Policies to Reduce CO₂ Emissions from Cars in Europe

A Partial Equilibrium Analysis

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1. Introduction

Policy makers in Europe have become increasingly aware of the need to curb the adverse effects of transport externalities, in particular the impact of transport on the environment (see, for example, Commission of the European Communities (CEC), 1992a and 1992c). Following the work of the International Panel for Climate Change (IPCC), the imperative to reduce CO₂ emissions in order to limit global warming has been gradually accepted and has been enshrined as a policy objective in the Framework Convention on Climate Change signed in Rio de Janeiro in 1993. Under current policies transport growth is likely to generate a significant increase in CO₂ emissions (CEC, 1992b).

These developments have led to a specific interest in transport as a source of CO₂ emissions. It should, however, be underlined that there are no good economic reasons a priori to concentrate action in one sector since the process of global warming does not depend on where emissions are generated (no “hot spot” problem). Consequently, economy-wide policy instruments are needed and the case for additional policies in transport to limit CO₂ emissions needs careful scrutiny. In a world with increasing sectoral marginal costs of emission abatement, too much focus on one sector carries the risk of incurring unnecessarily high abatement costs. This is especially relevant in the case of transport, as the structure of energy taxation in OECD economies implies CO₂ taxes on transport fuel which are significantly higher than on other energy products (Hoeller and Coppell, 1993).

One argument that is often raised to advocate additional action in transport is that it will not only reduce CO₂ emissions but will also help curb other transport externalities, such as congestion, accidents or local air pollution. The costs of these externalities are estimated to be around 5 per cent of GDP in some OECD countries (ECMT-OECD, 1993).

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However, the optimal policy instruments to address these externalities are unlikely to focus on \( \text{CO}_2 \) or involve strong increases in fuel prices (Koopman, 1993).

This article attempts to contribute to the policy debate by focusing on the cost-effectiveness of various possible instruments to achieve reductions of \( \text{CO}_2 \) emissions from transport.\(^1\) The analysis is based on a partial equilibrium simulation model for European passenger transport (EUCARS) that allows an assessment of the welfare costs of various measures. In addition to analysing the differences in cost-effectiveness across instruments in an equilibrium context, some brief reflections on the policy implications of market failures are provided.

The scope of this paper is as follows. Section 2 presents a short overview of some of the possible instruments and the available literature on the subject. The EUCARS model is briefly discussed in Section 3. Section 4 presents a number of EUCARS simulations, which help to analyse the cost-effectiveness of various policy options. Although a \( \text{CO}_2 \) tax is clearly found to be the most cost-effective, the cost differential with respect to some alternatives is smaller than is reported in some of the other literature. In Section 5, the issue of market failures is briefly discussed. In particular, it is argued that if consumers are myopic with respect to the future fuel consumption of new vehicles, a case could be made for an additional instrument aimed at influencing the vehicle purchase decision. Finally, Section 6 presents some conclusions.

2. Policy Options to Improve Fuel Efficiency and Reduce CO\(_2\) Emissions from Cars

2.1 CAFE and fuel taxes: the debate in the USA

There has been a lively debate in the USA on the impact of measures to improve fuel efficiency of passenger cars. Given that the US CAFE (Corporate Average Fuel Economy) standards have been in place since 1978, the US debate has focused strongly on the effects of the CAFE system. This system comprises minimum corporate average fuel economy standards for new light-duty vehicles as well as for light trucks and some other vehicle categories. This debate has centred largely on the effectiveness of CAFE in improving US fuel efficiency over the past decade, with relatively little focus on the cost-effectiveness (Fergusson, 1993). Most observers (Greene and Liu, 1988; Greene, 1990; Schipper et al., 1993) conclude that, since its introduction in 1978, CAFE has indeed been effective in improving fuel efficiency of US passenger cars, and attribute the bulk of US improvements in fuel efficiency to CAFE, leaving only a modest role for fuel prices during the short spells in which they were high. On the other hand, Crandall (1992), claims that the observed increase in fuel efficiency is largely due to other factors and that some of the perverse effects of CAFE (such as its tendency to increase vehicle use as the marginal costs

\(^1\) This paper does not address the (implicit) question whether differences across sectors in pre-existing taxes on fuels should lead to different \( \text{CO}_2 \) charges across sectors. For a discussion of this issue, see Newbery (1993) and Denis and Koopman (1994).
of driving are reduced and the incentive to switch to less fuel-efficient vehicles, such as light trucks) have largely undone reductions in overall fuel use from increased efficiency of passenger cars.

A well-devised system of fuel economy standards should, in principle, be able to reduce fuel use of the passenger car fleet unless the improvements in fuel efficiency lead to a "rebound effect" via increased travel that outweighs other sources of fuel saving.\(^2\)

Crandall (1992) raises the issue of cost-effectiveness and suggests that CAFE-type systems are relatively costly ways to reduce fuel use from the vehicle fleet. The basic argument for this finding is that fuel standards primarily address only one of the various sources of reducing fuel use (for example, technology) and do not tap other sources such as vehicle kilometres travelled, improved maintenance and more fuel-efficient driving styles.

Few empirical studies to date have estimated the cost differential between CAFE-type standards and fuel taxes. A notable exception is a study by Charles River Associates (CRA) (1991), which compares the costs of these measures for a representative consumer optimising his utility by annually determining the number of miles driven, the size of the representative vehicle and the consumption of all other goods. According to this study a CAFE system is four-and-a-half times more costly than a gasoline tax when aiming at ambitious fuel efficiency improvements (40 miles per gallon) because it only relies on technology without giving an incentive to reduce vehicle use.\(^3\)

2.2 Alternative policies to limit CO\(_2\) emissions from cars in Europe

In October 1990 a joint Council of Energy and Environment Ministers of the European Community adopted a CO\(_2\) emission target intended to stabilise emissions by the year 2000 at 1990 levels. In a Communication to the Council (SEC(91) 1744 final) the European Commission proposed a strategy containing various policy instruments, notably a fiscal initiative consisting of an economy-wide CO\(_2\)/energy tax. Transport was mentioned as a sector where action was especially needed and this concern was echoed in various policy documents (among which was a directive regulating conventional car emissions).

Although no specific CO\(_2\) target for the transport sector was adopted, a debate ensued on the best way to reduce CO\(_2\) emissions from transport, notably from passenger cars. Many instruments were proposed in addition to CO\(_2\)-based fuel taxes. Among the options discussed were several regulatory measures, which would entail the use of standard-based approaches. A suggested option was to make the emission standards dependent on the vehicle weight or motor capacity and to tighten standards over time.

\(^2\) However, this is unlikely to occur in reality since the elasticity of travel demand with respect to real fuel costs is found to be smaller than unity in empirical studies (Goodwin, 1992; and Oum et al., 1992).

\(^3\) The authors of the report claim that this estimate is likely to understate the true cost differential because in the analysis it is implicitly assumed that possible cost differences across vehicle types and across car manufacturers are exploited in an efficient way, which requires strong coordinating mechanisms (for example, efficient cross-subsidising and a system of tradable emission) that need not necessarily be forthcoming.
However, many participants in the debate felt that the use of economic instruments would be a more cost-effective way to reduce emissions, and pointed to the possibilities of using the elaborate system of transport-related fiscal policy in Europe (for an overview of which see ACEA, 1993). In addition to fuel taxes, an increase in annual car ownership taxes or purchase taxes related to the CO₂ emissions profile of the vehicle could be considered. An innovative economic instrument, which could be geared towards the same end and which has been proposed in various states in the US, is a gas-guzzler tax/surcharge rebate. Essentially such a system would make the purchase price of new vehicles dependent on their fuel-efficiency, by means of a fuel efficiency graded tax or subsidy. Introducing such a system could entail a budget-neutral modification (possibly combined with an increase in the average level) of existing purchase taxes, increasing the tax on vehicles with a fuel efficiency level below a yardstick, and offering a reduced purchase tax or even a subsidy on relatively fuel-efficient vehicles (see, for example, Johnson, 1991; CRA, 1991). Another option discussed was the introduction of a system of tradable emission credits which would allow car manufacturers more flexibility in reaching vehicle emission standards, by allowing both trading and banking for future use.

No comprehensive assessment has been made to date in Europe of the relative cost-effectiveness of these instruments nor has a decision been taken on the introduction of specific measures in the transport sector.

3. A Partial Equilibrium Simulation Model of European Car Ownership and Use

In order to shed some light on the costs of various policy instruments to reduce CO₂ emissions from passenger cars, a partial equilibrium simulation model of passenger transport in the European Union has been constructed that contains a detailed description of transport-related fiscal policy: EUCARS (EUropean CAR emissions Simulation model). This model is described in detail in Denis et al. (1994). Only a brief summary of the main elements is provided here (see Appendix for specific functional relationships). The model has not been estimated econometrically, but has been calibrated for the period 1985/1990 on available data sets.

EUCARS is explicitly based on optimising consumers and producers who maximise utility and profits, respectively. The latter feature of the model allows the assessment of the welfare costs of measures that reduce CO₂ emissions from transport. Although there are a number of simulation models that track the effects of policies on transport and fuel use (for example, Samaras and Zierock, 1991 and 1992; Acutt and Dodgson, 1993), few transport models developed in Europe can assess the welfare costs of such measures (see de Borger et al., 1993, for an exception).

The EUCARS model is dynamic in that it calculates equilibrium outcomes in the transport markets (markets for old and new vehicles and vehicle use) for 5-year periods, starting in 1985/1990 and ending in 2010/2015. These results, therefore, only take account of long- and medium-term effects of policies and do not encompass short term fluctua-
The car fleet consists of vintages (by 5-year period) which are handed over from period to period. The absence probability (that is, the probability that a vehicle of vintage \( i \) no longer belongs to the vehicle fleet in period \( t \)) is based on lifetime functions taken from Samaras and Zierock (1991) and is constant in the model.\(^5\)

The structure of EUCARS is depicted in Figure 1. A number of exogenous factors—mainly disposable income and oil prices—together with the system of transport fiscal policy set by the government are the main input variables in producers’ and consumers’

\(^4\) It is well known that conventional neo-classical models of consumer behaviour are generally not able to track short-run movements in the demand for consumer durables, which is why other approaches, such as stock adjustment models, are widely employed to this end (see Deaton and Muellbauer, 1980, pp.345-79). Working with average outcomes for five-year periods might improve the realism of an essentially neo-classical approach.

\(^5\) This is a standard procedure in modelling absence probabilities (compare, for example, De Pelsmacker, 1990; and Jørgensen and Wentzel-Larsen, 1990). In view of the observed relative stability of lifetime functions over time this seems a reasonable working hypothesis. However, it should be noted that as a result of this formulation policies affecting second-hand car prices will not have an impact on the size of the old car fleet (which could work via improved maintenance). As this effect has been found important empirically (Berkovec, 1985) it leads to an underestimation of the costs of CAFE-type systems in the model. A new version of the EUCARS model is currently under preparation in which scrappage is endogenous.
Table 1

Vehicle Categories in EUCARS

<table>
<thead>
<tr>
<th>Category</th>
<th>Number of Vehicles in 1990 (millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small (gasoline, motor content ≤ 1400cc)</td>
<td>57.9</td>
</tr>
<tr>
<td>Medium (gasoline, 2000cc ≥ motor content &lt; 1400cc)</td>
<td>36.7</td>
</tr>
<tr>
<td>Large (gasoline, motor content &gt; 2000cc)</td>
<td>7.2</td>
</tr>
<tr>
<td>Diesel</td>
<td>14.9</td>
</tr>
<tr>
<td>Liquefied Petroleum Gas (LPG)</td>
<td>1.7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>118.5</strong></td>
</tr>
</tbody>
</table>

decisions. Consumers make a number of hierarchically ordered choices when allocating disposable income to various consumption categories. This nesting structure is described in Figure 2 which shows that consumers first allocate income over transport services and other goods and services, after which they divide their spending on transport services over a number of bundles. Here explicit account is taken of public and private transport, various car types, new as well as old vehicles.

Consumer welfare is determined at the highest level of the consumption block where a choice is made between transport services and other goods and services. In the second step the transport services budget is allocated between public and private (that is, cars) transport services. Next, spending on private vehicles is divided over the five car classes that are distinguished in the model, listed in Table 1. All three stages are modelled via a constant elasticity of substitution (CES) (sub-)utility function. Subsequently, spending on a specific vehicle category is allocated to spending on “new” car services (from cars sold during the current five-year period) and “old” car services (from cars of other vintages) by means of an Indirect Addilog Demand System (IADS). The distinction between old and new cars is relevant in the context of CO₂ emissions limitation policies since some of these policies, such as gas-guzzler taxes, primarily affect new cars, whereas other policies, such as fuel taxes, exert a direct influence on the entire car fleet.

There are two car markets in the model: one for new cars and one for old cars. In order to capture the strong link between car ownership and car usage, while allowing some flexibility in the allocation of spending on (old and new) car services over ownership and

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5 The implied unitary income elasticities might appear somewhat unrealistic as public transport and small car ownership are found to have relatively low or negative income elasticities in many empirical studies (see, for example, De Borger and De Borger, 1988, for an application to Belgium). However, it is unclear whether past trends are relevant in the long-run context of this study (for example, will the penetration of small diesel cars observed in the eighties continue until 2010/15). In view of this uncertainty, and as the focus of the present study is more on simulations of various pricing policies, it was decided to choose a simple CES structure.
Figure 2
Consumption Block

N.B. 6 = technical elasticity of substitution
\( \varepsilon_{q_i}^{y_i} = \) direct own price elasticity
\( \varepsilon_{p_j}^{y_i} = \) cross price elasticity
\( \varepsilon_{y_i}^{y_i} = \) income elasticity
usage and retaining a relatively simple model formulation, the following structure has
been chosen in EUCARS. First, a joint demand for car ownership and a minimum annual
mileage is modelled which together constitute a service labelled committed car services.
In line with the findings of de Jong (1991) this minimum has been set at 65 per cent of
the observed average mileage in the base period (1985/1990). This minimum mileage is
fixed in the simulation period. Combined with car ownership it generates "committed car
services" via a Leontief function (sixth level). Secondly, there is demand for "flexible
vehicle services", which is the annual mileage above the minimum levels. The demand for
both committed and flexible car services are the two components in the fifth stage of the
nested consumption decision process shown in Figure 2. This has been modelled by a
Linear Expenditure System (LES) function, which implies gross complementarity be-
tween both components.  

The demand for car ownership following from this formulation is confronted with
supply. In the case of the demand for "old vehicles" - those that have entered the vehicle
stock in previous periods — supply is fixed by what remains of previous purchases
(according to the life-time functions). The market is cleared by the second-hand price
(OCMP in the Appendix). For new cars, it is assumed that \( \bar{n} \) for given technical
characteristics of the vehicle \( \bar{n} \) production is characterised by constant returns to scale and
that unit costs equal unit prices. Hence, supply is perfectly elastic.

The fuel efficiency of new vehicles can be improved by a number of measures and at
increasing costs for higher levels of fuel efficiency (US Office of Technology Assessment
(OTA), 1991). In a competitive market, profit-maximising producers will set fuel effi-
ciency so that the marginal benefits of fuel efficiency to consumers (that is, reductions in
the discounted fuel bill) equal the marginal costs of producing it. Fuel efficiency and new
car prices are modelled in EUCARS according to this rule. The fuel efficiency of old
vehicles has been determined in previous periods and is, consequently, fixed in EUCARS.  

There is considerable debate on the costs of improving fuel efficiency in vehicles
leading to a very broad range of estimates being reported in literature (see, for example,
CRA, 1991; OTA, 1991; and Ledbetter and Ross, 1990). Table 2 presents the cost
elasticities used in the simulations as well as the implicit elasticity of fuel efficiency with
respect to consumer fuel prices and vehicle purchase taxes. The elasticity of fuel use per
kilometre with respect to the consumer fuel price is in line with the long-run elasticities
reported by Goodwin (1992).

Increases in the purchase tax reduce fuel efficiency of new vehicles of different size
classes in EUCARS: a purchase tax is also implicitly a tax on fuel efficiency. This is
because the purchase tax is ad valorem, implying that it gives an incentive, when

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7 Complementarity at this level seems likely in an aggregate model of this kind as — at the household level
— a reduction in the number of cars will automatically lead to a reduction in the free vehicle services
associated with cars that are no longer in the vehicle fleet. Some substitution by increasing the "flexible"
mileage of remaining cars seems possible, but it seems unlikely that this will fully compensate the former
effect.

8 In a new version of EUCARS, both vehicle speed and in-use fuel efficiency (dependent on vehicle speed)
of old and new vehicles have been endogenised.
Table 2

Fuel Efficiency Cost and Price Elasticities of the Vehicle Production Block
( evaluated at 1990 levels)

<table>
<thead>
<tr>
<th>Vehicle Category</th>
<th>Cost Elasticity of New Cars w.r.t. Fuel Use per Kilometre</th>
<th>Elasticity of Fuel Use per Kilometre w.r.t. Consumer Fuel Price</th>
<th>Elasticity of Fuel Use per Kilometre w.r.t. Purchase Taxes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>-1.0</td>
<td>-0.3</td>
<td>0.06</td>
</tr>
<tr>
<td>Medium</td>
<td>-0.5</td>
<td>-0.4</td>
<td>0.08</td>
</tr>
<tr>
<td>Large</td>
<td>-0.5</td>
<td>-0.4</td>
<td>0.09</td>
</tr>
<tr>
<td>Diesel</td>
<td>-0.5</td>
<td>-0.4</td>
<td>0.09</td>
</tr>
<tr>
<td>LPG</td>
<td>-0.5</td>
<td>-0.4</td>
<td>0.08</td>
</tr>
</tbody>
</table>

For more details on the underlying functional forms, see Appendix.

designing new car models, to reduce car features that add to the before tax price, such as fuel efficiency. Clearly substitution effects across different vehicle categories will also contribute to the change in the average fuel efficiency of a particular vintage.

4. Simulation Results of Various Policies to Reduce CO₂ Emissions from Cars

EUCARS has been used to investigate the cost-effectiveness of the following policy instruments to reduce CO₂ emissions from cars:

- fuel tax (proportional increase in all excises)
- CO₂ tax (increase in excises on the basis of CO₂ content of fuel)
- annual car ownership tax (proportional increase in all annual car ownership taxes)
- CAFE standard/gas-guzzler-slipper rebate

The cost-effectiveness of the various instruments has been evaluated by comparing the welfare costs of reducing CO₂ emissions from passenger cars and public transport by 10 per cent from baseline levels in the period 2010/2015. Policies are introduced in 1990/95 after which they are kept constant for the remainder of the simulation period. This procedure allows a full adjustment of the various car fleets to the new equilibrium prices. The welfare changes are defined as the equivalent variation plus the change in the tax revenues and are expressed as percentage change from baseline spending on passenger transport (see equations 1 and 2 in the Appendix). They therefore ignore possible

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9 However, higher purchase taxes would also tend to reduce other vehicle characteristics that add to vehicle costs, some of which (such as power) are associated with high fuel use. As the model ignores these indirect effects, it might exaggerate the impact of purchase taxes on fuel use.
Table 3
Impacts of Various Policies to Limit CO₂ Emissions from Cars
(as percentage difference from baseline levels in 2010/15)

<table>
<thead>
<tr>
<th></th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
<th>Scenario 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ emissions</td>
<td>−10</td>
<td>−10</td>
<td>−10</td>
<td>−10</td>
</tr>
<tr>
<td>Economy-wide welfare effects</td>
<td>−1.9</td>
<td>−1.8</td>
<td>−5.0</td>
<td>−2.2</td>
</tr>
<tr>
<td>Welfare effects to producers and consumers</td>
<td>−4.3</td>
<td>−4.2</td>
<td>−22.7</td>
<td>−1.3</td>
</tr>
<tr>
<td>Government tax revenues</td>
<td>2.4</td>
<td>2.5</td>
<td>17.8</td>
<td>−0.8</td>
</tr>
<tr>
<td>Fuel use per kilometre</td>
<td>−7.1</td>
<td>−7.1</td>
<td>0.0</td>
<td>−11.8</td>
</tr>
<tr>
<td>Costs of ownership</td>
<td>3.8</td>
<td>3.6</td>
<td>41.8</td>
<td>5.6</td>
</tr>
<tr>
<td>Costs of usage</td>
<td>6.9</td>
<td>6.7</td>
<td>0.3</td>
<td>−5.9</td>
</tr>
<tr>
<td>Price of private transport</td>
<td>4.5</td>
<td>4.4</td>
<td>25.8</td>
<td>1.4</td>
</tr>
<tr>
<td>Car ownership</td>
<td>−3.6</td>
<td>−3.3</td>
<td>−18.4</td>
<td>−1.9</td>
</tr>
<tr>
<td>Car use (mileage)</td>
<td>−4.4</td>
<td>−4.3</td>
<td>−12.3</td>
<td>1.0</td>
</tr>
<tr>
<td>Use of public transport</td>
<td>3.2</td>
<td>3.1</td>
<td>17.6</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Scenario 1: Fuel tax, proportional increase in all excises by 42%.
Scenario 2: CO₂ tax, increase in excises on the basis of CO₂ content of fuel; implying an increase in petrol prices by 20.9%, in diesel prices by 27.8%, and LPG prices by 27.9%.
Scenario 3: Annual car ownership tax, proportional increase in all car ownership taxes by 470%.
Scenario 4: CAFE standard/gas-guzzler-sipper rebate; a CO₂ target of 179 grammes per kilometre and a tax (subsidy) equivalent to 300-500 ECU/(litre/100km) above/below the target level have been introduced. The tax level depends on the CO₂ content of fuels used.

In all scenarios both the price and the fuel efficiency of public transport services are assumed to remain unchanged.

economic effects, for example on agriculture and from rising sea-levels due to reduced CO₂ emissions. Furthermore, as discussed in the Appendix, this criterion does not take account of the destination given to the tax revenues collected, nor does it take account of impacts on other transport externalities.

Table 3 and Figure 3 present the main results of the various simulations. Table 3 shows that the impacts of a proportional fuel tax increase are very similar to those of a CO₂ tax. The CO₂ tax leads to somewhat smaller welfare losses, but the difference between the two scenarios is very small. This is largely because the share of gasoline-powered cars is very high which limits the quantitative importance of substitution effects. The welfare cost of the CO₂ scenario is equivalent to 1.8 per cent of baseline spending on transport.

Scenarios 1 and 2 imply an increase in the average price of fuel of more than 20 per cent. Fuel efficiency on new vehicles increases by 7 per cent which also raises new car
Figure 3

Results of Various Policy Scenarios to Limit CO₂ Emissions from Passenger Transport

Percentage change from baseline levels in 2010/2015
prices. Initially second-hand car prices drop as these vehicles become less attractive compared to new ones, but in the long run this effect peters out as the fleet is turned over. As capital and depreciation costs constitute the lion’s share of ownership costs, car ownership costs rise relatively strongly. The costs of car usage increase as a result of the steep increase in fuel prices, which is only partly compensated by better fuel efficiency. As a result mileage is decreased. The car park is also reduced, due to higher ownership and usage costs. In EUCARS the latter effect works via the increase in the price of committed vehicle services.

Ownership of small cars is hit relatively hard in the proportional fuel tax scenario (−5.1 per cent) as the share of fuel costs in total costs is higher than for other categories.\(^{10}\) Ownership of diesel cars is practically stable. This is due both to a low fuel costs share, and to relatively low pre-existing taxes on diesel, as a result of which the consumer price rise is below average. In the CO\(_2\) tax scenario, the carbon content (of fuels) constitutes the tax base; consequently low pre-existing taxes imply that diesel prices rise more than average.

Decreasing CO\(_2\) emissions from cars by using instruments that do not lead to higher fuel efficiency is likely to be an extremely costly option, as is demonstrated by the third scenario in which annual car ownership taxes are increased nearly fivefold. No incentive to improve fuel efficiency is provided and the reduction in emissions is obtained solely via reduced ownership. This reduction has to be very steep as reduced ownership does bring down mileage, but less than proportionally, resulting in significantly higher average mileage. The sharp increase in the price of private transport leads to a significant substitution effect favouring public transport. The overall welfare costs are nearly three times as high as in the least cost scenario. These welfare losses are the result of a very strong decrease in “consumers’ and producers’ welfare” due to the very high annual car ownership tax rates and a significant increase in the tax-take from the transport sector.

The CAFE scenario has been modelled as the revenue-neutral introduction of an equivalent gas-guzzler tax/sipper rebate.\(^{11}\) In the absence of different car manufacturers both approaches lead to an identical outcome for the optimal level of fuel efficiency (for proofs, see Johnson (1991) and Denis and Koopman (1994)).

In fact, a CAFE system pushes a manufacturer to select a least cost combination of fuel efficiency improvements on different vehicle types and mix shifting (by cross-subsidisation). The CAFE system, therefore, implies the introduction of an implicit tax on fuel efficiency. Basically, a gas-guzzler tax/sipper rebate gives the same incentive, but consists of an explicit tax on fuel efficiency. If the guzzler scheme is revenue neutral and the fuel efficiency target equals the CAFE target, then the gas guzzler tax is identical to the implicit tax in the CAFE system. Only the tax rate determines the degree of fuel efficiency improvement on individual vehicle types, whereas the interaction between

\(^{10}\) van Dijk and Cramer (1992) shows that the share of fuel costs in total costs is up to twice as large for the cheapest cars as for the most expensive vehicles in a number of European countries. Furthermore, the demand system chosen implies that substitution effects dominate income effects: consequently the demand for small cars is relatively hard hit in this scenario.

\(^{11}\) The fuel efficiency target has been modified to take account of differences in the carbon content of the various fuels.
targeted fuel efficiency, actual fuel efficiency on individual vehicle types and the size of the tax (or subsidy) determines the degree of mix shifting (Johnson (1991)). Mix shifting in the CAFE scenario analysed in Figure 3 increases ownership of LPG cars by 6 per cent, whereas the number of large cars in the fleet is approximately 5.5 per cent lower than in the baseline.

The CAFE guzzler scenario achieves the CO₂ limitation objective by an increase in fuel efficiency that is more than 50 per cent larger than in the CO₂ tax scenario. This implies that new car prices rise more than in the CO₂ tax case. Furthermore, the strong increase in fuel efficiency reduces the marginal cost of driving which gives an incentive to (new) car owners to drive more. The relatively significant increase in the average mileage illustrates this. However, the net “rebound” effect is fairly moderate as car ownership decreases which in itself leads to a reduction in kilometres. It is clear that this aspect is due to the existence of committed mileage in EUCARS.

Given that the net rebound effect is limited the welfare costs of the CAFE-type scheme are only somewhat higher (approximately 20 per cent) than in the case of a CO₂ tax. This is a relatively modest cost differential compared with studies in which the size of the vehicle fleet is not affected (for example, CRA, 1991). However, if one accepts that a reduction in the vehicle fleet will, other things being equal, lead to a reduction in vehicle use, then it is clear that the rebound effect will be modest. Obviously, the cost differential will increase if the CO₂ target is tightened as the marginal costs of fuel efficiency rise strongly. Moreover, to the extent that a CAFE scheme would lead to an increase in the lifetime of old vehicles (due to improved maintenance), costs would be larger than reported above.

5. Other Considerations

The CAFE scenario discussed above implies lower private welfare costs to consumers than the CO₂ tax case, while the latter scenario only leads to more favourable net welfare effects by generating significant tax revenues. This points to the importance of revenue redistribution issues in assessing the attractiveness of various policy instruments. For example, if tax revenues were used to cut other highly distortionary taxes in the economy, the welfare costs of the CO₂ tax could tax revenue recycling would be lower than presented above. On the other hand, political economy considerations might lead to favouring schemes that do not impose new taxes.

Inter-company differences in compliance costs imply that in reality the welfare costs of a CAFE system could be much higher than those reported above. Especially in Europe, where there is a strong divergence across the product mixes sold by various car manufacturers this aspect could be very significant. However, gas-guzzler tax schemes are not affected by this factor, as they have an in-built cap on costs.12

It has been argued that there are significant market failures affecting the vehicle purchase decision which lead to a sub-optimal demand for fuel efficiency in new vehicles.

12 Note that, under certain conditions, a tradable permit scheme will lead to the same results as the gas-guzzler tax analysed above (Johnson, 1991).
High implicit discount rates on fuel savings from consumer durables are quoted as evidence (see, for example, Train, 1985), and among the reasons forwarded are missing and/or incomplete second-hand markets (depressing prices of second-hand cars), principal agent problems (in the case of company cars, for instance), consumer liquidity constraints and informational externalities. Although the evidence on the existence of some of these market failures might seem relatively strong, the policy implications are not straightforward and are likely to differ strongly according to the specific market failure at hand. Furthermore, high implicit discount rates can be caused by uncertainty over future fuel prices and technologies (Crandall, 1992) and need not, necessarily, point to market failures.

However, it is clear that if consumers do not fully take account of vehicle lifetime fuel costs the introduction of an instrument — in addition to a CO₂ tax — could be beneficial, if it targets and corrects the market failure affecting the purchase decision (see, for example, Eriksson, 1993). This has been confirmed by a set of CO₂ tax simulations with EUCARS. First, it was assumed that new vehicle fuel efficiency is only improved up to the point where the fuel efficiency technology costs are outweighed by the extra fuel costs over the first three vehicle life-time years (“myopic” case). CO₂ emission reduction was 30 per cent smaller than in the fully rational case presented above. Secondly, adding a budget-neutral guzzler scheme was found to introduce no extra welfare costs in the “myopic” case whilst allowing the CO₂ reduction of the fully rational case to be attained. This suggests that, if market failures of the nature described above are of major importance, the case for a gas-guzzler tax scheme as an additional policy instrument could be relatively strong.

6. Conclusions
Limiting CO₂ emissions in a cost-effective manner requires the use of an instrument that equalises the marginal costs of emission abatement across all sources. Economy-wide carbon fees and tradable permit schemes are therefore first-best options and there are no good economic reasons why specific sectors should have a CO₂ emission reduction target. This suggests that limiting CO₂ emissions should not be restricted to passenger transport and that, as in other sectors, a CO₂ tax is likely to lead to the smallest welfare losses per tonne of CO₂ abated.

This hypothesis is borne out by simulations with a partial equilibrium model of European passenger transport (EUCARS) which show that carbon taxes are superior to CAFE/gas-guzzler systems and policies relying on increased annual car ownership taxes. The analysis with EUCARS suggests a clear ranking of the cost-effectiveness of the alternative options: whereas CO₂-based CAFE/guzzler schemes are only second best they are clearly preferable to a policy based on raising annual car ownership taxes, which, in turn, seems more attractive than policies relying on purchase taxes. For CO₂ emission abatement targets of the order of 10 per cent, the cost differential between CAFE/guzzler scheme and CO₂ taxes has been estimated at 20 per cent. The mechanisms via which the abatement target is achieved are, however, different: the CAFE/guzzler system relies much more strongly on improved fuel efficiency in new vehicles and vehicle fleet mix.
shifting. A strong increase in average fuel efficiency is needed to compensate an increase in mileage following the reduction of the marginal costs of driving. This so-called rebound effect is, however, relatively small at the aggregate level as the effect of increasing ownership costs in itself reduces both ownership and usage. As the costs of fuel efficiency increase more than proportionally with the fuel efficiency target the cost differential between CAFE/guzzler schemes and CO₂ taxes will widen strongly for more ambitious abatement targets.

In a real world with heterogeneous car manufacturers, the effects of CAFE and guzzler tax schemes are no longer identical as the CAFE scheme does not allow cost differences across manufacturers to be evened out, whereas guzzler schemes have an in-built cap on the costs of emission reduction and imply equalisation of marginal costs of fuel efficiency improvements across manufacturers (via the guzzler tax rate). This suggests that a pure CAFE system would imply dramatically higher costs in the context of the European car market with its large number of specialised producers. Guzzler and tradable permit schemes would seem to be more attractive, although little experience with operational performance exists. From an economic perspective, such policies are second best compared with a CO₂ tax. However, if consumers underestimated vehicle lifetime fuel use when purchasing a new vehicle, then a case could be made for introducing a gas-guzzler tax scheme in addition to a CO₂ tax.

Appendix

Consumer welfare

This is modelled by a simple CES demand system which, because it is linear homogeneous, allows welfare changes induced by policy measures to be directly translated to equivalent variations:

$$ EV = -(U_{new} - U_{old})/U_{old}Y $$

(1)

where $U_{new}$ and $U_{old}$ denote utility levels in the policy simulation case and the baseline, respectively. $Y$ stands for total expenditures on consumption. The total percentage welfare change ($RELWELF$) is defined as

$$ RELWELF = EV/BBUDG + DTAX/BBUDG $$

(2)

where $RELWELF$ is welfare effects of simulation (as a percentage of baseline spending on passenger transport); $DTAX$ is the change in all transport tax revenues with respect to baseline; and $BBUDG$ is the baseline spending on passenger transport. The first term in equation (2) obviously measures "private" welfare costs ($DPRIVWELF$), whereas the second represents changes in government revenues ($DTAX$). Hence, the current analysis does not take account of the welfare effects of changes in external costs of transport. To the extent that scenarios differ strongly in impacts on externalities this might bias the results somewhat. If information on the marginal dead-weight burden of the tax system were available, this should in principle be taken into account when determining the value of changes in tax revenues by multiplying these by an appropriate factor. In the absence of such information, this aspect has been ignored, which might imply a bias against revenue-raising scenarios.
Costs of car ownership and use
The prices faced by the consumer in markets for new and old cars are determined in a similar way. Prices of ownership comprise four elements of a conventional user cost of capital formulation:

\[ PCTSGA_{ownership} = FCE + FCP + DEPR + CAPC \]  

(3)

where \( FCE \) is an exogenous fixed cost component (part of maintenance, insurance and so on); \( FCP \) are annual vehicle taxes and other fixed charges; \( DEPR \) is depreciation; and \( CAPC \) are capacity costs.

Depreciation takes place according to a linear scheme, on the basis of the purchase price of the vehicle and the expected remaining lifetime. The capacity cost variable comprises both interest forgone on the book value of the vehicle plus a term describing expected capital losses and/or gains. For new vehicles the book value equals the new car price (minus current period depreciation); for old vehicles the (market) price of the relevant second-hand car type (minus current period depreciation). As old cars have only a limited life expectancy in the current period, expected capital losses and/or gains are ignored. For new cars, the expected capital loss/gain term equals the difference between the expected second-hand price of the relevant car type in the new period (proxied by the current price) and the book value at the end of the current period (purchase price minus cumulated depreciation). Implicitly it is assumed that at the end of each period accounts are updated (because, for example, cars change owner). For each new car category period capacity costs per vehicle amount to:

\[ \text{CAPC}_f = (\text{INT}/100) \times 3.8 \times \text{NCPC} + 4.0 \times \text{NCPC} - \text{OCMP} \]  

(4)

where \( INT \) is the interest rate; \( NCPC \) is the consumer price of a new vehicle (including purchase taxes); and \( OCMP \) is the current period price of the vehicle on the second-hand market.

Prices of car usage are determined according to the following equation for the various vehicle categories:

\[ PCTSGA_{usage} + VCE + FEFF \times (PFUEL + VCP) \]  

(5)

where \( VCE \) is an exogenous component (comprising maintenance, oil use, and so on); \( FEFF \) represents the fuel use of the car (given in litres used per kilometre); \( PFUEL \) is the fuel price before taxes of the relevant fuel type (gasoline, diesel and lpg); and \( VCP \) denotes fuel excises.

Fuel efficiency and car prices
Fuel efficiency on new vintages is determined by car producers operating in a fully competitive market. Hence, producers optimise fuel efficiency up to the point where technology costs outweigh fuel savings. As different car types use different fuels and the fuel efficiency differs across vehicle types, new vehicle prices are calculated for new cars of all types. The rule is:

\[-dRF/d(1/FEFF) = dNCPC/d(1/FEFF)\]  

(6)

where \( RF \) are the discounted vehicle lifetime fuel costs. Furthermore:

\[ RF = FEFF \times (PFUEL + VCP) \times Z \]  

(7)

where \( Z \) is the discounted value of lifetime mileage.
Producer prices \((NCPP)\) of new vehicles are determined by the following technology cost curve:

\[
NCPP = \Omega \exp(\alpha \ 1/FEFF \ \text{TIME}); \tag{8}
\]

whereas consumer prices are also determined by \textit{ad valorem} purchase taxes

\[
NCPC = (1 + OCP)NCPP \tag{9}
\]

where \(\Omega\) and \(\alpha\) are vehicle type specific constants: these have been calibrated so as to arrive at the elasticities presented in Table 2. \(\text{TIME}\) is a shift parameter of autonomous technical progress (an autonomous energy efficiency improvement of 1 per cent per year has been assumed on the baseline).

Costs of improving fuel efficiency increase exponentially. As purchase taxes are largely \textit{ad valorem} in Europe (ACEA, 1993), increases in producer prices following improved fuel efficiency are translated proportionally into consumer prices. Equations (6) to (9) can be rewritten to arrive at the following expression for optimal fuel efficiency:

\[
1/FEFF = \left(1/(1 + OCP)\right) NCPP \alpha \text{TIME/(PFUEL + VCP)} - 0.5 \tag{10}
\]

Car prices on the second-hand market are determined by confronting demand for car ownership from the consumption block with the fixed supply of old cars (according to the lifetime functions) and imposing that excess demand equals zero.

\textbf{References}


