iv) California has a rich and educated population genuinely concerned about air pollution, thus providing support for policies being maintained, rather than the reverse, when under pressure.

The first of these items indicate, of course, that an initiative that is not credible and thus not effective if launched by an individual jurisdiction, could be effective if launched at a higher jurisdictional level (federal, say) or by countries in coordination.

Heterogenous consumers, and three smart variations on a theme

In reality, of course, consumers do not have the same exact needs. Some households would use their car to travel little, others more; some would need weight and carrying capacity, others a small vehicle for two person in their commute. A sensible way to account for this is to let a fuel efficiency standard be averaged – or traded – across a larger population of cars. This was the essential spirit of the USA's corporate average fuel efficiency standard. In effect, the averaging standard changes relative prices so as to make the more efficient cars more attractive both to producers and to consumers. It is as if a fuel-inefficient car is taxed at the point of purchase, and the revenues are being used to subsidize the more efficient ones. As mentioned earlier, the scheme had important flaws in its implementation, but the essential idea was a good one. Presently, the EU is discussing CO_2 standards for cars in the range of 120 to 130 grams per vehicle kilometer, and it will probably be implemented with a kind of averaging, though with lessons from CAFÉ. An alternative approach is pursued in Norway's 2007 formula for taxes on new cars, with its explicit taxation of the model's certified CO_2 emissions per vehicle kilometer.

These instruments have in common with the simple model of a fuel economy standard that they supplement fuel taxes in an attempt to modify the characteristics of the vehicle stock, and that they do this by shifting the characteristics of new cars being sold. They do influence both each vehicle model and the sales composition, via a range of responses on an axis from university researchers and car developers through the household's car purchase decisions. By influencing the entering vehicle stock in a direction of fuel efficiency, average fuel dependency will decline, this will be expected, and this allows higher fuel taxes to be expected.

V. Conclusions and Recommendations

We have used a simple model to guide a discussion of how fuel taxes and fuel economy standards can or should be used together if policy objectives – externalities – relate fairly closely with fuel consumption. It is solidly based in simple welfare economics that fuel taxes alone can do a very good job in addressing such objectives, a class that should include concerns of security of oil supply (for importing countries) as well as greenhouse gas emission reductions.

In basic theoretical terms fuel taxes take a supreme role as a policy instrument because they leave it open to the consumer whether to reduce consumption by acquiring more fuel efficient cars or by using the car less. For fuel efficiency standards, in contrast, the policy maker prejudges the role that should be played by improved fuel efficiency, and to some extent forces this judgment on the market as a whole. If the standard fails to be accompanied by fuel taxes, there will be a rebound in travel once people have lower operating costs, and perhaps increased external costs of travel associated with this rebound.

The case that can be made for fuel efficiency standards requires more elements than those employed in the basic model, and typically one draws on a number of arguments that are related. An essential feature is that capital goods, such as cars, last a long time, so if consumers and producers pay enough attention to fuel efficiency, they must do so in a setting where they understand the difference between available cars and value the differences in terms of future fuel savings appropriately. Analysts and regulators have addressed both the information issue (labeling standards and certification standards) and the issue of whether consumers discount too heavily future fuel savings of more efficient vehicles, either because they are financially constrained or because they behave myopically. Of course, if buyers do not sufficiently value the expected fuel savings of more efficient cars, producers and inventors will also spend too little on developing them, even if it fuels are taxed at appropriate levels.

We bring in the additional question of whether, for policy instruments such as fuel taxes, governments are unable to convey, with sufficient strength and credibility, a path of high or increasing fuel taxes in the future. Of course, if car purchases and car efficiency inventions are to be optimal, consumers must base their investments on *expected* fuel taxes, and producers on their beliefs of peoples' expectations. In brief, without fuel economy standards, if the government cannot credibly raise *expected fuel prices* to the level it would prefer, then cars will be sub optimally fuel efficient.

An additional case for fuel efficiency standards is therefore made if the government with these can raise the fuel economy to a path where it would have been if a desirable path of future fuel taxes could be committed to and conveyed credibly. As it happens, if people are pushed to buy more efficient cars, then tomorrow they'll have more efficient cars than they otherwise would, and this can reduce the political resistance to higher fuel taxes. If, in addition, an announced path of future fuel efficiency standards can be credible, then this announced path could raise not only fuel efficiency as it is purchased by consumers (and firms and cities) today, but also raise research and development on how to attain higher efficiency in the future. Graph 2 demonstrates that many jurisdictions have decided on fuel economy standards well in advance.

It would not be mere speculation, thus, to state that the case for fuel economy standards rests on difficult challenges of relating policy measures today to the influence of expectations about the future. Importantly, it also rests on working together with fuel taxes, since it is well demonstrated in theory and practice that fuel efficiency standards can be directly harmful if applied alone.

It is tempting to add, once one has accepted that we can meet policy goals more effectively if we can signal future policies more credibly, that international coordination is indicated as a promising proposition, and for several reasons. First, if there are scale economy issues in technological development, a firm would invest more to meet the standard in a larger market than in a smaller one, so tougher future standards would be credible if applied to more countries (greater markets, more accurately). Second, if collusion against the regulator is part of the threat to credibility, then the threat is smaller in a larger market (see literature on regulatory capture, highlighting the danger of regulators being too understanding of the industry). Thirdly, international treaties may make policies more credible through institutional rigor.

These propositions should not be seen as merely speculative, but rather indicating that economists should not be as puzzled by the presence of fuel economy standards as the literature has tended to imply. Apart from that, we believe future research should focus on the possible case for international coordination and on the payoffs of technological research to make cars more fuel and/or emission effective. It may appear that technological development does not get the attention it deserves in this area, and if so a range of policy instruments should be considered. But the possibility that expected future fuel prices and emission costs will be too low allows for the possibility that simple policies such as R&D programs and future standards – and perhaps internationally coordinated – could play a role.

Maybe the case for standards is strong without international coordination, but it is possible that this would add potential without costing too much. At least for a small country, the prospects are slim that you can influence car makers and inventors unless you move in a pack with others. For makers and inventors, surely, it could be more tempting to invest in a particular direction for the long term, as large markets have signaled firmly an interest for such a direction.

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Annex: Illustrations with Cross Country Data

Figure A1: The Relationship between Vehicles Density and Percapita GDP

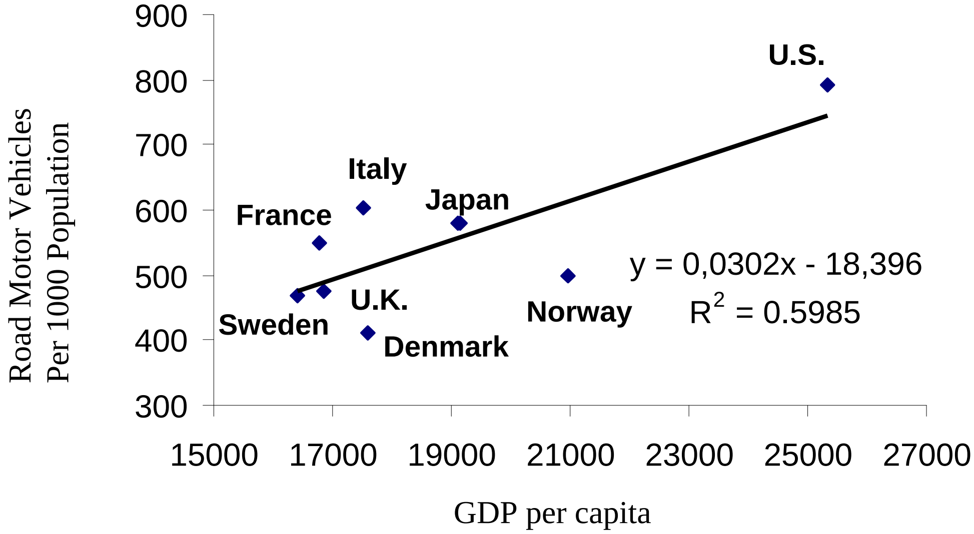


Figure A2: Plotting vehicle stock fuel use (per 100 km) against income per capita (IEA and OECD data).

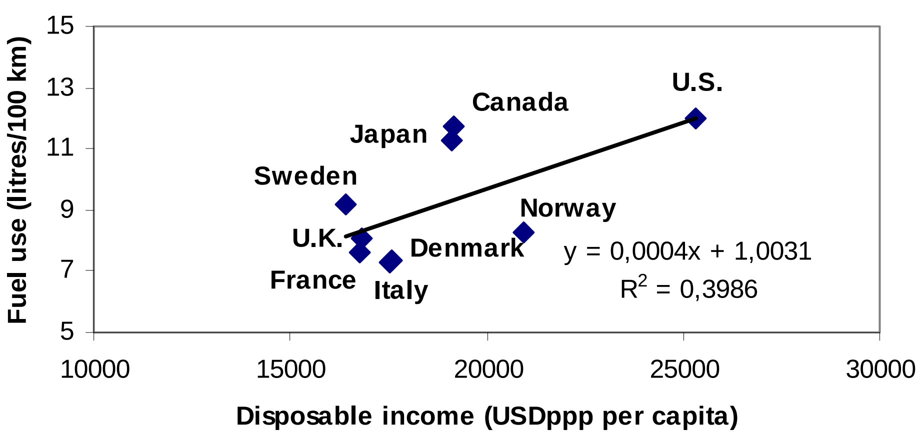


Figure A3: Fuel use of new car sales plotted against income per capita.

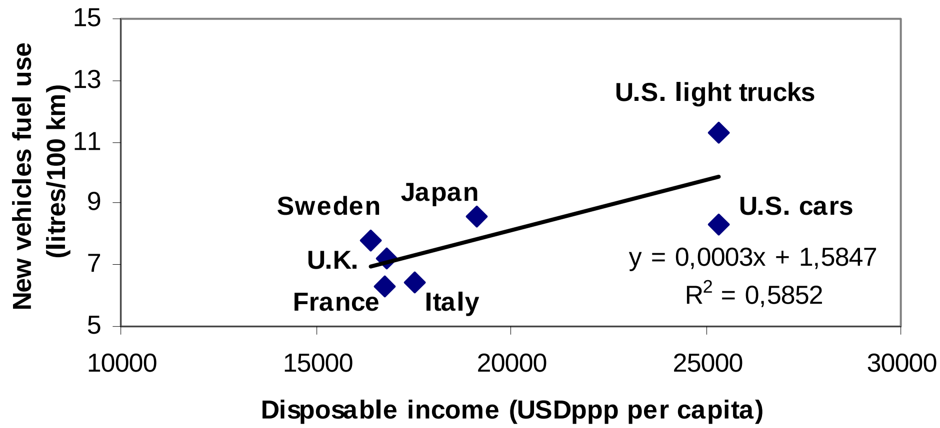


Figure A4: How weight and income per capita has evolved in the OECD

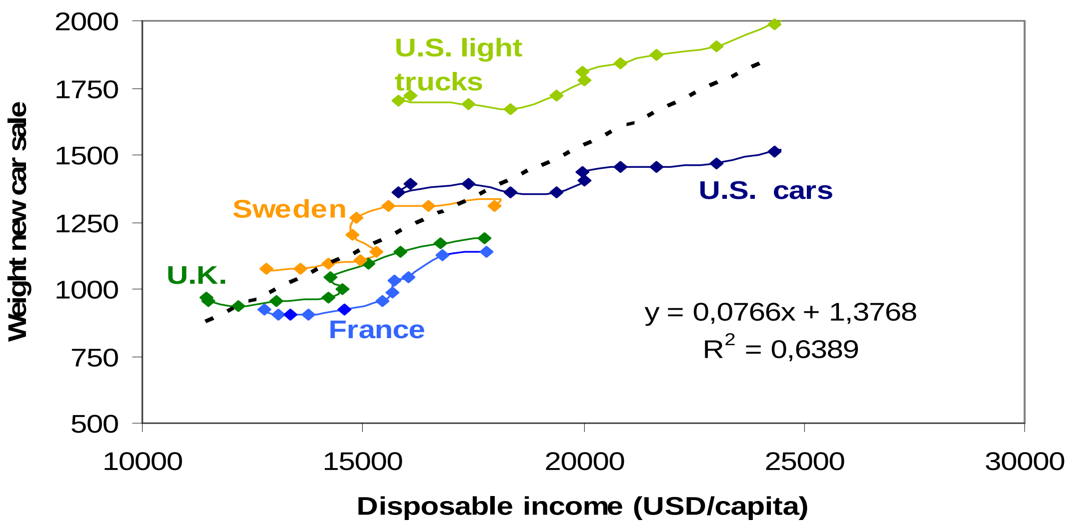
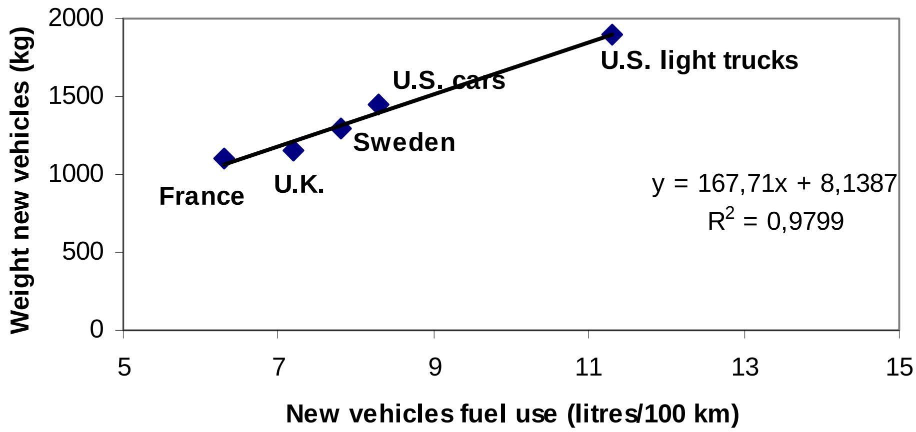


Figure A5: Average, for new vehicles sold, of weight and fuel use (for the US, by two vehicle categories).



FigureA6: Fuel use per 100 km for the car fleet average

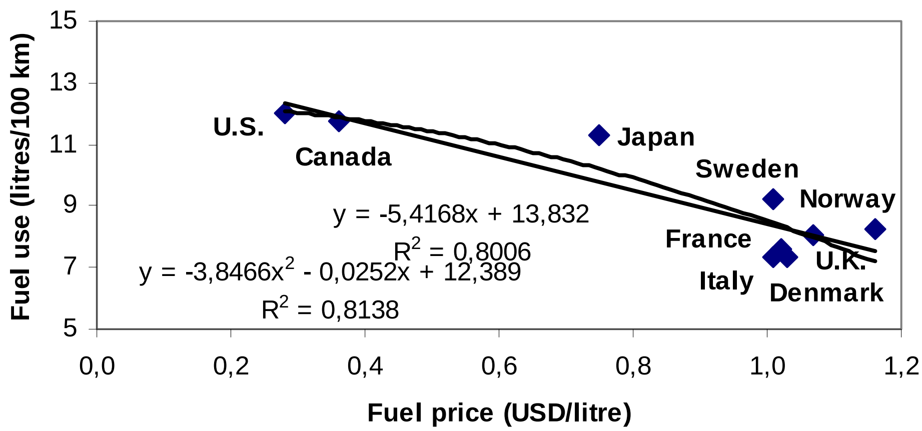
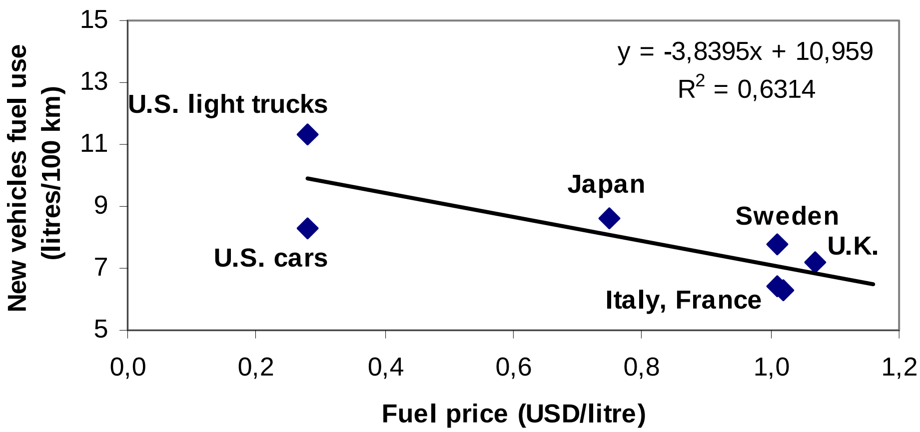


Figure A7: Fuel use per 100 km for new cars and light duty trucks, average, IEA data, plotted against fuel price (averaged over fuel types).



Source: IEA and OECD data

Figure A2-4: Average, for new vehicles sold, of weight and fuel use (for the US, by two vehicle categories).