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Transport sector policies already contribute to moderating greenhouse gas emissions from road vehicles, and are increasingly designed to contribute to overall societal targets to mitigate climate change. The Round Table investigated the effectiveness and costs of various mitigation options. The question of how to decide on the distribution of abatement efforts across sectors of the economy was also discussed. Within the broad topic of addressing greenhouse gas emissions from transport, the Round Table focused on emissions of CO_2 from road transport and, in particular, from light-duty passenger vehicles.

Policies that reduce fuel consumption below non-intervention levels are in place in most countries; many have been adopted for reasons other than reducing CO_2 emissions. In the US, both fuel taxes and fuel economy regulations have been in force for some decades. European governments have adopted high fuel taxes, but are now considering introducing fuel economy regulations.

A first core question for the Round Table was whether such a combination of instruments is justified. A second question was whether current policies, and the level of taxes and standards, are in line with societal climate change mitigation goals and, more generally, how such goals ought to be defined.

Combining instruments

There are two general arguments to motivate combining fuel economy regulations and fuel taxes. First, if prevailing levels of fuel taxes fail to stimulate the desired level of reduction in fuel consumption, and if increasing taxes is not politically feasible for the foreseeable future, regulating fuel economy is attractive. Using regulations may be a more costly way of reaching targets, but this approach trades off these costs against political expediency.

Cap-and-trade systems that allocate CO_2-emission permits to drivers free of charge are another potential approach to reducing fuel consumption that might be more politically acceptable than higher fuel taxes. Here too, political feasibility comes at a cost, as free permits imply a loss of valuable public tax revenue, and to a stronger extent than with standards. The comparative administrative cost of permit systems, taxes and standards is still subject to debate.

The second argument to combine fuel taxes and fuel economy regulations is that there are imperfections in the market for vehicles that are not satisfactorily dealt with by fuel taxes. When analysing vehicle purchase decisions, it is important to keep in mind that a vehicle is a collection of attributes of which fuel economy is just one. When increasing fuel economy implies a reduction in power, for example, the increase in consumer benefits from better fuel economy needs to be weighed against the loss of benefits from lower power. There are indications, however, that consumers under-invest in fuel economy: buying more fuel-efficient vehicles that are more expensive but otherwise identical would lead to net benefits through reduced expenditures on fuel over the lifetime of the vehicle. This holds at reasonable levels of private discount rates and, *a fortiori,* at social discount rates.

The reasons for these imperfections are not entirely clear empirically, but are related to:

(a) insufficient information at the point of purchase on the trade-off between more expensive technology and lower fuel costs;
(b) frictions in markets for used cars;
(c) inappropriate incentives in company car markets; and
(d) uncertainty for manufacturers about the reactions of car buyers and manufacturers competing to produce more efficient but more expensive vehicles. These frictions can justify such interventions as providing better information and regulating fuel economy.

When it is judged useful to employ a combination of instruments, the issue becomes designing the package to be cost-effective. Exactly what level of fuel tax should be combined with what standard depends on how important are the frictions in vehicle markets. A conceptual understanding of these imperfections is emerging, but their quantitative importance is largely unknown. Estimates of the technology costs associated with better fuel economy are also uncertain. More research on these specific issues would be valuable. At present, it is not clear if prevailing or proposed stringencies for standards are justified by the imperfections observed. Some experts think, for example, that the proposed EU standards are too ambitious given prevailing fuel taxes; others think that technology costs are sufficiently low and market imperfections sufficiently strong to justify stringent standards.

Cost-effectiveness is one objective in the design of standards, but regulators often also have to take fairness considerations into account, and specifically the interests of manufacturers that focus on relatively fuel-intensive vehicles. This leads to attribute-based standards, where the allowed level of CO_2 emissions depends on a vehicle attribute like weight or footprint (wheelbase x width). The choice of attribute is not neutral, and there is considerable agreement that footprint is better than weight. This is because weight-based standards may reduce the appeal of reducing weight to improve fuel economy, and with a poorly designed standard an incentive to add weight rather than cut emissions might result. Footprint-based standards avoid such problems to a large extent, as footprint is more difficult to change without affecting vehicle characteristics that consumers value highly.

Transport, climate change and other external costs

A comparison of marginal external cost estimates and transport charges suggests that current charges more than cover external costs for passenger cars in many circumstances, with the exception of driving in highly congested conditions. At the same time, CO_2 abatement costs are likely to be lower in some other sectors of the economy. One view is that this calls into question the routine statement that transport should contribute to abatement of greenhouse gas emissions, as road transport is already subject to more than sufficient levels of fiscal incentive to reduce its CO_2 emissions to an optimal level; it is taxed well above the marginal costs of CO_2 emissions. If fuel taxes are seen as an instrument to tackle the main external costs of driving, they are sufficiently high except for driving under heavily congested conditions. Only very ambitious overall CO_2 abatement targets, out of line with damage estimates, could justify further abatement in transport. This view is far from universally accepted, for at least three reasons:

First, deviations from charges set at the level of marginal external costs may be justified in an economy characterised by multiple inefficiencies. While such inefficiencies clearly exist, the evidence on their magnitude does not point in the direction of sharply increasing transport charges.

Second, current marginal external cost estimates relating to greenhouse gas emissions are uncertain and strongly risk-averse policymakers implicitly may wish to use higher values. Discussions at the Round Table underlined that such risk-averse behaviour comes at a cost.

Third, the case for internalising external costs is that it improves efficiency and hence net economic surplus. Policymakers may trade off this objective against others, and therefore choose to deviate from efficiency-oriented policies. Here too, economic analysis points out the costs of such an approach.

1. INTRODUCTION

Transport generates a large and growing share of anthropogenic greenhouse gas emissions. While measures that discourage fossil fuel use in transport are in place, the sector has yet to shift to using low carbon intensity fuels on a large scale. With ambitious greenhouse gas reduction targets, all sectors in the economy will have to de-carbonise to some extent. But how can greenhouse gas emission reductions from transport be best put into effect?; and what guidance can be given on the distribution of abatement efforts between transport and other sectors?

This paper discusses these issues, with a nearly exclusive focus on road transport and, in particular, light-duty vehicles. The analysis is also mostly limited to policies affecting vehicle technology through regulation of fuel economy and policies affecting vehicle choice and use through regulation, fuel taxes and tradable CO_2-emission permits. Other policies, such as fuel quality regulation or explicit attempts to modify mode choice, are ignored although they clearly merit consideration in a broader policy package to reduce carbon emissions from road transport.

We begin by discussing which combinations of policy instruments are likely to mitigate transport greenhouse gas emissions most effectively (Section 2). To many economists it seems strange that this issue even needs to be brought up. Basic microeconomics tell us that greenhouse gases from transport are an externality, and that a carbon tax is the ideal instrument to confront users with the marginal external cost of carbon and reduce emissions to efficient levels. While much is to be said in favour of this principle, it is not clear that it offers *complete* guidance for an effective policy, for at least four reasons.

First, not all parties involved may regard least-cost emission reduction or an efficient level of greenhouse gas emissions as an overriding policy target. Economists tend to focus on efficiency as the pre-eminent policy objective, but this view is only one input to a policymaking process that also considers other objectives to which it may give more weight. Consequently, marginal external damage estimates or estimates of efficient charges are not necessarily a yardstick for policy evaluation. We emphasize the necessity to separate discussions on policy objectives from those on instruments in subsection 2.1.

Second, cost-minimising mechanisms are often taken to be difficult to achieve politically. This implies that the cost-minimising properties of incentive-based mechanisms need to be weighed against other factors, including political feasibility. This is briefly discussed in subsection 2.2.

Third, if consumers make socially desirable decisions when trading off fuel economy against other vehicle attributes and vehicle prices, carbon taxes (or the equivalent) would be sufficient to align consumer behaviour regarding fuel use with societal interests. But there is evidence to doubt whether consumers' decisions on fuel economy are in line with what is socially desirable, suggesting that complementary instruments such as fuel economy standards may be justified. Clearly, such a motivation in no way eliminates the need for improved transport charging structures. The appropriate stringency of existing and proposed standards depends on a further set of considerations, examined in subsection 2.3.

Fourth, greenhouse gas abatement policy does not operate in a vacuum. The transport sector is heavily regulated and heavily taxed (especially in Europe), on grounds ranging from safety to raising public revenue. How do greenhouse gas abatement policy and these other objectives interact, given the current state of policy?; and how does this fit in a framework for improved transport policy that addresses all the major externalities? Subsection 2.4 deals with these questions.

The outcome of the discussion in Section 2 is that there are reasons to view fuel tax and fuel economy standards as key complementary elements of the policy package to manage greenhouse gas emissions from road transport. Section 3 focuses on the design of standards, taking into account that while the market does not operate perfectly, the alternative of government intervention also struggles to achieve perfection. Hence, how should standards be designed to correct market imperfections? Should standards be uniform across all vehicle types, or rather allow emissions per unit distance to increase with vehicle weight or footprint? Should there be a built-in system to increase stringency over time? In order to answer these questions, it is imperative to be clear about (1) what the policy aims to attain and (2) how easy it would be to adapt the measure, in the context of changing political aspirations and increased knowledge about demand and supply responses. For the first question, the design of a standard depends on whether the main goal is to influence the composition of the (new) vehicle fleet or to change the technology used in the (new) fleet without affecting fleet composition, although it is clear that aiming to change the vehicle mix increases the potential to reduce emissions. Regarding the question of "future proofing" regulations, it seems important to formulate a policy that provides sufficient certainty for producers facing major investments while retaining enough flexibility to integrate the standard with potential improvements in transport pricing.

Given the insights from Sections 2 and 3 on greenhouse gas abatement strategies in transport, Section 4 briefly touches on the problem of how the costs of the strategies should be shared across the community (burden sharing). Decisions on how much abatement effort to require from the transport sector depend on the overall abatement target and on the costs of abatement in transport relative to other sectors. Determining abatement costs in an economic sense is difficult, and opinions on relative magnitudes diverge. Overall, the evidence suggesting that abatement costs are relatively high in transport does not seem sufficiently strong to counter the rationale underlying the policy approach outlined in Sections 2 and 3, but it raises questions about the tendency to prioritise transport in abatement efforts and highlights the need for careful abatement cost evaluations. Section 5 sums up and concludes.

2. EFFECTIVE POLICY PACKAGES TO REDUCE GREENHOUSE GAS EMISSIONS FROM ROAD TRANSPORT

While debates on policy instruments to reduce greenhouse gas emissions are often cast in terms of either economic incentives (such as taxes or tradable permits) or command and control instruments (such as emissions standards), there are strong arguments to combine these approaches in the transport sector. In particular, there are analytical grounds for combining carbon or fuel taxes with a fuel economy standard. More practically, an increasing number of regions around the world already have or are likely to adopt fuel economy standards in addition to fuel taxes. Irrespective of whether this approach is taken primarily for reasons of climate change policy or is otherwise justifiable, it is important to understand the interaction between standards and taxes.

The main arguments in favour of fuel economy standards, even when fuel taxes exist and are high, are as follows:

(1) Taking current policy preferences as given, standards are more politically palatable than (even) higher taxes. The trade-off between lower political costs and higher economic costs becomes less of a concern when elasticities of the demand for driving are low because better fuel economy triggers only limited additional driving in that case (subsection 2.2).

(2) Carbon or fuel taxes are not sufficient to align consumer choices with the socially desirable choices, as their influence on some choices is only very indirect. Specifically, standards improve choices of vehicle fuel economy, but they affect only new vehicles so that it takes 15 to 20 years before their full impact on fuel consumption is realised (subsection 2.3).

In discussing these arguments, it is useful to keep in mind the tension between "standard" economic argumentation, favouring a Pigouvian approach to policy assessment and policy design, and policy objectives that imply deviations from this approach (subsection 2.1). Furthermore, while using standards seems reasonable, they are likely to be used jointly with taxes, for reasons explained in subsection 2.4.

2.1. Marginal external costs and policy design: some clarification

It is a key principle of environmental and transport economics that efficiency is obtained when consumers' and producers' choices are based on prices that reflect marginal social costs. When there are external costs, such as those related to greenhouse gases, local pollution and congestion, charges reflecting those external costs are the ideal way of aligning prices with marginal social costs. This is the rationale underlying Pigouvian charges.

The partial-equilibrium Pigouvian principle has been challenged in the economics literature on the grounds that it applies only in a world where there are no other significant distortions to the efficient allocation of resources in the transport sector. It also implies that policies to mitigate transport externalities should not be influenced by inefficiencies elsewhere in the economy. As neither of these conditions prevail there is a strong case for "second-best" reasoning, and deviations from the simple Pigouvian approach are justified. While conceptually valid, the debate on exactly which deviations are justified is far from resolved. Some economists argue, for example, that transport taxes should be kept fairly low because transport taxes fall particularly on commuting, and thus on labour which is already heavily taxed (see Section 4). In this paper, we take the practical point of view that even if second-best arguments potentially justify deviations from marginal cost pricing, the existing (not even second-best) transport charges are so poorly related with marginal external costs that a reform of those taxes to bring them closer in line with external costs will improve efficiency[1].

However, accepting that a comparison of marginal external costs and transport charges informs us about the degree of efficiency in transport markets is not the same as declaring that efficiency is or should be the only policy objective. Even a superficial glance at policy objectives and actual policy shows that policy is not concerned with efficiency alone, but also with equity, industrial policy, trade promotion or protectionism, serving interest groups, etc. Recent policy on biofuels in the EU and the US may serve as an example (OECD/ITF, 2008a). The challenge becomes to determine the relevance of efficiency-based reasoning in the policy process. One approach is to participate in the debate and insist on the importance of efficiency as an objective. Another approach is to employ economics to determine the most cost-effective way to attain the political objectives. Both approaches are legitimate and useful, but it needs to be recognised that they differ and that both imply value judgments (insisting on efficiency is not value free, nor is taking policy objectives as given). But confusion arises when both approaches are mixed in the debate, as the following example illustrates.

One common argument against fuel economy regulation, especially in Europe, is that current fuel taxes already exceed marginal external costs, except for severely congested traffic. But this matters only in as far as policy targets are roughly in line with what a Pigouvian approach would prescribe. Such an approach can be defended but will not necessarily be accepted. The point is that this debate is essentially about policy objectives, not about the design of effective policies to attain them. The observation that taxes more than cover external costs in many cases then highlights that policy objectives are in play that do not imply efficient use of scarce resources, an issue that conceivably deserves explicit justification.

A somewhat more subtle version of the same problem arises when considering marginal external costs of greenhouse gas emissions. The comparison of marginal external costs to taxes is often done by referring to some kind of average estimate of the marginal external cost. The use of such an average is reasonable when uncertainty on cost estimates is limited, but harder to defend when there is large uncertainty as, in that case, an average is not very meaningful. Given the current controversy among climatologists and economists on the magnitude and the discounting of future damages, it is fair to say uncertainty on the marginal damage costs of CO_2 emissions is large. How to analyse policy when uncertainty is large? One solution is to work with several values of the marginal external cost, including very high ones. But again it is useful to realise that ultimately the discussion is about policy objectives. There is a sense that current policy gives a high weight to avoiding catastrophic consequences of climate change, even if the probability of such a catastrophe is low[2]. One can dispute the desirability of this policy stance, but the issue remains that this policy goal – presumably based on subjective evaluations of probability[3] – implies valuations of greenhouse gas emissions that exceed those used in most comparisons of taxes to marginal external costs. If the policy objective is taken as given, the point that current fuel taxes already cover marginal external costs means nothing more than that other factors than efficiency are considered.

2.2 Economic costs, political expediency and instrument choice

A strong argument in favour of incentive-based approaches, like taxes or cap-and-trade programmes, is that they generally minimise the costs of attaining a policy target. Standards can also be designed to minimise costs, but this possibility relies on all the necessary information being available to policymakers[4]. The informational requirement for incentive-based instruments is much less demanding, as the implementation of the cost-minimising solution is decentralised to parties that presumably have the required information, or can collect it at a lower cost than a regulator. One more attractive feature of incentive-based approaches like fuel taxes or carbon-trading schemes is that they affect all transport users, not just those who contemplate buying new cars. But these attractive traits of incentive-based approaches need to be weighed against others. We consider four examples: political feasibility, administration costs, asymmetric information, and uncertainty on cost and damage functions.

First, cost-minimising policies may not be politically feasible at present. It is routinely argued that this applies to higher fuel taxes, and not only in the US (e.g. Raux, 2008). Even when the economic costs of a standard are as high as, or higher than those of a tax, a standard is more politically palatable than higher fuel taxes and therefore is a practical though costly way forward, particularly in the short run. At the Round Table, this point of view raised concerns that regulation reflects a need to show willingness to act but boils down to little more than political window-dressing. Nevertheless, many experts are of the opinion that regulation is useful, even if it is not the ultimate or only solution. In particular, support for fuel economy regulation does not imply lack of support for improved pricing structures.

It is clear that difficulties with increasing fuel taxes have different implications depending on prevailing tax levels. Fuel taxes in the US are relatively low and when increasing them is deemed impractical in the near future, alternative policy approaches become attractive. Making the same argument for Europe and Japan, with higher fuel taxes, is less straightforward; convincing evidence to justify regulation on other grounds, some of which is discussed below, then becomes of key interest.

In this context, it is worth mentioning that the downsides of a standard compared to a tax are more limited when the elasticities of demand for driving are low, while these same low elasticities increase the political difficulties of appropriate fuel taxes because the appropriate taxes are higher when elasticities are lower (Small and Van Dender, 2007b). The empirical evidence on the elasticities of demand for fuel and for travel also indicates that both are substantially below one, and that drivers respond to higher fuel prices by investing in better fuel economy to a larger extent than by reducing driving (Johanson and Schipper, 1997) – and increasingly so, at least according to US evidence (Small and Van Dender, 2007a). By the same logic, a fuel economy standard may mimic the response that consumers would have had to higher fuel prices (in terms of fuel economy) quite well, and the amount of extra driving generated by lower fuel costs per mile (because of better fuel economy) is limited. The latter effect, known as the rebound effect, is a source of concern to the extent that increased driving leads to higher costs associated with non-internalised externalities related to congestion, accidents and air pollution[5]. But the evidence suggests these concerns are not major ones because the rebound effect is rather small, and partly offset in congested conditions (where external costs from extra driving are largest). Also, mitigating extra costs related to the rebound effect is best done by tackling those externalities directly, instead of giving up the goal of reducing fuel consumption.

Second, the cost-minimisation argument for incentive-based instruments in general ignores the administrative costs of implementation and operation. But administration costs are relevant when considering cap-and-trade greenhouse gas policies in transport. Raux (2008) proposes a cap-and-trade instrument in transport through a system that allocates greenhouse gas permits freely on a per capita basis. The reason for giving permits to drivers is that this makes the programme politically acceptable, on the argument that drivers will accept a cap if they receive rights but not if taxes are increased or permits are auctioned. While Raux argues that the operation costs of such a system are limited because it is added on to existing financial and distribution networks, others fear costs would be higher than anticipated. In addition, many argue that the combination of increased fuel taxes with explicit and transparent revenue redistribution schemes may attain the same goal of political and social acceptance at a much lower cost. Of course, the efficiency properties of such revenue redistribution schemes are not necessarily ideal[6], although they may compare favourably to the loss of revenue implied by tradable permits. Administrative costs of cap-and-trade at upstream levels (e.g. refineries) are likely lower, but then the social acceptance advantage is lost[7], and the case for cap-and-trade becomes weaker in that sense.

Third, in a world where all information is common knowledge, a standard and a tax are equivalent in the sense that a tax rate can be set that produces the same amount of abatement as would a standard[8]. The true case for a tax is that it requires less information on the policymaker's behalf than a regulation, because decisions on how to reduce emissions are made by consumers and firms, not by the regulator. Collecting and processing information on abatement costs is costly for businesses emitting CO_2 or producing vehicles emitting CO_2, but more costly for a regulator. This is because information provision is prone to incentive problems when collected by the regulator (businesses and other interest groups may misrepresent costs and levels of emissions). This suggests that a standard is likely to turn out more costly than a tax.

Fourth, the comparison of price-based instruments (such as taxes) and quantity-based instruments (such as cap-and-trade systems and, in a setting of common information, standards) is complicated by uncertainty. The seminal article by Weitzman (1974) tells us that the relative performance of price- and quantity-based instruments depends strongly on the slope of the marginal damage function. If marginal damages are more or less constant, i.e. each extra unit of emissions causes damage similar to the previous unit, then small deviations from the desired total level of emissions will not cause major extra costs, and taxes work well. But if, in contrast, damages increase sharply with emission levels, then it is important to get the quantity target right, because exceeding it entails large and possibly catastrophic consequences. In this case, instruments that give direct control over the level of emissions, like cap-and-trade systems, are attractive. A standard works well too, at least if the regulator knows enough about individual sources' abatement costs. Stavins (1996) considers more general patterns of uncertainty than Weitzman, and finds stronger support for quantity-oriented instruments[9].

So which type of marginal damage function is relevant for greenhouse gas emissions? This brings us back to the last issue of subsection 2.1. The view in many economic analyses is that the damage function is fairly flat, suggesting tax-based approaches are more suited. But some climate change and economic work and much of the political rhetoric are more consistent with a sharply rising damage function (threshold effects implying there is a benefit to acting quickly). A quantity-based approach is more in line with this "sense of urgency" because it gives the regulator more control over total emissions. While this argument holds true in general, there are some issues with its validity for a fuel economy standard. First, controlling fuel economy is not the same as controlling fuel consumption of new cars. Second, the standard initially only affects fuel economy of new cars and takes up to twenty years to affect the whole fleet. Both arguments call for complementary measures, i.e. a standard may be justified but is not the only part of the policy package.

2.3. Addressing vehicle purchase decisions

At present, the main goal of climate change policy in transport is to reduce CO_2 emissions from carbon-based fuel use[10]. Fuel use is determined by how much people drive and by the fuel economy and fuel type of their vehicles. Fuel economy is heavily determined when a vehicle is purchased, although driving behaviour, maintenance and aging matter as well. Is a fuel tax, or ideally a carbon tax, in itself sufficient to address both vehicle purchase and vehicle use decisions? It should be if the carbon tax is set at the level that is consistent with the cost of CO_2 emissions, or the carbon reduction target for road transport, and if car buyers trade off investments in fuel economy against higher fuel expenditures and other vehicle attributes, like comfort, safety and power. However, there are several arguments favouring an extra instrument to guide purchase decisions. We briefly consider some of these arguments, focusing first on private car buyers, and next on the company car segment.

For private car buyers, one argument is that private discount rates are higher than social discount rates. In that case, private discounted values of future fuel savings are below the social discounted values, leading to private underinvestment in fuel economy from the social point of view, even in the presence of appropriate fuel taxes[11]. The issue here is not that consumers make “wrong” decisions in the sense of miscalculating savings from better fuel economy from their private point of view, but that private and social valuations of future benefits and costs differ. It is worth noting that this argument for a policy intervention is controversial: regulators do not generally[12] interfere with private investment projects because private discount rates are thought to be higher than the ones used in public project appraisal, and it is not obvious why a different approach should apply to vehicle purchase decisions. The reasoning is especially unclear if fuel taxes cover marginal external costs, because in that case the policy rationale must be that consumers should be induced to discount at the social rate. The higher discount rates can be due to the option value of more flexibility for consumers (waiting for an even better technology, uncertain car needs, etc.) and it is not clear why the problem is more acute in vehicle purchase decisions than in other energy-saving decisions (e.g. domestic heating and cooling). Nevertheless, the argument receives considerable support.

A further argument is that consumers pay little attention to fuel economy, because they care more about other attributes, and the share of fuel costs (and therefore, *a fortiori*, the size of savings from better fuel economy) in total purchase and use costs is small[13]. There are also imperfections in the used car market (see Greene and German, 2007, for argumentation, and Turrentine and Kurani, 2007, for survey evidence; subsection 3.3 picks up on these issues in the discussion of the EU proposal for regulating CO_2 emissions). With little effort from the buyers’ side, it is possible that fuel economy investments are not optimal, although it is less clear why there should be a systematic error in the direction of underinvestment. It was noted that, contrary to expectations, fuel economy decisions for company car fleets and for freight trucks are prone to similar imperfections to those for privately owned light-duty vehicles[14]. From the manufacturers’ perspective, little attention to fuel economy from consumers may translate into strategies that steer vehicle design towards more highly valued attributes, like power and comfort. With such a supply response, available fuel economy probably is lower than in a world where consumers do make highly sophisticated and accurate decisions on fuel economy. A manufacturer will not be inclined to use technology to provide better fuel economy if there is large uncertainty as to whether consumers will want to buy it as well as to how competitors will deal with the same problem. A standard can correct this problem, as it provides clarity on what performance level needs to be reached by the manufacturer and its competitors.

In many European countries, a substantial share of new cars is purchased by companies rather than private car buyers. For example, according to Nieuwenhuis and Wells (2006), the share of company cars in the UK is between 50% and 70%. High market shares are also observed in The Netherlands and Sweden. Company cars are, on average, larger and more powerful than private cars. This size effect spills over into other market segments, as private buyers' aspirations are affected by company car characteristics, and company car characteristics affect the supply in used car markets some years down the line. It was also noted that the value of fuel-intensive cars depreciates more quickly than that of smaller cars, indicating that there may be a mismatch between large car characteristics and private buyers' willingness to pay (partly driven by income).

The UK Government has responded to these issues by changing the "benefit-in-kind" tax advantages for company car users to make them strongly dependent on the CO_2 emissions of company cars. This measure has had a marked effect on the characteristics of the vehicle stock, and company cars are now on average more efficient than new cars purchased privately. OECD/ECMT (2007, pp. 70-72) shows that in 2001 the average CO_2 emissions of new private cars equalled around 176g/km, while those of the average company car were around 181g/km; in 2005, the average for private cars was 173g/km against 167g/km for company cars.

Given the evidence on prevailing imperfections in vehicle markets, the question remains whether the stringency of existing and proposed regulations is in line with what is justified on the basis of the previous arguments. It may be the case that existing and proposed standards require bigger improvements in fuel economy than can be explained by failures in markets for vehicles such as those explained above. Indeed, the stringency of standards seems consistent with a policy approach that either starts from the assumption that technology to improve fuel economy is very cheap, or that explicitly aims to go beyond correcting market imperfections and steers vehicle buyers away from their preferred choices. This highlights, as mentioned earlier, that there is a political choice to be made as to whether higher vehicle costs and/or foregone consumer surplus are a price worth paying for the desired CO_2 reductions. There is a more in-depth discussion of these issues in Section 3.

2.4. Standards and taxes

The gist of the previous subsections is that there are arguments to suggest incentive-based approaches and fuel economy standards should work in tandem to govern fuel use in road transportation. Among incentive-based instruments, it was argued that taxes are likely to outperform trading schemes because they can attain social acceptance similar to that of trading schemes at a lower cost, at least if taxes are accompanied by explicit and transparent revenue-use schemes. There also is reason to favour taxes or auctioned permits over grandfathered permits: the former generate valuable public revenue, the latter do not. Of course, underlying this statement is the assumption of efficient or at least not wasteful revenue use. This assumption is not straightforward as there is a potential conflict between acceptability, as achieved through revenue redistribution, and efficiency of revenue use. Finally, if revenue is important, one must consider that a standard, through its effect on fuel economy, will reduce revenues as well, which is one more reason to think carefully about which standard to combine with which tax. We discuss these points next.

High transport taxes were in place, at least in Europe, well before energy security and climate change concerns moved up the political agenda. Transport is a source of considerable public revenue, and economic analysis suggests it is also a “good” source of revenue, because low elasticities result in relatively low economic costs of raising tax revenue from transport. This means that policies that reduce transport tax revenues are likely to meet political resistance and/or may cause additional economic costs. If transport tax revenues are not replaced by other sources, this poses a budgetary problem. If they are replaced, it is likely that the economic costs of raising the same amount of revenue increase. These public revenue concerns are relevant for any policy that reduces tax rates or the tax base. In particular, this trade-off reduces the appeal of tradable permits, at least if they are given away instead of auctioned, because of their large impact on fuel tax revenues (standards also affect the tax base but presumably less drastically so)[15].

The revenue argument not only applies to surface transport, but also to maritime transport and aviation, sectors for which inclusion in the European Trading System is anticipated. Even if permits for those sectors do not replace existing taxes but add new constraints, the public value of foregone revenue needs to be considered, and this suggests permits should be auctioned, not grandfathered or otherwise distributed for free. The choice between distributing permits for free or auctioning them is neutral when the market for permits works well (not straightforward) and when the social value of permit revenues does not depend on who gets them (whereas it is argued above that they are more valuable as public revenue). If it does not matter how permits are allocated, it does not matter who acquires the property rights, from an efficiency perspective. One argument for grandfathering then is that the agents who initially used a resource (like the atmosphere) for free and are now faced with constraints on that usage, merit the property right. A different view is that the atmosphere is common property, so public ownership (leading to public revenue through auctions or taxes) is preferred. The latter position is more in line with the Pigouvian approach, which rests on the view that users of a scarce resource should incur the full social costs of using it.

One position is that the foregone permit revenue is the price to pay for politically feasible abatement options. Another view is that revenues might be used so inefficiently that reducing them is not very costly to society (although it still may be politically challenging). A less extreme view is that more modest abatement targets need to be set if it turns out that politically feasible instruments turn out to be very expensive. It can also be argued that improved transport charging systems, in the sense of better aligning charges with key external costs including congestion, are more likely to increase revenues than reducing them if the right instruments are chosen (OECD/ECMT, 2003), and it does seems feasible to gather a political coalition in favour of such a reform.

At first sight, it does not seem opportune to combine a cap-and-trade policy with a fuel economy standard, simply because both instruments aim to control fuel use directly, unless the arguments regarding the steering of vehicle purchase decisions (subsection 2.3) are also thought to hold under a tradable permits scheme. But a standard can be seen as an accompanying measure to influence the supply of vehicles and ensure consumers have the option of switching to more fuel-efficient cars in response to higher costs of CO_2 emissions. Standards may also be designed to stimulate technological development, in the anticipation of future (more stringent) caps. If taxes and standards are combined, and the standard is binding in the sense that it pushes fuel economy beyond what it otherwise would have been, fuel tax revenues decline and the revenue issue reappears in a less extreme form. One approach is to compensate the erosion of the tax base by higher unit taxes. A different take is that the vehicle market imperfections discussed in subsection 2.3 actually lead consumers to pay too much fuel tax at present, so that the social value of fuel tax revenues is lower than it would be in a perfectly functioning market. In the latter case, compensating fuel tax increases should be, at most, partial.

It was noted in the previous subsection that standards are, in one sense, attractive to manufacturers in that they reduce uncertainty on exactly what level of fuel economy needs to be attained. But with a standard alone, there may be considerable tension between what the standard requires and what consumers desire. Arguably, the US approach of combining low fuel taxes with a standard has provided manufacturers with an incentive to evade the standard, for example, by focusing on the light-truck segment of the market. As is well known, the original motivation for less stringent requirements for light trucks was to protect farming and business interests, as the light-trucks segment of the market mainly concerned pick-up trucks. But manufacturers developed minivans and SUVs, considered light trucks under the regulation but predominantly used for passenger transport. The market share of these new types of light trucks rose quickly, a tendency reinforced by low real fuel prices[16]. These observations illustrate that provisions to protect particular groups in a regulation may have unintended and undesirable consequences, an issue to be kept in mind when designing a regulation (Section 3). In addition, it is clear that the tension between regulatory targets and consumer preferences can be weakened by (higher) fuel taxes, and this is one more reason to view both instruments as complements.

A last point, before discussing the design of standards in some more detail, is that the main approach up to now has been to compare the effects of combining taxes and standards with using either instrument in isolation. A somewhat different approach is to view standards as a reasonable and feasible interim approach in anticipation of a more comprehensive overhaul of transport policy in the future. From this perspective, standards are sometimes seen as a reasonable "quick fix", as long as they do not constrain future policy developments too much. If such future policy goes in the direction of fiscally discouraging CO_2 emissions, then current regulations should stimulate options to abate CO_2. But since any regulation will be gamed in ways that cannot be anticipated, there is a risk that unproductive compliance strategies are implemented, leading to pure waste and little steering towards low-carbon options[17].

As pointed out before, the value of standards as an interim solution needs qualification because long lead times and slow fleet turnover rates imply that standards take a long time to reach their full intended effect. In contrast, charging for fuel or carbon has an immediate effect (although impacts in terms of increasing investments in fuel economy also take time). The value of standards as a "quick fix" is related to their appeal in terms of political action rather than to immediate impacts on fuel consumption.

3. THE DESIGN OF FUEL ECONOMY STANDARDS

This section discusses issues to be taken into account when designing a fuel economy standard. Subsection 3.1 elaborates on the seemingly obvious point that the structure of a standard should reflect its objectives. In many cases, an attribute-based standard is chosen and subsection 3.2 discusses the choice of attributes. In subsection 3.3, we deal with the costs of attaining a standard, and subsection 3.4 handles the issue of discrepancies between test cycles, used to measure manufacturers' performance, and on-road performance. It is worth noting that the absence of a similar section in this paper on the design of price structures reflects the focus of the debates in the Round Table on which this paper is based, and in no way implies that the design of price structures is unimportant.

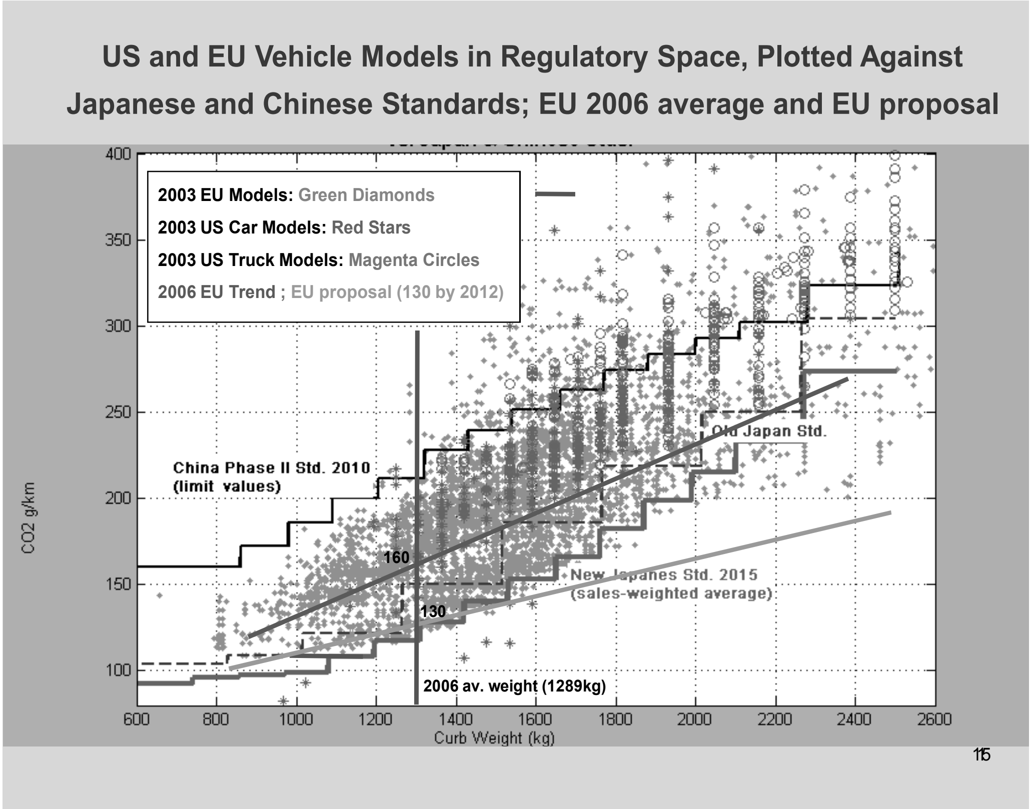
3.1. Goals and characteristics of a standard

The broad goal of a car or truck fuel economy standard is to reduce fuel consumption from road transport by pushing vehicle or fleet economy beyond market levels[18]. But this overall objective can be pursued in two ways. First, the standard can aim to modify the mix of new vehicles sold; for example, it can try to discourage the production and purchase of larger, more powerful, and less fuel-efficient vehicles. Second, the standard can focus on improving the fuel economy of the types of vehicles that are being sold. Such fuel economy improvements likely require the use of costly new technologies or the redeployment of available technology to improve efficiency rather than performance or comfort. While many regions or countries are using or plan to use fuel economy standards for light-duty vehicles, they differ in the emphasis put on these two goals. The revised CAFE standards in the US apparently focus on improving the economy of vehicles currently marketed, less on modifying the vehicle mix. This approach fits well in a culture that refrains from regulatory intrusion in private choices whenever possible. The revised standards also help shield domestic producers from international competition. Given the increased share of light trucks in the light-duty fleet (a rise partially triggered by CAFE itself), this approach does limit the potential to save fuel, even when gasoline prices are high. The Japanese top-runner approach, where standards are determined by good performers within a vehicle class, is similar in spirit to CAFE: the idea is to improve fuel economy within a class, not so much to affect the market mix of different classes of vehicle.

The Chinese standards (see Figure 1) are explicitly designed to discourage the production and purchase of heavier vehicles, as the weight-dependent standard is relatively more stringent for heavy vehicles and less so for light ones. Many current heavy EU and US cars and US light trucks do not meet the Chinese standards, while all lighter cars do. On condition that the standards are actually enforced, they can be expected to generate a vehicle mix that differs markedly from what an unregulated market would have produced, with lower emissions of CO_2 as a likely consequence. It is equally likely that enforcement of the standards carries a cost in terms of foregone consumer surplus. According to some observers (*FT*, 2008, p. 4), Chinese consumers are particularly status-sensitive when purchasing cars, leading them to buy large cars when they can. To the extent that status is related to the absolute size, power and comfort of the vehicle, this means that the foregone surplus is large. But when status mainly depends on how one vehicle differs from others, the standard helps avoid a race to the top, and the foregone surplus is limited. Such considerations apply to all markets, not just China.

In December 2007, the European Commission launched a proposal to introduce a weight-based fuel economy standard aiming to attain an average fuel economy corresponding to 130g CO2/km as of 2012 (EU, 2007a). The proposal is shown in Figure 1, along with the 2006 weight-CO_2 relation for newly sold cars. The European Parliament since communicated that it prefers a standard of 125g CO_2/km as of 2015, but the basic structure of the policy remained unchallenged (EP, 2008). The way the standard is structured provides considerable flexibility on whether it is attained by changing the mix of vehicles sold or through the improved fuel economy of types currently sold. In particular, the standard allows higher emissions for heavier vehicles, but the improvements to be made for heavier vehicles are larger than for lighter ones, if one compares with the weight-emissions relation for 2006 vehicles as well as if compared with the technical relation between weight and emissions. This feature suggests there are incentives to reduce weight (or at least discourage upsizing) and affect the vehicle mix[19]. But a pooling provision, which can be seen as a system that essentially allows manufacturers to trade or bargain between each other in groups (although the price of a unit of CO_2 emissions is not necessarily made explicit), may change this apparent incentive to reduce weight[20]. Overall, it appears the EU's main aim is to reach the target for the average fleet, and it accepts higher costs of reaching this target in return for a "fair" treatment of producers that currently focus on larger cars (see subsection 3.2). The proposal also reflects a judgment that an extra vehicle cost of € 1 300 on average, in case the vehicle mix is unaffected, is acceptable.

Figure 1. **Vehicle models and fuel economy regulation**



The figure compares the relation between weight (kg) and CO_2 emissions (g/km) for existing vehicle models and for existing and proposed fuel economy regulations. For vehicles, it shows:

- The 2003 EU models (green diamonds),
- The 2003 US car models (red stars) and the 2003 US truck models (magenta circles),
- The 2006 EU average relation between weight and emissions for vehicles sold (blue line);
- Also shown is the average weight of 2006 EU cars sold (vertical line at 1 289 kg).

For regulations, the figure shows:

- The China Phase II Std. for 2010 (black stepped line);
- The old Japanese standard (dashed blue stepped line);
- The new Japanese standard (red stepped line);
- The proposed EU standard of 130g/km on average as of 2012 (turquoise line).

Source: Feng An, Presentation at IEA/ITF Workshop, 28-29 January 2008, with JTRC additions.

3.2. The choice of attributes and the timing of the standard

All standards, except in China, apply to the sales-weighted average for each manufacturer's vehicles (sometimes differentiated by category of vehicle); the Chinese standards apply at the level of each individual vehicle. A sales-weighted average standard provides manufacturers with more flexibility than vehicle-specific standards would. The US CAFE regulation for cars is uniform, as the same target is set for each manufacturer's fleet. Alternatively, standards can be varied on the basis of attributes, such as weight or footprint (area delineated by the four wheels of the vehicle). The Chinese and the proposed EU standards are weight-based, and the revised CAFE standard for light trucks uses footprint. The effect of adopting attribute-based standards is that targets differ from one manufacturer to another to the extent that their sales mix differs. Most existing or proposed standards are static, where by static we mean that a policy decision is required to change requirements. A dynamic standard would include a mechanism to modify stringency over time. Only the policy proposed for the EU contains a dynamic element, as the weight-CO_2 relation used in the regulation will be adjusted if substantial increases in vehicle mass are detected before the year of implementation (that is, if vehicles become noticeably heavier by 2012, the standard will become stricter)[21].

Regulators can use attribute-based standards to strike a balance between objectives to manage the vehicle mix and "fairness"-related objectives. For example, if the regulator wishes to reduce the share of fuel-intensive cars (or avoid their widespread adoption), a uniform standard would provide a strong signal in that direction. But a uniform standard may simply be unattainable for manufacturers of the fuel-intensive cars (which could be deemed unfair), unless it is set at a level that is too lax to have an impact on manufacturers of less fuel-intensive cars. A standard that is based on a vehicle attribute that correlates to fuel intensity provides an intermediate solution, as it allows trading off cost-minimization and fairness concerns.

Given this motivation for attribute-based standards, the question remains which attribute is best, with the debate focusing on the choice of weight or vehicle footprint. There are reasons to think a footprint-based standard is more appropriate than a weight-based one. Reducing weight increases fuel economy, so it would be perverse to produce a standard that is *so much* stricter for light vehicles that the weight-reduction strategy becomes unattractive[22]. More generally, weight-based standards reduce the appeal of reducing weight as a compliance strategy, compared to a uniform standard. This is problematic, as large increases in fuel economy will require weight reductions unless performance is reduced and/or very strong increases in the market share of alternative-power trains are realised (see Cheah *et al.*, 2007, for an analysis of the trade-offs between these efficiency-improvement strategies). Footprint-based standards avoid this problem to a large extent. Reducing the weight of a vehicle with the same footprint does not change the goal set by the standard for that vehicle, but it does improve its fuel economy. Footprint is also less prone to strategic manipulation than weight, because changing the footprint of existing models is difficult, and increasing it on new models tends to increase weight, which leads to lower fuel economy and/or reduced performance. In addition, consumers' willingness to pay for vehicles is arguably more closely correlated with its footprint than with its weight, meaning that manufacturers will be less inclined to manipulate footprint for compliance reasons alone. The fact that footprint is less closely related with fuel economy than is weight, is in this sense a good thing rather than a flaw.

Weight reduction has been criticised as a compliance strategy, particularly in the United States, because of its presumed negative impacts on traffic safety. But this view is no longer considered to be the barrier to policies that promote lighter vehicles that it once was. According to, for example, Ahmad and Greene (2005) and Dynamic Research (2004), safety correlates more with vehicle size than with weight, as size allows for crush space. In that sense, standards that encourage lighter but not smaller cars are acceptable. Safety also strongly correlates with the degree of heterogeneity of the vehicle fleet on the road. A crash between two mid-size cars poses less fatality and injury risks, other things being equal, than a crash between an SUV and a small car[23]. So standards should probably not stimulate heterogeneity of the fleet (which the CAFE regulation, unfortunately and unintentionally, has done); by contrast, the weight-based approaches discussed above seem well designed in this regard)[24].

Finally, it is noted that the stringency of standards is often discussed in terms of the average target and the way it is implemented. However, given long lead times in vehicle manufacturing, the timing of the standard is crucial as well. A case in point is requiring an average fuel economy improvement in the EU from 160g CO_2/km in 2006 to 130g CO_2/km as of 2012, which will be challenging, especially since no final decision has been taken yet (in early 2008). Even if technological solutions to this end are available, an implementing period of four years or so is difficult and costly[25]. Delaying implementation in return for a tougher target (125g cO2/km by 2015) as proposed by the European Parliament seems a reasonable option in that sense, although it has been argued that policy in the European Union towards achieving a fuel economy target of 130 g/km, or indeed 120 g/km, in 2012 has been clear for several years already.

3.3. The costs of improving fuel economy through standards

If improving fuel economy were costless, would it not be achieved by the market unaided? Section 2 listed some reasons why vehicle markets do not necessarily spur optimal decisions on fuel economy, even if externalities are priced in accordance with policy objectives. A different issue is that of technology cost estimates. Debates on, and announcements of, regulation often generate a range of cost estimates, with those by regulated entities higher, those of beneficiaries' interest groups lower, and the regulator's in the middle. *Ex post* estimates tend to be below the *ex ante* estimates. For the case of the EC's proposed regulation, many think that cost estimates in the Commission's Impact Assessment (EU, 2007b) are on the high side, since they do not account for economies of scale, learning by doing, or consumers' response in terms of moving away from heavier cars[26]. The force of economies of scale in driving down costs tends be important in practice. In addition, strict standards are thought to contribute to technological leadership, which may favourably impact regional industry's comparative advantage in the anticipation of increased fuel economy requirements elsewhere. In this view, the costs to meet fuel economy requirements are seen as productive investments. But, even if the basic argument is accepted, there is little indication that they are the best possible investments[27].

The Impact Assessment of the EC's proposed regulation (EU, 2007b) produces an average retail price increase of € 1 300 per vehicle. According to the same source, this cost increase is accompanied by average lifetime fuel cost savings to the consumer of from € 2 200 to € 2 700, at fuel prices of € 1/l and € 1.20/l respectively, using a discount rate of 4%, a vehicle lifetime of 13 years, and an annual distance driven of 16 000 km. Vehicle attributes other than fuel economy are kept constant.

The calculation implies net savings, or an increase of consumer surplus, of around € 1 000, at a constant vehicle quality and a discount rate of 4%. In order to equalise costs and benefits, a discount rate of around 20% would need to be used[28], much higher than values for private discount rates. Consequently, the assessment suggests that, on average, the regulation produces consumer surplus gains instead of losses unless consumers use very high discount rates. This does not imply that using the (cost-increasing) technology to boost fuel economy is optimal from the consumer's point of view, as alternative deployments, e.g. boosting performance and/or comfort, may yield larger surplus gains[29]. But the figures do question the efficiency of the new and/or used vehicle markets, as in a fully efficient market any available net surplus gains would be realised. So, while these numbers are not definitive evidence, they do point to the existence of market imperfections that justify a policy intervention. If policy steers the use of technology towards fuel economy, the cost needs to be calculated as the difference in surplus produced by the use of technology best liked by consumers, and the surplus from using technology to improve fuel economy.

Allowing for consumer responses in terms of vehicle choices and the amount of driving implies a downward adjustment of technology cost increases, as indicated by the TREMOVE simulations included in the EU Impact Assessment. Economies of scale and of learning may very well also lead to lower costs, as is suggested by theory and by experience with earlier regulations, but there is no reliable or widely available evidence to substantiate the possible size of these effects. One reason for this lack of hard evidence is strategic, as industry has obvious incentives not to divulge information they may have before the standard is introduced. Another reason lies in the limited understanding of the exact processes that drive economies of scale or learning effects.

3.4. Test cycles and on-road fuel economy

The goal of a standard is to control on-road fuel economy, in order ultimately to reduce fuel consumption. Standards are enforced at the level of new car sales, based on fuel economy as measured on a standardized test driving cycle. Unfortunately, large discrepancies between current test results and on-road performance have been measured, usually in the direction of on-road performance being worse than the test cycle suggests. Test cycles can never match on-road behaviour perfectly and a single test cannot reflect the prevailing road and traffic environment for every single driver, but some improvements to standard test cycles can be suggested. The US EPA applies a uniform reduction factor to the test results on fuel economy for light-duty vehicles, to provide consumers with figures for new vehicles that are much closer to fuel consumption typically achieved on the road.

There is the issue that manufacturers can tune vehicles to perform optimally in a test cycle, in the knowledge that on-road performance will be worse. To avoid this, one possibility is to work with a range of test cycles, e.g. highly congested urban, off-peak urban, interurban, rural, etc., so reducing the possibility of optimizing on one or two cycles. For vehicle efficiency labelling in particular, it is useful to provide figures for both urban and extra-urban driving cycles, allowing consumers to choose the cycle that corresponds more to their normal usage.

Technologies have recently become available for measuring exhaust emissions in real time, with the potential to record violations of emissions limits under any driving conditions or modify the electronic engine management system when violations are recorded. This is being deployed to control NOx emissions, but the technique could conceivably be used also for CO_2 emissions (which are relatively easy to measure as they are directly determined by fuel consumption), allowing non-excedence limits to be set to all driving conditions. But how such limits would be enforced is another matter; the practicality of the approach is questionable.

A related concern is the difference in test cycles among regions and countries. Not only does this make comparison of fuel economy requirements difficult, it also may make the exploitation of economies of scale by global producers harder, although the high degree of differentiation by region of non-regulated specifications for models sold on several continents suggests such economies of scale may be exaggerated. At the same time, such costs may be outweighed by benefits of regional standards that are tailored to regional conditions. For example, driving in congested cities in Europe may be sufficiently different from driving in congested cities in Japan or the US that a uniform cycle implies a loss of precision for all three.

Modifying test cycles and achieving international harmonization takes time, and the current negations for a world-wide standard test cycle for light-duty vehicles at the UNECE is expected to take over a decade. A harmonized test cycle therefore faces the difficult task of being fit to regulate technologies entering the market far into the future, and needs to be suited to hybrid and electric vehicles if it is to be universal. This ultimately requires moving to a well-to-wheel measurement of CO_2 emissions.

Test cycles not only employ standardized driving patterns but also standardized vehicle configurations. The tests are run with all peripheral equipment, such as heating and cooling systems and electric motors for opening windows or driving windscreen wipers, turned off[30]. Some potential fuel economy enhancements are thus not reflected in test results and cannot be influenced by CO_2 emissions or fuel economy standards as currently formulated (e.g. improved air conditioners and high-efficiency electrical systems). The use of low-friction lubricating oils or low-rolling resistance tyres does affect test results, but there is no guarantee they will be used in vehicles on the road. The potential savings from better lubricants, tyres, air conditioners and electrical systems are not trivial and can amount to 5 or 10% of current average fuel consumption (OECD/ECMT/IEA, 2005). Moreover, they tend to have low costs and in some cases are amenable to retrofitting. For these technologies to be taken up, specific incentives may be required because they are immune from conventional vehicle standards and because they are even more weakly affected by fuel or carbon taxes than vehicle purchase decisions (see subsection 2.3).

4. BURDEN SHARING

Many multi-sector models, including the ones underlying Proost (2008), find that abatement costs in the transport sector are higher than those in other sectors, such as power generation, some industries and domestic heating and cooling. Consequently, *if* least-cost attainment of targets is desired, they suggest relatively modest efforts in transport, at least when abatement levels are in line with marginal damage estimates (see subsection 2.1 for a discussion of why this may not be the case). This argument can be challenged on at least two grounds.

First, as mentioned in subsection 3.3, the estimates of costs of technological improvements towards better energy efficiency in transport may be too high, as they are typically derived in a static framework that ignores economies of scale and learning. The question remains whether over-estimates are more frequent for transport than for other sectors. The argument that the costs of further improvements in transport are high appears reasonable in areas with a long history of high fuel tax levels in transport and not in other sectors. That such high taxes matter seems clear from a comparison of fuel economy levels in the EU and the US, although taxes are not the only explanation.

Second, even if technology costs are high in transport, this does not in itself imply that the economic costs are particularly high. This is because economic costs are not driven by resource costs alone in an economy characterised by multiple sources of inefficiency. One reason to think economic costs in transport are relatively low is that demand for it is relatively inelastic. Transport activities are tied to local production and consumption, so are not a mobile tax base. This is in contrast to some industries that may relocate in response to strict targets or higher taxes and the consequent increase in local costs (such relocation options are taken into account in the models used in Proost, 2008). It was noted that the profitability of some industries involved may be low or negative, implying limited or no losses of surplus from relocation. If one views the local loss of industrial activity as a cost (a view not universally accepted), then requiring larger efforts from transport may be justified.

A further question is how environmental and revenue-raising concerns should affect the level of transport taxes. If transport really is a relatively non-distortionary tax base, then taxes exceeding marginal environmental damage are justified, because the economic costs of imposing an extra burden on it for environmental reasons are limited, at least if measures are chosen that generate public revenue. One specific reason why the costs of high transport taxes might be low in terms of efficiency would be that they fall mainly on non-labour activities, an attractive feature because labour tax distortions are already high. The empirical evidence on this issue is scant, but suggests that road transport taxes are more or less neutral with respect to labour supply, so do not exacerbate labour market distortions too much (West and Williams, 2007, find that transport and labour supply are slightly substitutable in some cases and independent in others). Aiming for taxes that reflect marginal external costs is a reasonable way forward from an efficiency point of view. Clearly, this is very different from requiring carbon taxes over and above current fuel taxes, a view that is difficult to defend on efficiency grounds. According to the bulk of the empirical evidence, improving transport charges does not necessarily mean focusing on CO_2 but instead on congestion, external accident costs and local pollution. Such a policy likely entails sizeable CO_2 benefits, but it prioritises transport policy instead of energy policy (OECD/ITF, 2008b).

5. CONCLUSION

There is considerable consensus, but no unanimity, that pursuing climate change goals will require greenhouse gas abatement efforts in the transport sector, and that a combination of incentive-based instruments and regulation of fuel economy is appropriate. Agreement on just how much effort should be asked from transport, and consequently on the stringency of transport policy packages, is less wide. The case for substantial effort from transport relies to a considerable extent on assertions that technology costs for improving fuel economy are quite low and that market inefficiencies exist, particularly regarding consumer and producer decisions on fuel economy. These same arguments favour a policy package where regulation and incentive mechanisms complement each other. The case against particularly strong efforts in transport relies on assertions that cheaper abatement options exist in other sectors, as well as on the policy position that current measures already cover marginal external costs, making further efforts undesirable.

Against this background, one conclusion is that if there is a political decision to reduce greenhouse gas emissions from transport, this should be done by combining carbon or fuel taxes with standards. Taxes are preferred over “grandfathered” permits because they generate public revenue, although hybrid systems can mitigate the revenue loss from permits; if permits are auctioned rather than distributed for free, they also generate revenue, but their social and political appeal (compared to taxes combined with revenue redistribution schemes) is then weakened.

A second conclusion is that there is a need for more research. As such, this is a foregone conclusion, but some priorities can be defined. First, careful analysis of greenhouse gas abatement costs in transport and in other sectors is needed. While conceptually sound, the empirical underpinning of many of the arguments as to why costs are high or low is rather weak. Second, this paper argues that regulation of fuel economy is justified when there are imperfections in vehicle markets. Here too, the conceptual framework is convincing and there is evidence that there really are imperfections, but a clear quantitative understanding of the size of the inefficiencies (and consequently of the stringency of a regulation designed to correct them) is lacking.

It needs also to be recognised that policy is developed under uncertainty and with incomplete evidence. Policy needs to be underpinned by research into the likelihood and the costs of making errors. A policy imperative to achieve climate change mitigation implies giving a high weight to possible but unlikely catastrophic events. This, in turn, implies reducing the weight given to other transport and environment policy goals that have more certain, immediate and potentially larger benefits, as in the case of reducing particulate emissions or congestion. Research in this area may help achieve balance in policy priorities.

NOTES

1. A full alignment of charges with external cost estimates may lead to higher CO_2 emissions as off-peak driving charges decrease (cf. cost and charge comparisons in Proost *et al*., 2002). Retaining the overall structure of current charges and adding localised congestion-pricing schemes is more likely to reduce overall driving and CO_2 emissions, but is not optimal for the conventional cost estimates.

2. For example, the high marginal damage costs in the Stern Report (Stern, 2006) relate to the discounting method used, and this method is interpretable as translating strong aversion to extreme events into a regular discounting framework.

3. It is also possible that the policy objectives are defined on the basis of electoral attractiveness. This is more problematic, as it leads one to expect climate change will soon be replaced by a different issue, and this makes it hard to come up with credible long-run policies. Arguments on economic costs then may be used to defend abandoning the cause (all this irrespective of whether one thinks climate change policy in transport or in general is justified).

4. This is a necessary but not a sufficient condition. An additional requirement is that policy aims to minimise costs, rather than seeking rents.

5. The rebound effect is good news in the sense that increased driving resulting from lower fuel costs leads to more consumer surplus (keeping other quality attributes of the vehicle constant).

6. Existing or proposed systems routinely imply some form of earmarking of revenues to the transport sector, a constraint that may lead to suboptimal revenue use.

7. Experience with electricity companies in the European Trading System suggests refiners can be expected to pass on the costs of tradable permits in fuel prices even if permits are initially distributed free of charge. As soon as permits are tradable they become an asset, and the companies holding them maximise the returns they can obtain from these new assets. Because of this ability to pass through opportunity costs to final consumers, the European Commission proposes to amend the EU Directive on emission trading to impose auctioning of permits on the power sector earlier than in industrial sectors that consume energy [COM(2008)16 Final].

8. In finding this tax rate, the behavioural responses to both instruments need to be accounted for (e.g. a tax makes driving more expensive, but a fuel economy standard reduces the fuel cost of driving a unit distance).

9. In applying Weitzman's arguments and their generalisations, we implicitly assume it is justifiable to apply it directly to transportation. The discussion of burden-sharing in Section 4 points out that this assumption is controversial.

10. A broader approach may be called for as other emissions also have climate effects. For example, emissions of particulates (particularly generated by diesel engines) modify the albedo-effect, darkening the surface of polar ice and reducing the reflection of solar radiation. Jacobson (2002) argues that controlling this form of black carbon is a very effective way of quickly reducing transport's climate impacts.

11. See Verboven (1998, for econometric evidence that car buyers' discount rates are in line with "rational" private discount rates, given available vehicle models. The author remarks that this finding differs from results for other durables, implying that policy rationales differ as well.

12. Although some such interventions exist, e.g. through subsidies for home insulation.

13. Provision of more information for consumers, clearly and strikingly presented (e.g. through window stickers) at the point of purchase may help.

14. This is partly an information problem. Since fuel economy evaluations for trucks relate to stand-alone engines, they do not provide very good guidance for making decisions on which level of fuel economy to buy. It was pointed out that manufacturers simulate fuel consumption of various truck configurations, but do not voluntarily share it. Furthermore, since externalities per unit distance are high for trucks and fuel tax rebates are common, the divergence between privately and socially optimal decisions may be larger for trucks than for cars.

15. The revenue impact of permits can be mitigated to some extent by, for example, providing them for free to households but auctioning them for commercial transport. More generally, hybrid permit systems, for example, those that add permits on top of existing taxes, may have a role to play in a policy package that trades off revenue concerns, acceptability, and effectiveness in reducing CO_2 emissions.

16. The strong rise in fuel prices in the US in recent years has reduced the market share of light trucks in new vehicle sales. CBO (2008), p. 15, shows a decline in the market share of light trucks in new vehicle sales from 2004 to 2006 from 55.2% to 52.8%. More recent figures show a continuation of this trend, likely reinforced by a slowing economy, as sales of large SUVs declined by 40% between January 2007 and January 2008, while many more small cars were sold (*FT*, 2008, p. 5).

17. An additional future policy lever deserving close attention is spatial planning, as land-use patterns can limit excessively the potential to reduce travel demand.

18. While recognising that there are important differences, we do not distinguish here between standards that aim to reduce fuel consumption and those that aim to reduce CO_2 emissions.

19. Reducing the slope of the curve as weight increases is a way of further discouraging heavy vehicles. For example, the line could be made horizontal, starting from a weight of 2 000 kg or so.

20. The inclusion of the pooling mechanism is based on fairness considerations, but it may affect incentives to change weight. Trading does reduce compliance costs, as can be seen from the EC Impact Assessment Report (EU, 2007b), and from a study on CAFÉ, which suggests costs of the same target are about 15% lower when trading is allowed (Austin and Dinan, 2005).

21. This dynamic feature potentially harbours perverse incentives. A manufacturer producing vehicles well below the weight-CO_2 curve would, in theory, have an incentive to increase the weight of its models in order to provoke tougher standards that would have a relatively more severe impact on its competitors.

22. Not *every* weight-based standard entirely eliminates the rationale for weight reduction as a means to improve fuel economy, hence the italics on "so much". The EC proposal seems carefully crafted to avoid falling into this trap. Nevertheless, manufacturers may switch to diesel engines (which are heavier than gasoline engines) to arrive at a laxer standard and improve fuel economy in the process. Such intensified dieselisation is not necessarily ideal from a broader public health perspective (OECD/ITF, 2008b).

23. See Anderson (2007) for an econometric analysis of the relation between light truck market shares and traffic fatalities.

24. With a sufficiently homogeneous fleet, cars can probably be lighter and smaller without increasing safety costs (Evans, 2004 and SMP, 2004).

25. If redesigned vehicles can use technologies that are ready for mass production, the lead time is two to three years. If not, five to six years' preparation time is needed. Incorporating the technologies into the entire fleet takes even longer.

26. Of course, this consumer response may entail a welfare loss.

27. In addition, it is not clear in general why policy would be required for producers to take up profitable business opportunities (e.g. Palmer *et al.*, 1995). But in this specific instance, the business case depends heavily on policy itself, so the argument for leadership is reasonable from a regional perspective, given sufficient confidence that other regions will ultimately adopt similar policies.

28. Number taken from a March 12, 2008 email exchange with Richard Smokers, with permission.

29. The point here is that there seem to be imperfections in car purchase markets (and if Verboven's 1998 results are general, these imperfections are not related to discounting), not that the numbers justify the proposed stringency of the regulation. Evaluating the stringency also requires valuing the loss of public revenue due to the erosion of fuel consumption as a tax base, an issue of social relevance, but ignored in consumers' decisions on fuel economy.

30. Beginning with model year 2008, the US Environmental Protection Agency uses five cycles to determine fuel economy for the Fuel Economy Guide. One of these tests has air-conditioning running. But the fuel economy used for CAFE compliance uses only two tests (city and highway), with air-conditioning off. (http://www.epa.gov/fueleconomy/420f07066.htm).

BIBLIOGRAPHY

Ahmad, Sanjana and David Greene (2005), Effect of fuel economy on automobile safety – a re-examination, *Transportation Research Record*, 1941. (http://www-cta.ornl.gov/cta/Publications/Reports/Effect_of_Fuel_Economy.pdf)

Anderson, Mark (2007), Safety for whom?, The effects of light trucks on traffic fatalities, *Journal of Health Economics*, forthcoming.

Austin, David and Terry Dinan (2005), Clearing the air: the costs and consequences of higher CAFE standards and increased gasoline taxes, *Journal of Environmental Economics and Management*, 50, 3, 562-582.

Cheah, Lynette, Christopher Evans, Anup Bandivadekar, and John Heywood (2007), Factor of two: halving the fuel consumption of new US automobiles by 2035, Laboratory for Energy and the Environment, Massachusetts Institute of Technology, Cambridge, Mass.

Congressional Budget Office (CBO) (2008), Effects of gasoline prices on driving behavior and vehicle markets, Congressional Budget Office.

Dynamic Research (2004), A review of the results in the 1997 Kahane, 2002 DRI, 2003 DRI, and 2003 Kahane Reports on the effects of passenger car and light truck weight and size on fatality risk, DRI-TR-04-02.

European Parliament (EP) (2008), More science funding needed to meet CO_2 targets for car industry, Press Release, Industry, 15-01-2008. (http://www.europarl.europa.eu/sides/getDoc.do?language=EN&type=IM-PRESS&reference=20080111IPR18243)

European Union (EU) (2007a), Proposal for a Regulation of the European Parliament and of the Council: Setting emissions standards for new passenger cars as part of the Community's integrated approach to reduce CO_2 emissions from light duty vehicles, COM(2007) 856 Final.

European Union (EU) (2007b), Commission Staff Working Document – Accompanying document to the Proposal from the Commission to the European Parliament and Council for a regulation to reduce CO_2 emissions from passenger cars – Impact Assessment, SEC(2007)1724.

Evans, Leonard (2004), How to make cars lighter and safer, SAE Technical Paper Series, 2004-01-1172.

Financial Times (FT) (2008), Motor Industry Special Report, March 48.

Greene, David and John German (2007), Fuel economy: the case for market failure, Presentation at the Asilomar 2007 Conference on Transportation and Climate Policy, http://www.its.ucdavis.edu/events/outreachevents/asilomar2007/presentations/Day%202%20Session%202/The%20Case%20for%20Market%20Failure%20-%20Asilomar%20Aug07.pdf

Johansson, Olof and Lee Schipper (1997), Measuring the long run fuel demand of cars: separate estimations of vehicle stock, mean fuel intensity and mean annual driving distance, *Journal of Transport Economics and Policy*, 31, 277-292.

Jacobson, Mark. Z. (2002), Control of fossil-fuel particulate black carbon and organic matter, possibly the most effective method of slowing global warming, *Journal of Geophysical Research - Atmospheres*, 107(D19), 4410-4432.

Nieuwenhuis, Paul and Peter Wells (2006), CO_2 and company cars: the UK experience, Presentation at an IEEP – DG ENV Workshop, Brussels.

OECD/ITF (2008a), *Biofuels: Linking Support to Performance*, OECD/ITF, Paris, and JTRC Discussion Paper 2008-7.

OECD/ITF (2008b), *Oil Dependence: Is Transport Running Out of Affordable Fuel?* OECD/ITF, Paris, and JTRC Discussion Paper 2008-5.

OECD/ECMT/IEA (2005), *Making cars more fuel efficient: technology for real improvements on the road*, OECD/IEA, Paris.

OECD/ECMT (2003), *Reforming Transport Taxes*, OECD/ECMT, Paris.

OECD/ECMT (2007), *Cutting Transport CO_2 Emissions – What progress?* OECD/ECMT, Paris.

Palmer, Karen, William Oates and Paul Portney (1995), Tightening Environmental Standards: The Benefit-Cost or the No-Cost Paradigm? *Journal of Economic Perspectives,* 9, 4, 119-132.

Proost, Stef (2008), Full Account of the Costs and Benefits of Reducing CO_2 Emissions in Transport, JTRC Discussion Paper 2008-3.

Proost, Stef, Kurt Van Dender, Bruno De Borger *et al.* (2002), How large is the gap between present and efficient transport prices in Europe? *Transport Policy,* 9, 1, 41-57.

Raux, Charles (2008), How should transport emissions be reduced? Potential for emission trading systems, JTRC Discussion Paper 2008-1.

Small, Kenneth and Kurt Van Dender (2007a), Fuel efficiency and motor vehicle travel: the declining rebound effect, *The Energy Journal*, 28, 1, 25-51.

Small, Kenneth and Kurt Van Dender (2007b), Long run trends in transport demand, fuel price elasticities and implications of the oil outlook for transport policy, JTRC Discussion Paper 2007-16.

SMP – Sustainable Mobility Project, 2004, Mobility 2030: Meeting the challenges to sustainability, World Business Council for Sustainable Development. (http://www.wbcsd.org/web/publications/mobility/overview.pdf)

Stavins, Robert N. (1996), Correlated uncertainty and policy instrument choice, *Journal of Environmental Economics and Management*, 30, 2, 218-232.

Stern, Nicholas (2006), *The Economics of Climate Change: The Stern Review*, HM Treasury, London.

Turrentine, Thomas and Kenneth Kurani (2007), Car buyers and fuel economy? *Energy Policy*, 35, 1213-1223.

Verboven, Frank (1998), Implicit interest rates in consumer durables purchasing decisions – Evidence from automobiles, CEPR Discussion Paper 2069.

Weitzman, Martin (1974), Prices *vs.* quantities, *Review of Economic Studies*, 41, 4, 477-491.

West, Sarah and Roberton C. Williams III (2007), Optimal taxation and cross-price effects on labor supply, *Journal of Public Economics*, 91, 593-617.

REPORTS

EXAMINING FUEL ECONOMY AND CARBON STANDARDS FOR LIGHT VEHICLES[1]

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SUMMARY

Washington, November 2007

1. INTRODUCTION

Under the European Union's Voluntary Agreement with car manufacturers, average light-vehicle CO_2 emissions in 2004 were 12.4% below 1995 levels but appeared unlikely to achieve the 25% reduction needed to reach the 140 g/km target for "per vehicle" CO_2 emissions for 2008. The EU is now considering a regulatory approach to further reduce average vehicle emissions, in the form of CO_2 emission or fuel economy standards. Such standards have been used by a number of countries, including the United States (although US standards have been little altered since their 1975 promulgation), Japan, China, and several others; and those that have been in existence for some time - e.g. in the United States and Japan – have been successful in achieving their targeted levels of new vehicle fuel economy.

The purpose of this paper is to examine various aspects of fuel economy and carbon standards for light vehicles, including their rationale, methods of establishing stringency, regulatory structure and timing, with the hope of assisting the decision process for new standards. Because the Corporate Average Fuel Economy (CAFE) standards adopted by the US in 1975 are the longest-standing and most studied of the various standards now in existence, much of the focus of this paper will be on the US standards.

2. DO FUEL ECONOMY STANDARDS MAKE SENSE?

Fuel economy standards for light-duty vehicles have been widely promoted as an effective means of reducing oil consumption and, more recently, carbon emissions. They have been justified on the basis that vehicle manufacturers and purchasers do not seem to properly value fuel economy improvements that would easily pay for themselves in future fuel savings, and do not account for social benefits that would arise from reductions in oil use, such as improved energy security and reduced emissions of greenhouse gases.

Nevertheless, there is strong opposition to fuel economy standards, not only from automakers, automobile unions and auto enthusiasts but also from many in the economics community. This opposition centers around a range of arguments about the limitations of new standards and their impacts on oil use, public safety, consumer choice, vehicle markets, and the economy.

There is an extensive base of economics literature critical of fuel economy standards, and this paper will not attempt to discuss it in any detail. In summary, however, the two key economic arguments against such standards are:

1. They are economically inefficient and have costs to consumers and producers that greatly exceed their benefits; and

2. In reducing the cost of driving, they cause increased travel – the so-called "rebound effect" – that has externality costs (in terms of increased air pollution, congestion, and traffic injuries and fatalities) exceeding any societal benefits associated with reduced fuel use.

The economic efficiency arguments against fuel economy standards generally depend on the assumption that vehicle manufacturers and purchasers are economically rational and that there are no significant market failures in the market for new vehicles. It is argued that forcing manufacturers to build vehicles that are more efficient than the market demands will inevitably lead to market distortions and large economic losses.

The primary counterargument to this is that, for several reasons, society would choose higher levels of fuel economy than will private consumers:

1. **Society places more value on future benefits than consumers do.** Even for rational, well-informed consumers, society would choose higher fuel economy than private consumers will because private discount rates are much higher than social discount rates. For example, Gerard and Lave (2003) show that society (assuming a 4% discount rate) would be willing to pay about USD 400 more than a private purchaser (20% discount rate) for an increase in fuel economy from 22 to 25 miles per gallon.

2. **The net gains to consumers from increased fuel economy may be small, even when society gains a great deal.** Several US studies have estimated that the net benefits of fuel economy increases – lifetime fuel savings minus increased vehicle purchase price – are relatively small over a range of fuel economy increases. In other words, although fuel economy increases may be cost-effective, the economic reward is not large and consumers may be relatively indifferent to the increases – though society would favour increases because of their energy security, greenhouse emissions, and other benefits. With the large costs of redesigning vehicles to obtain higher efficiency, coupled with the technical risks associated with new efficiency technologies, automakers can be reluctant to undertake these investments in the face of such indifference. Further, automakers face market uncertainty about the extent to which their competitors will pursue greater fuel economy or instead use their resources (and available technology) to increase performance, add luxury features, and increase vehicle size and weight. Fuel economy standards reduce this uncertainty by demanding that all manufacturers pursue some minimum improvement in fuel economy.

3. **Consumers' aversion to loss will tend to make them wary of betting on fuel economy technology, whereas society's risk of loss is much lower.** The high level of uncertainty in the value to the consumer of fuel economy gains, coupled with the inherent loss-aversion behaviour of consumers, implies that consumers will tend to reject bets on fuel economy increases. Greene, German and Delucchi (2007) point out that fuel economy benefits are inherently uncertain because fuel economy levels actually attained by consumers can vary over a wide range; future fuel prices are highly uncertain (and a fall in prices will cut the monetary benefits of fuel savings); and consumers do not know with certainty how much driving they will do or how long their vehicles will last. The authors then apply loss aversion theory to show that an average consumer would decline an estimated fuel economy increase from 28 to 35 mpg even though its expected net present value is USD 405; aversion to

> the possibility of a financial loss outweighs the greater odds of a gain in this case. In contrast, society averages benefits across all vehicles and their drivers, reducing sharply its risk of losing the fuel economy bet.

Further, there is ample evidence that vehicle purchasers do not behave as “rational consumers”, at least in terms of how economists define such consumers. Surveys have shown, for example, that consumers virtually never attempt to evaluate the tradeoff between higher costs for fuel saving technology and money that would be saved from lower fuel bills (Turrentine and Kurani, 2004). They demand extremely rapid paybacks when they are asked explicitly how much they would be willing to pay to save a few hundred dollars a year from reduced fuel use. A survey sponsored by the US Department of Energy in 2004 found that consumers wanted to recover their higher vehicle costs within about two years.

The magnitude of the rebound in the developed economies – and its impact (from increased driving) on pollution, accidents effect, etc. – has declined over time with growing income. Recent estimates for the United States set the effect at about 10%; that is, a reduction in per-mile fuel costs will cause about a 1% increase in driving (Small and Van Dender, 2004).

The argument that any increased travel caused by the rebound effect will create costs well in excess of travel benefits can be countered by noting that, where this is the case, it is a problem of fuel pricing and should be solved by adjusting prices, not by forgoing policies that address other problems. Saying that increased travel creates high net costs is synonymous with arguing that transport fuels are seriously under priced (Gerard and Lave, 2003) or interventions to reduce accident or air pollution costs should be strengthened. This argument is especially potent in the United States, which has comparatively low gasoline and diesel prices because its fuel taxes are far lower than those in the EU countries. Whether US (or EU) fuel taxes are too low depends on the magnitude of externality costs, and there is little agreement about their magnitude. The US National Academy of Sciences estimated these costs at about USD 0.26/gallon in its 2002 examination of fuel economy standards (NRC, 2002), equivalent to about 1.5 cents/mile at the then-average fleet fuel efficiency of 17 miles/gallon. At the other end of the scale, Lutter and Kravitz (2003) estimated these costs at 10.4 cents/mile (even though they did not include costs for national security and global warming, which *were* included in the NAS estimate), equivalent to about USD 1.75/gallon[2]. Whichever of these estimates may be correct, one can argue that the appropriate policy response is not to forgo fuel economy standards but instead to correct the market distortions caused by under-pricing of fuel. In European markets, however, it is much harder to argue that the rebound effect will create costs in excess of the benefits of reduced fuel use - European tax levels on transport fuel are higher than even the upper estimates of externality costs.

Opponents of fuel economy standards have argued that they have caused terrible market distortions, pointing especially to distortions that have occurred in the US market for new vehicles. Fuel economy standards do distort the market; all regulations do, in some sense that is their purpose. However, the worst distortions that have occurred in the US market appear to have been caused by the unusual structure of the US standards (for example, the artificial division between cars and light trucks in the US system). Most of these distortions should be avoidable by paying careful attention to properly structuring a new standard…..see the discussion below (“Structure of a New Standard”).

In the United States, automakers and other opponents of more stringent CAFE standards have argued vigorously that the standards have seriously degraded highway safety. Past studies by the US National Highway Traffic Safety Administration (NHTSA) concluded that vehicle downsizing associated with the original US CAFE legislation caused upwards of 2 000 traffic fatalities yearly (Kahane, 2003), and CAFE opponents have argued that new standards would force vehicle weight downwards and cause a wave of new fatalities. This argument has been vigorously disputed, and an evaluation of its merits deserves *at least* a lengthy paper all its own. The primary counterarguments to the charge that new fuel economy standards will compromise safety are:

- New studies that separate the effect of size and weight changes in vehicle safety indicate that the increased fatalities detected in the NHTSA studies were due to reduced vehicle size rather than reduced weight (Van Auken and Zellner, 2003). These studies conclude that reducing the average weight of the light-duty vehicle fleet would actually lead to *improved* safety if average vehicle size – measured by wheelbase and track width – remained unchanged.

- Examination of the variation of fatality statistics across the fleet, coupled with a focus on the combined risk of vehicle to their own passengers as well as to the passengers of vehicles they strike, shows that vehicle design plays a more critical role than weight in vehicle safety (Ross and Wenzel, 2002) – for example:
    - Fatality statistics for vehicles in the same weight and size classes vary substantially; in particular, some of the inexpensive subcompacts exhibit twice the risk of safer subcompacts such as the Honda Civic and Volkswagen Jetta. Better-designed vehicles have safety records as good as their much larger counterparts.
    - Pickups and SUVs are about twice as dangerous as cars to vehicles that they collide with, apparently because of their high bumpers and rigid frames.

- A re-examination of the relationship between light-duty vehicle fuel economy and highway fatalities from 1966 to 2002 (Ahmad and Greene, 2005) indicates that, if anything, higher fuel economy is correlated with *fewer* traffic fatalities, not added fatalities.

It is quite certain that the argument about fuel economy standards and safety is not dead and will be vigorously argued in any future debate on new standards. In particular, concerns may be raised about the effect on overall fleet safety of mixing a new generation of lightweight vehicles with their older, heavier counterparts. However, arguments that fuel economy standards will automatically lead to reduced fleet safety should be treated with skepticism.

3. HOW AMBITIOUS SHOULD NEW STANDARDS BE?

Policymakers considering new fuel economy standards or their equivalent, e.g. CO_2 emission standards, must consider several aspects of a new standard, including its numerical fuel economy targets and their timing as well as the structure of the standard, that is, how the targets are assigned to different vehicles and different vehicle manufacturers. The magnitude of the targets is often the most contentious issue, but the timing and structure are equally important. The discussion of fuel economy targets that follows focuses primarily on the US fleet; it is followed by a discussion of how conditions in Europe may affect the setting of appropriate targets.

It would be useful if there were a way to calculate an optimum target level for a new fuel economy standard. Unfortunately, there is no such method. Instead, it may make sense to try a few different approaches to setting new standards to get a broad perspective for what options might be open to policymakers.

3.1. "Cost-effective" standards

A common method of identifying fleet targets for a new standard is to identify a fuel economy level that would create fuel savings over the vehicles' lifetimes that, at the margin[3], would be greater than the added cost of fuel saving technologies. For example, the US' National Academy of Sciences, in a recent study of fuel economy standards (NAS, 2002), identified "cost effective" fuel economy gains of 12-27% (depending on vehicle size) for passenger cars and 25-42 % for light trucks in the US' new vehicle fleet. The NAS targets were arrived at by establishing baseline vehicles and theoretically adding, one by one, a series of fuel-saving technologies in order of their cost-effectiveness (highest first), until adding the next technology on the list would cost more than would be saved in reduced fuel consumption. Using standard economic methods, future fuel savings were "discounted" to the present. Similar methods have been used by the Office of Technology Assessment in the early 1990s (OTA, 1991), and others.

This method is useful for getting a general sense for what is achievable by available technologies, but it has several problems. First, the method treats the analysis as if it had only two variables, technology cost and fuel savings. In this formulation, both the vehicle designer and purchaser are simply deciding whether adding fuel economy technology to a vehicle is worth the cost in fuel savings. In reality, however, all fuel saving technologies are dual purpose: they can be used to save fuel, or they can be used to gain something else – better performance, larger size, more luxury, or even greater safety – without having to use more fuel. Thus, an engine improvement that allows more power to be squeezed out of an engine can lead to a more powerful vehicle without increasing engine size, or a more fuel-efficient vehicle with a smaller engine and the same power. Or the vehicle designer can compromise and get some of each – more power and better fuel economy, but less than the maximum possible for each. See Box 1 for an illustration of the tradeoff between fuel economy and other vehicle features. Vehicle purchasers attach real value to the attributes that "compete" with greater fuel economy for the benefits of efficiency technology. Consequently, asking them to forgo improvements in these attributes in favour of higher fuel economy won't be "free", even though fuel savings may outweigh the technology costs.

A second concern with the method is that, as noted above, there is strong evidence that the great majority of vehicle purchasers simply do not perform even rudimentary analysis of the tradeoff between higher first cost and fuel savings over time (Turrentine and Kurani, 2007). In other words, the method by which analysts estimate "reasonable" levels of fuel economy improvements bears little relationship to how vehicle purchasers actually value fuel economy. Further, when consumers respond to surveys that ask direct questions about how they value fuel savings, their answers imply that they want any added purchase cost to be repaid within just a few years. If translated into potential fuel economy savings, this criterion would yield very little improvement. For example, the NAS did an alternative analysis of fuel economy potential using 3-year payback as a criterion. The average improvement was estimated to be -3 to 3% improvement for cars and 2-15% for light trucks (NRC, 2002).

A third concern is that this method has tended to focus only on currently available technology and generally fails to account for likely improvements in technology performance and cost over time, and the development of new technology that conceivably might play a significant role during the time period of the analysis (if this is 10 years or more). This leads to conservative results, although these factors are hard to quantify.

Finally, the targets identified by this method depend on:

- fuel prices over the lifetime of the vehicles (highly uncertain);
- the discount rate chosen to represent the value of savings in the future (contentious);
- estimates of technology costs (hotly debated); and
- whether or not the value of externalities such as climate change damages and energy security costs (also highly contentious) are included in the calculation.

For example, repeating the NAS analysis using fuel prices more in line with recent US prices - USD 2.00-USD 3.00/gallon – raises the cost-effective increase to 30-50% for the fleet.

3.2. “Top runner” method

The Japanese essentially avoided this debate by setting standards based on the idea that vehicles that represent the “best in class” of the current fleet – weeding out vehicles that are anomalous in performance or that have especially expensive technology – can be exemplars of what the average vehicle could be in 8 to 10 years. Japan used this “top runner” method to identify a series of fuel economy targets for vehicles in different weight classes for its 2010 standards. This represented a 22% increase in fleet fuel economy over the regulatory period (assuming there would be few changes in average vehicle weight over the period). Although this method (or at least the Japanese version of it) is conservative in that it ignores the potential for newer technologies (such as hybrid drivetrains) to achieve reduced costs and become far more common, it does provide another potential fuel economy target that can inform the ongoing debate. Further, the method can be extrapolated further into the future by conjuring up a vision of a “leading edge” vehicle, that is, the best *mass-market* vehicle that could be available a number of years in the future and call for the fleet average several years later to achieve the same fuel economy as these “top runners”.

The US Environmental Protection Agency has performed “top runner” analyses for the new 2006 US car and light-truck fleet (Heavenrich, 2006). Their analysis answers the question: “What would the fuel economy of the new fleet be if the current fleet were replaced by:

1) the best four vehicles in each size class (there are nine size classes in both the car and light-truck fleets);
2) the best dozen vehicles in each size class; and
3) the best dozen vehicles in each inertia weight class?”

The answer is that the car fleet would be 17-20% more efficient, and the truck fleet would be 14-24% more efficient. However, the fleet would be somewhat slower (for the largest boosts in efficiency, cars would take 10.2 seconds to go from zero to 60 mph, versus the actual fleet’s 9.5 seconds, though the higher-efficiency trucks would actually shave a second off of their times). Trucks would move sharply away from 4-wheel drive, which significantly reduces efficiency; the share of hybrid drivetrains would grow sharply, from 1.6 to 14% for cars and from 1% to 36% for trucks (but only 5% for cars and 12% for trucks for the next best case, with only a 1 mpg loss in fuel economy); and many automatic transmissions would be exchanged for continuously variable transmissions and manual transmissions. Unfortunately, this mixing of the effects of efficiency technology and utility-oriented vehicle attributes limits the usefulness of this type of analysis in setting standards – but it can offer a useful added perspective if interpreted cautiously.

Let’s try to identify what the “top runners” for the US fleet might be in the year 2020. Over the next 10-15 years, large and small changes in the technology embedded in cars and light trucks could have a dramatic impact on fuel economy. There could be a greater than 50% improvement in fuel economy for a “leading edge” vehicle with conventional drivetrain, and perhaps as much as a doubling in fuel economy for such a vehicle with a hybrid drivetrain…assuming that the technology is used primarily for fuel economy rather than for performance and other attributes. To understand fuel saving technology and the potential for improving it, it helps to understand a bit about why vehicles need energy and power and how they obtain it. This is discussed in Box 2.

The major part of industry’s focus on raising fuel economy has been on the power-train, but vehicle load reduction can play an important role. As noted in Box 2, reducing vehicle weight through sophisticated design and use of enhanced materials – high-strength steels, aluminum, plastics and composites – has considerable leverage on vehicle efficiency because weight reduction reduces both inertial loads and rolling resistance losses. The US Department of Energy’s Vehicle Technologies Program has established the ambitious goal for 2015 of reducing the weight of the vehicle structure and subsystems by 50%[4]. However, over the past decade, a considerable portion of the weight reduction potential of structural redesign and materials substitution has been used for improving vehicle stiffness and structural strength rather than for reducing weight. These attributes yield consumer benefits in better crash protection and a more solid “feel”, which is highly valued by vehicle buyers. Assuming that some further gains in these attributes will be sought, weight reductions of 20% or so may be a more realistic estimate for what might be achieved by 2020, assuming strong pressure to maximize fuel economy. More drastic reductions might be possible if vehicle structures of carbon composites become practical for mass market vehicles in this time-frame. A 20% weight reduction could yield a 12-14% fuel economy improvement if vehicle performance was unchanged.

Improvements in aerodynamics are hard to predict because aerodynamic drag is closely tied to vehicle appearance, and consumer acceptance becomes a key issue. However, relatively subtle changes involving smoothing out the vehicle’s undercarriage, reducing body gaps, and making small changes in the vehicle’s rear end can obtain important benefits, and the best coefficient of aerodynamic drag in the current fleet (0.26) is obtained by the Lexus LS430, which is quite conventional in appearance. By 2020, a C_D of 0.22 may be possible for mass-market cars with side mirrors replaced by cameras, continued improvements in manufacturing tolerances for body panels, smoothing of vehicle undersides, and careful aerodynamic design.

Reducing rolling resistance by improving tyre design and materials is also possible. However, a tyre’s design and materials affects not only its rolling resistance characteristics but also its resistance to wear and its handling performance, and there can be tradeoffs among these characteristics. The first generation Prius had tyres with a rolling resistance coefficient C_R of 0.006, an excellent value, but consumers complained of their rapid wear and they were replaced with tyres that were slightly less efficient but that had better wear and handling characteristics. There is little publicly available information about tyre research; a goal of achieving widespread use of tyres averaging about a 0.006 C_R should be considered an educated guess.

Engines have improved dramatically over the past two decades, and they will continue to improve. Recent presentations by a number of automakers and suppliers at the 2007 Society of Automotive Engineers’ World Congress presented a fairly unified picture of the potential future evolution of the gasoline engine. Currently, the most efficient gasoline engines have direct injection fuel systems with continuously variable valve lift and timing on inlet and exhaust valves and variable intakes. Because downsizing will yield significant benefits in efficiency, a “best-in-class” 2020 gasoline engine will probably use a turbocharger with variable geometry vanes; larger engines will shut down a third or half of their cylinders at low load. Improvements in emissions control should allow high air/fuel ratios (“lean burn”) that will further improve efficiency, although this will likely require further reductions in the sulfur content of gasoline. Continued improvements in valve controls and in-cylinder monitoring should allow use of more efficient thermodynamic cycles (than the current Otto cycle) under some load conditions, bringing gasoline engines much closer to diesels in efficiency. Overall, efficiency gains of about 25% should be possible from engine improvements alone.

Advanced direct injection turbocharged diesel engines currently are about 30% more efficient than naturally aspirated gasoline engines of similar performance. Diesels will improve further with improved combustion chamber designs and higher pressure injection systems, but their efficiency advantage relative to gasoline engines should shrink as gasoline engines become more diesel-like.

Hybrid drivetrains will certainly be an important part of the fleet in 2020, but the magnitude of their role is highly uncertain, dependent on fuel prices and on reductions in component costs. Hybrid sales have grown rapidly since the 1999 introduction of the Honda Insight. In the near future, a variety of new hybrid systems, from simple stop-start mechanisms to the General Motors/Allison two-mode full hybrid system, will be introduced to the fleet. However, the more efficient systems currently can pay for themselves with fuel savings only if gasoline prices remain high and only for high mileage drivers who spend much of their time in urban stop-and-go driving, where hybrids maximize their efficiency advantage over conventional vehicles. The key to making them into a dominant technology is to shift to lithium ion or other energy storage technologies that may be less expensive than current nickel-metal hydride batteries (which have limited cost-reduction potential because of high nickel prices), as well as driving down the cost of their expensive electronic controls.

Although plug-in hybrids – hybrids with larger batteries and motors, that can fuel some of their daily miles with electricity from the grid – are not yet commercially available, they might begin to play a role in the new vehicle fleet by 2020 if their battery costs are driven down. Two factors can help accomplish this: first, although their batteries are considerably larger than those used in today’s hybrids, their battery costs will not scale linearly with their storage capacity; and second, batteries will achieve substantial economies of scale as production ramps up. A new report by the California Air Resources Board (Kalhammer, 2007) projects that lithium ion batteries, capable of a 20-mile range (about 7 kWh of capacity), would cost about USD 5 000 at a production rate of 20 000 batteries/year and less than USD 3 000 at a production rate of 350 000/year. However, this report’s optimism about the likelihood that these batteries can last a vehicle lifetime is controversial.

Although there will certainly be an argument about what a 2020 “leading edge” or top runner midsize passenger car might look like, a reasonable guess – *assuming a very strong focus on fuel economy, coupled with a very vigorous R&D program* – might be as follows:

- Full hybrid drivetrain, assuming battery and electronics costs are driven down sufficiently for hybrids to become fully mainstream;
- Curb weight reduced about 20% from today’s cars;
- Rolling resistance of the tyres at 0.006, compared to about 0.008 for today’s mainstream tyres;
- Aerodynamic drag coefficient 0.22, compared to today’s best-in-class 0.26;
- Downsized gasoline engine with full (possibly camless) valve control, mode switching from Homogeneous Charge Compression Ignition to Atkinson cycle to Otto cycle depending on load, turbocharging and perhaps super-charging.
- Automated manual transmission.

A 2003 Massachusetts Institute of Technology (MIT) study estimated[5] that such a car would get about 60 (adjusted) mpg (92 gCO_2/km) compared to a 26 mpg car (212 gCO_2/km) in 2001, a 130% improvement; a conventional counterpart, without the hybrid drivetrain, would obtain about 42 mpg (131 gCO_2/km), about a 60% improvement (Heywood, 2003). A more recent MIT study (Kromer and Heywood, 2007) used a 2005 Camry 2.5 litre, 4-cylinder engine as its baseline engine and more sophisticated engine mapping and transmission optimization. For a 2030 advanced gasoline vehicle using similar assumptions about vehicle load reduction as the 2003 study, it found approximately the same percentage fuel economy improvement for the vehicle with a conventional drivetrain and naturally aspirated engine; 82% improvement for the same vehicle with a turbocharged (and radically downsized) engine; and 187% for the vehicle with a parallel hybrid drivetrain[6].

The 2007 MIT study also examines a 2030 diesel vehicle, but does not compare it to a 2005 diesel. However, the 2030 diesel attains an emission rate of 111 gCO_2/km (Kromer and Heywood, 2007), which represents about a 55% increase in fuel economy over a 2005 diesel with the same characteristics (other than the engine) as the 2005 baseline gasoline vehicle[7].

3.3. Adding it up, for the US light-duty fleet

The availability of NAS-style calculations of “cost effective” fuel economy targets and visions of future “top runner” or “leading edge” vehicles will not add up to a certain view of a “correct” fuel economy target, but they are valuable in informing a decision about targets. The suggestion here is to combine the perspectives gained from these analyses with a careful consideration of how urgently society needs to combat climate change and the economic security problems associated with US dependence on an unstable fuel supply.

Policymakers must also carefully consider their views on consumer freedom of choice, because a future shift to faster acceleration capability and increased weight (associated with more size or other features) will significantly reduce the fleet’s fuel economy improvement potential. Thus, the NAS-style calculation offers a way to get a sense for a conservative view of what an “economically rational” consumer might want if (s)he did not care about getting a bigger or more powerful vehicle - or if policymakers were determined to push the fleet away from the “performance race” characteristic of the past twenty years. On the other hand, fleet targets might be more ambitious if auto-makers could promote smaller cars by emphasizing safety and comfort in their design. Similarly, growth in sales of four-wheel and all-wheel drive – which have significant weight and fuel economy penalties – might conceivably slow and even reverse as the perceived safety and traction advantages of these systems shrink with universal penetration of electronic stability control and traction control – which do not carry an efficiency penalty. A reasonable conclusion that could be drawn from these considerations is that the type of fuel economy improvement goal derived from an NAS-style calculation – about 30-50% improvement over a 12-15 year period – may be a decent starting point for negotiations. Technological optimism and a strong sense of urgency in reducing oil use and GHG emissions would tend to push the goal upwards; a hard-headed realism about trends in performance and other efficiency-reducing vehicle attributes would tend to push in the opposite direction.

For a longer-term and less conservative perspective, projecting future leading-edge vehicles provides a good view for what developing technology could do for fleet fuel economy. For the longer term – say to 2025 or 2030 – it makes sense to take a much stronger position towards improving fleet fuel economy. In this time-frame, a doubling of passenger car fleet fuel economy, and somewhat less for the light truck fleet (because towing requirements limit the benefit of hybrid drivetrains), would be quite possible, assuming either strong reductions in the cost of hybrid drivetrains or simply the willingness to treat reduction in oil use and GHG emissions as societal requirements, in the same way that reductions in emissions of criteria pollutants are treated. A more conservative goal of a 50-60% improvement would reflect less willingness to impose costs on vehicle purchasers and/or less technological optimism.

An important added consideration will come into play if it becomes important for the world to make a strong shift to oil substitutes. The most straightforward substitutes are alternative liquids from unconventional oil sources (e.g. tar sands, heavy oil), natural gas and coal. These will yield substantial increases in "per gallon" emissions of greenhouse gases, and large increases in vehicle efficiency will be needed to avoid large increases in total emissions. Biomass liquids can represent a strong alternative if they can be obtained from cellulosic materials, but they will provide a large share of transport fuel requirements only if fleet efficiency is greatly improved. Also, hydrogen and electricity have severe on-board fuel storage problems that are likely to be solved only if less fuel (or less battery storage capacity) is needed – that is, only if overall vehicle efficiency is very high. In other words, greatly increased vehicle efficiency is a crucial requirement if the world needs to move dramatically away from its dependency on imported oil.

3.4. Application to Europe

The above discussion is quite applicable to an analysis of new fuel economy standards for the European Union, but several adjustments are necessary. The European light-duty fleet and the economic and policy environment that affects it have important differences from conditions in the United States. Among the most important differences:

- The physical makeup of the European fleet is quite different from the US fleet:

    - Engine power (for vehicles of the same size) tends to be considerably lower, on average, in the European fleet;
    - Diesel engines make up close to 50% of new vehicle sales in Europe, while light duty diesel sales are negligible in the US;
    - Manual transmissions are the norm in Europe, automatic transmissions in the US;
    - Light trucks form a small part of the new vehicle fleet in Europe, and over half the new vehicle fleet in the US.

- Fuel prices are far higher in Europe, at about double those in the US.

- Vehicles are driven more intensively in the US – at about 13 000 miles/year *vs.* 7 000-9 000 miles/yr in Europe.

- Vehicle prices, and the prices of efficiency technologies in Europe tend to be higher than those in the US because of substantial value-added taxes.

- In Europe, a large share of light vehicles is purchased by companies and institutions, often to be resold within two to three years. According to Kageson (2005), company cars comprise 30-50% of new car sales in Germany, the Netherlands, Sweden and the United Kingdom.

The higher fuel prices in Europe will tend to make new fuel efficiency technologies more cost effective than they would be in the US, but this advantage is substantially reduced by the lower intensity of use in Europe and the somewhat higher prices for the technologies (because of value-added taxes).

The technology differences between Europe and the US should reduce somewhat the short-term improvement potential for the European fleet. Manual transmissions already are substantially more efficient than automatics, so the improvement potential of continuously variable transmissions and improved automatic transmissions is significantly lower in the European fleet; however, there remains some efficiency potential for manual transmissions in moving towards 6-speed transmissions from the current 5-speed. Also, the improvement potential of the current generation of direct injected diesels in the European fleet is lower than the potential for gasoline engines.

Ricardo has projected that a baseline 2003 diesel car could obtain a CO_2 emissions (and fuel consumption) reduction of about one-third, by shifting to a mild hybrid drivetrain (integrated starter-alternator with motor assist, similar to the Honda system used in its Civic), advanced transmission, and substantially downsized engine, at a cost of about 3 000 euros. At a lower cost of about 1 300 euros, a 23% emissions/consumption reduction could be obtained with a 42-volt belt hybrid, advanced transmission, and a lesser degree of engine downsizing (Owen and Gordon, 2003). Other measures, such as weight reduction, improved aerodynamics and low friction tyres, could reduce emissions and oil consumption further. The implication is that a fleet CO_2 emissions rate target of 130 g/km, and probably 120 g/km as well, is obtainable; the real issue is how to structure a standard that can achieve the target in a manner that doesn’t distort the market, and how to define a reasonable timetable for attainment.

4. THE STRUCTURE OF A NEW STANDARD

The economic impacts of a new standard, and perhaps even its fuel economy improvement potential, will depend not only on the stringency of the standard (the MPG target) but also on its structure – the method by which fuel economy targets are distributed among competing manufacturers, and the boundaries and definitions that identify the types of vehicles to be regulated. Some examples of regulatory structures currently in use are:

- Application of a single target to all passenger cars in each auto-maker’s fleet, regardless of size or other attributes (US passenger cars);
- Identification of a target as an average for the entire fleet of vehicles manufactured by all auto-makers (EU Voluntary Agreement, though applied separately to European, Japanese and Korean manufacturers);
- Identification of targets based on vehicle attributes, e.g. weight (Japan, China) or “footprint” (wheelbase x track width, US light trucks).

Another important aspect of regulatory structure is the extent to which manufacturers can average the fuel economy achieved by each vehicle type across their fleets. Currently, no standard allows trading of credits (obtained by overshooting fuel economy targets) among different auto-makers (although the Voluntary Agreement implicitly does this by requiring only the achievement of a target across multiple companies), and there are different schemes for trading within each manufacturer’s fleet. The US allows full averaging within each of three groups of vehicles (domestic passenger cars; imported passenger cars; light trucks) for each auto-maker. Japan allows averaging within a manufacturer's fleet, but credits for topping a target in one weight class are reduced by half when applied to another weight class. China demands compliance for every weight class, with no averaging between classes.

Opponents of US fuel economy standards have long complained about the various market distortions that the current standards appear to have created, including:

- The virtual elimination of the station wagon, and its replacement by minivans and sports-utility vehicles that provide similar utility but generally obtain lower fuel economy;
- The advent of very large SUVs whose weight puts them outside of the light-duty fleet (as defined by the regulation), and free from CAFE standards;
- The movement of larger (3/4 and 1 ton) pickup trucks over the CAFE weight limits;
- Among the "Big Three" US manufacturers, pricing of some small car models that appeared to be below production cost;
- Deliberate foreign sourcing of key components of some full-size cars and their resulting inclusion into the "import" fleet.

These distortions appear to have little to do with the stringency of the standards, and much to do with their structure, in particular: the separation of passenger cars and light trucks with very different fuel economy targets (the light truck target is far more lenient); the separation of "domestic" and "import" fleets, each of which must meet the assigned targets; and the assignment of a uniform fuel economy target to every auto-maker, regardless of the mix of vehicles they produce. For example, the car/truck separation, with light trucks having a much lower standard (20.2 mpg *vs.* 27.5 mpg for cars), produced a strong incentive for auto-makers to find a way to move their least efficient passenger cars into the light truck fleet. This incentive should not take sole responsibility for the rise of strong markets for minivans and SUVs, however. Minivans turned out to be extraordinarily attractive vehicles for suburban families, and SUVs were terrific for the auto-makers' bottom lines – the early SUVs were relatively simple modifications of pickup trucks, relatively inexpensive to manufacture, and could be priced at a large premium to their manufacturing cost.

Many of the problems of the current US system could be overcome by eliminating separate domestic and import fleets (which are an anachronism in an age of multinational auto-makers). This would ensure that artificial weight ceilings do not allow vehicles to escape from compliance, and move away from uniform standards to standards based on the attributes of each auto-maker's fleet, as long as the attributes are reasonably related to vehicles' fuel economy potential. The central idea of attribute-based standards is that they provide individual fleet targets to each auto-maker which reflect the degree of difficulty faced by that auto-maker in order to comply with the standard. This can greatly reduce a problem associated with the current standards: manufacturers of small vehicles may be able to comply with the standard without any action to improve efficiency design and technology, while manufacturers of larger vehicles, or a mix of vehicles, may have to take strong measures for compliance. It also may allow combining car and light-truck fleets, because such a standard can shrink the difference in "degree of difficulty" in compliance faced by cars and light trucks – the primary reason for keeping the fleets separate. Note that policymakers might find it politically impossible to set standards that some domestic manufacturers could not comply with – so that attribute-based standards, by evening out the degree of difficulty faced by different manufacturers, can allow policymakers to set a more stringent standard than would be possible if the standard demanded the same target for each manufacturer.

The attribute most closely related to fuel economy is vehicle weight, and Japanese and Chinese fuel economy standards are weight-based standards (that is, auto-makers producing larger, heavier vehicles have lower fuel economy targets than those making primarily small, lighter vehicles). Studies of the US passenger car fleet show that the relationship between curb weight and vehicle fuel consumption is quite strong. Figure 1 shows a plot of fuel consumption, in gallons/100 miles, *versus* curb weight in pounds, for the 1999 US new passenger car fleet. The strength of the correlation implies that a weight-based standard is likely to be reasonably uniform in the degree-of-difficulty it applies to a diverse set of auto-makers (although some companies that stress high-powered sports cars would tend to face a more severe test with this type of standard, or virtually any other). Further, although certain characteristics of light trucks (for example, their boxy shape) tend to make them less fuel-efficient than passenger cars of equal weight, the difference is not especially strong. Figure 2 shows the fuel consumption *vs.* curb weight correlation line of the 1999 US light truck fleet, superimposed on the passenger car plot. As seen in the figure, a fuel consumption standard applied to both fleets combined seems practical.

Figure 1. **Fuel Consumption, gallons/100 miles *vs.* Curb All cars, 1999**

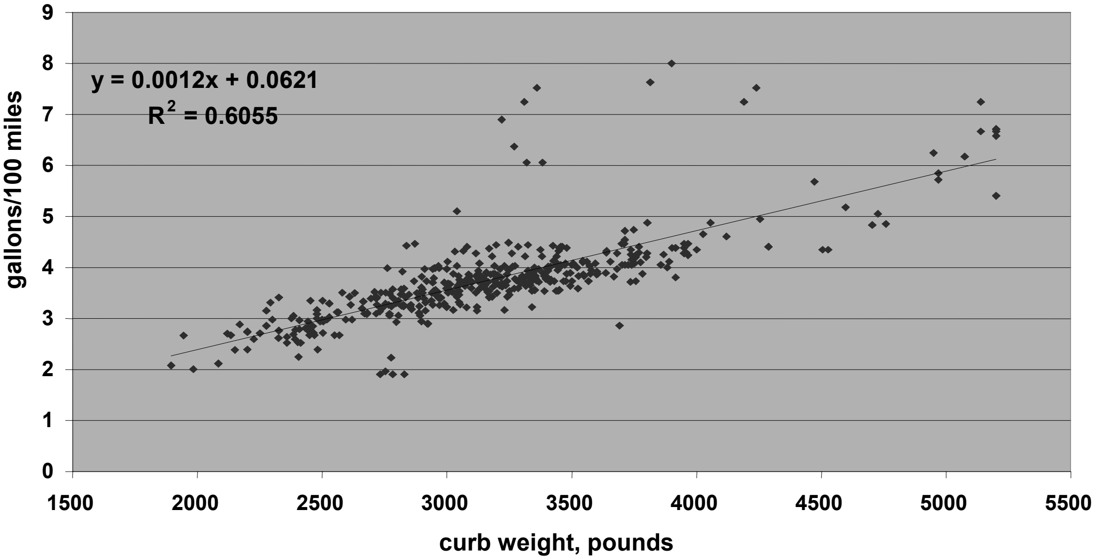
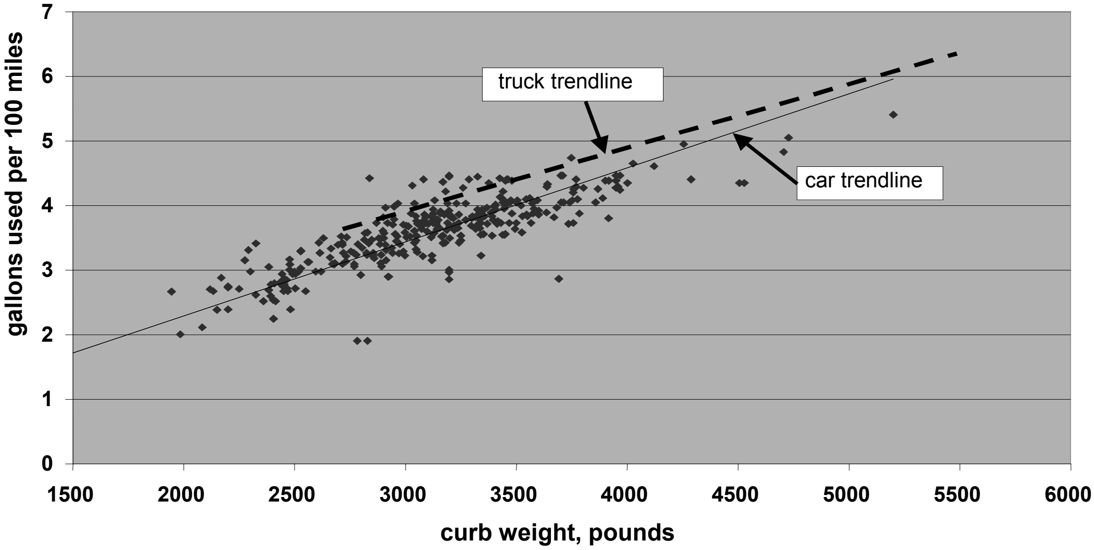


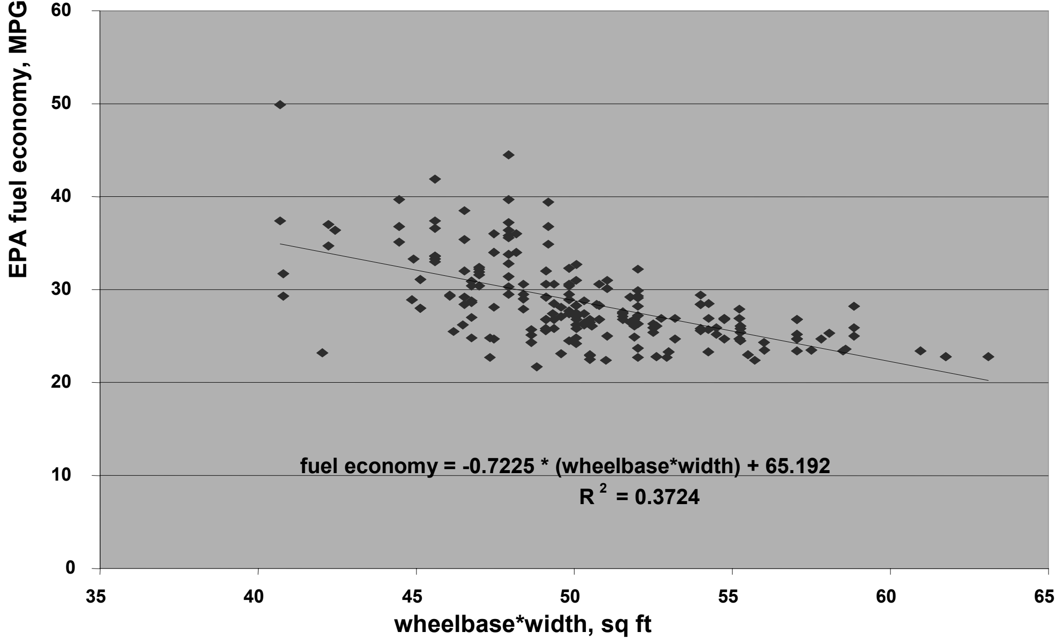
Figure 2. **Automobile Fuel Consumption, gallons/100 miles, *vs.* curb weight, with truck trendline superimposed**
Sales>1000



An important shortcoming of weight-based standards, however, is that they tend to reduce or eliminate weight reduction as a strategy for compliance – since reducing weight, while improving fuel economy, will make the vehicle's fuel economy target more stringent, with no net regulatory benefit to the company if the targets are set in proportion to the correlation trendline. Weight reduction can be an important component of fuel economy improvement – obviously, since fuel economy and weight are so strongly correlated. Thus, weight-based standards limit the degree of improvement that a new standard can demand. Although fuel economy targets based on vehicle weight can be set to provide some incentive to reduce weight – by deliberately reducing the stringency of standards for lighter-weight vehicles – the effectiveness of this measure will be limited by the need to avoid severe market distortions.

In setting new standards for US light trucks, NHTSA chose standards based on a vehicle's "footprint" – track width multiplied by wheelbase. This footprint is much less closely correlated with fuel economy than is vehicle weight – in statistical terms, a plot of fuel economy *vs.* weight for the 1999 passenger car fleet (Plotkin, Greene and Duleep, 2002) had an R^2 of about 60%, *vs.* about 37% for footprint (see Figure 3). However, footprint is attractive as the basis of a standard because it preserves the incentive to reduce weight; it resists distortion – any tendency to increase either track width or wheelbase will be limited by the need to essentially redesign the vehicle (not the case with weight); and because increasing either of these dimensions would tend to be beneficial to vehicle safety. Wider track width will reduce a vehicle's potential to roll over, and a longer wheelbase may provide more space for crash management and improve directional stability.

Figure 3. **Fuel economy vs. wheelbase x width, 1999 cars > 5 000 sales**



Attribute-based standards are favoured by some because they tend to equalize the degree of difficulty of meeting fuel economy targets among competing manufacturers, regardless of the size mix of vehicles they produce. This feature of attribute-based standards may not, however, be seen as a positive factor by all groups. Vehicle mix is an important determinant of fleet fuel efficiency, and many would like to exert pressure on manufacturers to shift their mix towards smaller, more efficient vehicles. Uniform standards such as those in the United States do exert such pressure, while attribute-based standards do not. However, there is no evidence that the US standards have been effective in pushing the fleet mix towards smaller vehicles, and there is little expectation that such a standard, if applied in Europe, would succeed in significantly changing the mix there either.

5. TIMING OF A NEW STANDARD

The question of *when* fuel economy targets must be achieved is as important as how stringent the targets should be. Companies adopting a new technology will have to go through a product development process to fit the technology to its vehicles. They will want to introduce the technology cautiously: introducing it into a limited number of models, gauging its performance over a few years, and then – if the introduction is successful – rolling it gradually into the fleet as model redesigns are scheduled. Product development will take at least two or three years, *after* the technology is deemed ready to leave the laboratory. Proving the product after its initial introduction (in a limited number of models – sometimes just one) will take another two to three years; and spreading the technology across the company's fleet will likely take a minimum of five more years.

Companies adopting a commercial technology may shrink this timeline, but the degree to which they can move more quickly depends on a number of factors. These include overall industry experience; whether the technology is an "add on" component or must be carefully integrated into vehicle systems; and whether the technology is owned by a competing automaker or by a supplier capable of providing extensive design consulting.

Translating the above into a schedule for moving *multiple* technologies into the fleets of multiple vehicle manufacturers is not straightforward, and there does not appear to be much literature on the issue of scheduling for fuel economy standards. Nevertheless, it appears that regulators should allow about 10 to 12 years for a standard with targets based on technology already introduced into the commercial marketplace. More time should be allocated for rigorous targets, requiring redesigns that might strongly test consumer preferences if the targets are based on an underlying assumption that the entire fleet of new vehicles is extensively redesigned. Shorter periods would be reasonable for intermediate targets that could be satisfied with redesign of only a fraction of the fleet or with less extensive changes to most models.

The EU faces a somewhat different challenge from the one that faces the US, which currently is debating standards that would presumably require redesign of the entire fleet over a time period of 12 years or more. The European industry clearly will not achieve the 140 g/km CO_2 target set for 2008, and current discussion of a target for 2012 focuses on 130 g/km, a 13% reduction in emissions (or 15% increase in fuel economy) if the industry emissions average is around 150 g/km for the 2008 model year (as predicted by Kageson, 2005). This is a quite ambitious target for such a short time period. Although a fleetwide target of a 15% fuel economy improvement probably could be achieved with a redesign of about half of each manufacturer's fleet *and* an attribute-based system that narrowed the differences in degree-of-difficulty among competing automakers, four years is a short period to achieve such a redesign. On the other hand, some have argued that the industry has been well aware for a number of years that greater effort at fuel economy improvement is required and has failed to take adequate measures to achieve the current 2008 target.

6. ON-ROAD VERSUS TESTED FUEL ECONOMY

As currently structured, fuel economy standards will improve the *tested* fuel economy of the vehicle fleet. The actual on-road fuel economy of the fleet will tend to follow the direction of these tests, but with important differences that should be understood in considering new standards.

The US Environmental Protection Agency fuel economy tests involve operating the vehicle on a dynamometer – a sort of treadmill for cars – while a driver uses the accelerator and brake to match a speed/time profile called a driving cycle. There are two profiles on the test, a relatively slow cycle designed to simulate city driving, and a faster one designed to simulate highway driving. However – partly because of the limited capabilities of dynamometers at the time the tests were designed – both driving cycles are "gentle" cycles with modest rates of acceleration and braking, and the highway cycle never tops 60 mph. The tests are conducted with heating, air conditioning, lights and other accessories turned off, and the temperature is held at 68-86^{o}F. To obtain an "average" fuel economy, it is assumed that 55% of driving is on the city cycle and 45% on the highway cycle, with the average calculated by applying these weights to the vehicle's fuel *consumption* (the inverse of fuel economy) on the cycles.

EPA quickly discovered that the test gave fuel economy values that were considerably higher than drivers were actually obtaining, and, using the data available at the time, reduced the city test result by 10% and the highway result by 22% for the fuel economy estimates actually communicated to consumers. The value calculated this way is the one that appears on the window sticker of new cars and light trucks. However, even this adjusted fuel economy has proved to be optimistic for most drivers[8], especially as congestion has spread, highway speeds have increased and air conditioning has become almost universal. EPA has instituted new requirements for the "window sticker values" on new cars, to be based on a series of five driving cycles. Some of these are driven with air conditioning on or at cold temperatures (20^{o}F); some duplicate driving that is considerably faster (up to 80 mph) and more aggressive (2.5 times the acceleration on the original tests) than the original two cycles. This new method is expected to reduce estimated city fuel economy values by an average of 12% (and a maximum drop of 30%), and highway values by 8% (25% maximum) (Edmunds, 2007).

Although there remain doubts about whether the new testing series will yield accurate results, they will *at least* take some account of measures that manufacturers can take to improve "real world" fuel economy, but that will not make a difference on the formal two-cycle test. For example, improving the efficiency of the air-conditioning system, insulating the vehicle or adding special coatings to the windows to reduce heat gain during the summer will all improve actual fuel economy but will be ignored by the two-cycle test. In other words, automakers that incorporate energy-saving designs that will not "count" on the test will at least be rewarded by having the benefits of these measures appear on the sticker.

If new standards are formulated, this modest incentive could be strengthened by awarding credits towards satisfying the standards for the "invisible" technologies and designs. Although it might seem more logical simply to change the official test driving cycles to reflect these factors accurately, such a change is problematic without considerably more confidence in the new tests.

Europeans face precisely the same issue regarding the difference between tested fuel economy and actual on-road values. The New European Duty Cycle (NEDC), used to test fuel economy, is a bit slower than the US combined city/highway cycle but is similar, including its failure to include air-conditioning loads.

7. MAINTAINING FUEL ECONOMY “AFTER THE SALE”

In general, fuel economy standards have been aimed at new vehicles, with no attempt to affect what happens to vehicles after they are sold.

Vehicle fuel economy can degrade significantly after a vehicle is sold. Some of the causes are:

- Under-inflation of tyres, which increases rolling resistance (and, because the added resistance causes more tyre heating, can adversely affect safety).
- Replacement tyres generally are less efficient than original equipment tyres. Automakers have a strong incentive to install high-efficiency tyres to maximize reported fuel economy values. There is no rating system for tyre efficiency, however, and no way for the vehicle owner to know the added “price”, in increased fuel costs, of a less efficient replacement.
- Poorly maintained vehicles will lose fuel economy through loss of engine efficiency.
- Added weight from heavy materials left in the trunk add to inertial losses, and vehicle body add-ons, such as ski and bicycle racks, add weight and reduce aerodynamic efficiency.
- Driving style greatly affects fuel economy. As noted previously, aerodynamic loads grow with the square of velocity, so high-speed driving can be very inefficient, and rapid acceleration and failure to stay even with the flow of traffic – demanding frequent braking and acceleration – also reduces fuel economy.

Technology requirements can address some of these issues. Requirements for automakers to incorporate tyre safety warning systems should reduce the incidence of severely underinflated tyres; however, the current US requirements do not demand actual measurements of tyre pressure, so mild underinflation is unlikely to be affected.

Efficiency requirements for tyres may be regulatory overkill, but NHTSA or EPA (and the EU for Europe) could try to develop a tyre efficiency rating and labelling system that communicates the likely value of excess fuel use over the tyre’s lifetime.

Another possibility is to give a fuel economy credit to vehicles that incorporate real-time fuel economy indicators on their vehicles’ dashboards. US, European and Japanese studies have indicated that fuel economy improvements on the order of 10% or more can be obtained if drivers are aware of the effects of their driving style on efficiency and adjust their driving accordingly (ECCJ, 2003, ECMT/IEA, 2005). Similarly, policymakers might consider awarding credits for “economy” switches for automatic transmissions that optimize shift points for fuel savings – although driver use of such switches should be studied to verify their value.

Vehicle inspection systems tied to emissions and safety should tend to reduce some of the maintenance problems, but these inspections are limited in geographic coverage and may be a difficult sell, politically. Furthermore, convincing vehicle owners to remove unnecessary material from trunks and dismantle detachable vehicle racks when not in use may be difficult, though it certainly is worth an information campaign to communicate just how much fuel these changes can save.

8. COMPLEMENTARY POLICIES

Vehicle purchasers generally can choose among a wide range of features that affect fuel economy and CO_2 emissions, both across the fleet and within individual vehicle categories and even specific models. These features include vehicle size, fuel type (diesel or gasoline), engine power (with the same model, there usually are two or more engine options), type of transmission, luxury accessories, choice of two-wheel or four-wheel drive, etc. Unless vehicle manufacturers sharply restrict consumer choice, satisfaction of fuel economy and CO_2 emissions standards depends on *both* the manufacturers' design and technology choices *and* on consumer purchasing decisions favourable to vehicle efficiency. Consequently, the market environment influencing vehicle choice decisions – fuel prices, consumer knowledge, vehicle sales taxes and registration fees, advertising, etc. – will play an important role in determining the degree of difficulty faced by vehicle manufacturers in complying with these standards.

A key criticism of US standards has been that they exist in a policy environment distinctly unfavourable to consumers' choice of improved efficiency – with low fuel prices and sales and annual taxes that do not distinguish between efficient and inefficient vehicles.

In Europe, a variety of policies exist that would be complementary to new fuel economy standards, in that they share the basic aim of promoting higher efficiency vehicles. Kageson (2003) has catalogued these policies:

- **Fuel taxes** – which are quite high in EU countries, and clearly have an effect on vehicle fuel economy. Because diesel fuel taxes are considerably lower than taxes on gasoline in the majority of EU countries, sales of (more efficient) diesel vehicles have soared, with subsequent improvements in fleet fuel economy (and reductions in CO_2 emissions/km). Kageson has noted a potential concern with the diesel/gasoline price differential – that the rebound effect (increase in driving caused by more efficient vehicles' lower driving cost/km) has appeared to be quite strong in shifts to diesel vehicles, with apparent increases in vehicle kilometres driven for diesel vehicles. Whether this effect is as strong as portrayed is uncertain, however, because drivers who would ordinarily take longer trips, or who are contemplating a shift in driving habits towards greater driving, would tend to prefer diesel vehicles; and, in a multi-vehicle household, a new diesel vehicle might absorb some of the trips of other vehicles in the household. These effects make it difficult to separate out a "rebound" from a preference for diesel among higher-mileage drivers.

- **Annual circulation taxes based on engine power, cylinder capacity, vehicle weight and fuel consumption**. Kageson argues that these taxes have generally been too low to affect market preferences significantly; however, increases in these taxes could be effective in supporting fuel economy standards. The form of the taxes is important – fuel consumption (or CO_2 emissions) as a basis should provide the most direct support of standards; weight and power somewhat less so. Basing taxes on cylinder capacity would help some; wide use of such taxes would likely tend to promote highly-boosted engines and manufacturer focus on increasing engine power density (kW/cc), which should tend to reduce fuel consumption.

- **Sales and registration taxes based on cylinder capacity (Belgium, Greece, Ireland, Portugal and Spain) and fuel consumption (Austria).** Kageson also mentions taxes based on power and weight but does not identify any. Because purchasers of many new vehicles will not keep them more than a few years, these taxes should be more effective than annual circulation taxes in affecting buyer decisions about vehicle fuel efficiency.

It might be argued that fuel economy standards should be adequate *by themselves* to boost fuel economy to desired levels, since standards require compliance. The obvious counterargument is that economic incentives that align consumer interests with the vehicle manufacturers' responsibilities under standards make ambitious standards politically feasible. The risk that lack of consumer interest might damage a vital industry would likely limit government support for such standards. Further, continued improvements in vehicle efficiency will demand substantial and continuing investments in new technology that can only be made by a financially healthy industry.

9. CONCLUSIONS

The process of developing new fuel economy standards is inherently more complex than can be done justice to in a short paper. The timing of standards was discussed only briefly here, but timing is clearly a crucial element of any new standard – redesigning vehicles is a time-intensive and very expensive process that requires large engineering teams. Redesigning the large part of the new vehicle fleet will require at least a decade, and automakers must proceed cautiously in introducing new technologies to avoid maintenance and operational disasters. Another issue not discussed in depth here is the economic impact of new standards. In the past, economic analyses of proposed standards have tended to follow a common script – the industry and its consultants forecast huge negative impacts, the environmental community forecasts large positive impacts. In all cases, the results flow primarily from the input assumptions, not from robust analysis – the automakers tend to assume that consumers will resist purchasing new models or that they will have to shift to less profitable market segments, while the environmental community assumes that sales will remain robust and the greater vehicle content will generate new jobs (OTA, 1991). As already noted, safety has been and will be a crucial factor in negotiations about new standards in the US, and the subject is complex enough to deserve its own paper.

The decision-making process that will create new fuel economy standards is intensely political, and it should be. Scientific analysis can define the possibilities, but in the end the process is about trading off competing societal values: the relative importance of global warming and energy security concerns; the value of the free market; the ability of consumers to drive whatever kind of vehicle they want; or the value of future savings *versus* present costs. Scientists can inform this process, but they should not rule it. Further, as anyone who has watched this debate over the years knows intensely well, there are strongly variable scientific positions about all of the issues in the debate. What does seem certain, however, is that the extremes of the debate – that fuel economy standards don't work and don't save fuel, or that fuel economy standards can be cost-free – are both incorrect.

The extent to which fleet fuel economy can be improved is controlled not only by technology but also by consumer desires. In the United States over the past 20 years, and in the absence of more stringent standards, a cascade of fuel efficiency technologies has been widely disseminated in the fleet, but their potential to improve fuel economy has been totally cancelled by the changes in vehicle attributes desired by vehicle buyers, especially increased performance, larger size and higher weight (due to both the larger size and increased luxury and safety equipment). Similar trends have occurred in Europe, but there at least a portion of the benefits of new technology has gone to improving vehicle fuel economy. The tendency to use new technology for attributes other than improved fuel economy can continue in the future. New standards might constrain trends to larger, heavier, more powerful vehicles, but vehicle manufacturers (through advertising and design decisions), government and civic leaders (through their ability to inform and influence the public) have a strong role to play.

In the near-term (12-15 years), fuel economy improvement goals of 30-50% seem to be a reasonable starting point for negotiations between government and industry; although higher values would be possible if governments felt that the urgency of energy security and climate change issues justified asking consumers to pay more for new technologies than they would likely economise in future fuel savings. In the longer term, considerably higher increases appear quite feasible, especially if adverse vehicle attribute trends are stopped and if progress continues in cutting the costs of hybrid drivetrains and other new technologies.

In Europe, the approaching decision appears to be a shorter-term one. Because it appears that the industry will not achieve the 140 gCO_2/km target for 2008 (or 2009 for the Japanese and Korean automakers), the EU has proposed to set mandatory targets, perhaps for as early as 2012. The EU must make difficult decisions about the stringency and timing of the targets as well as their format – and the two are related, because a format that places very different challenges on different segments of the industry is likely to cause some segments to fail or, to avoid this, to limit how stringent the targets can be. This paper examines some alternative formats, but none is without difficult tradeoffs. As for timing, policymakers must wrestle with the knowledge that 2012 is very early for a demanding redesign of a major portion of the fleet, but at the same time it has been clear to the industry for some time that this challenge is coming. There is no simple technical analysis that can simplify this difficult political decision.

As a final point, there are actions that policymakers can take, aside from new fuel economy standards, that can add to overall fleet efficiency and fuel savings. Some of these actions address the limits of current vehicle compliance testing and the effect of post-sale consumer decisions on efficiency. These actions include:

- Developing a measuring system for tyre efficiency that could be used for labeling or as a framework for standards;
- Awarding credits to automakers for improved air conditioning systems and other accessories whose efficiency is not measured on the testing cycle. (A regulatory agency would have to determine a method for estimating the average emissions savings associated with

such accessories and award a credit in relation to the tested fuel economy to be factored into the rating of the vehicle in relation to a standard or incentive system);

- Awarding credits to automakers for onboard fuel economy/consumption displays and possibly for "economy" modes for automatic transmissions.

Policymakers can also promote economic incentives that are in alignment with new standards, such as registration and circulation taxes tied to fuel efficiency. To the extent that such incentives make higher efficiency vehicles more attractive to vehicle purchasers, they may significantly reduce the market risks to automakers of new standards.

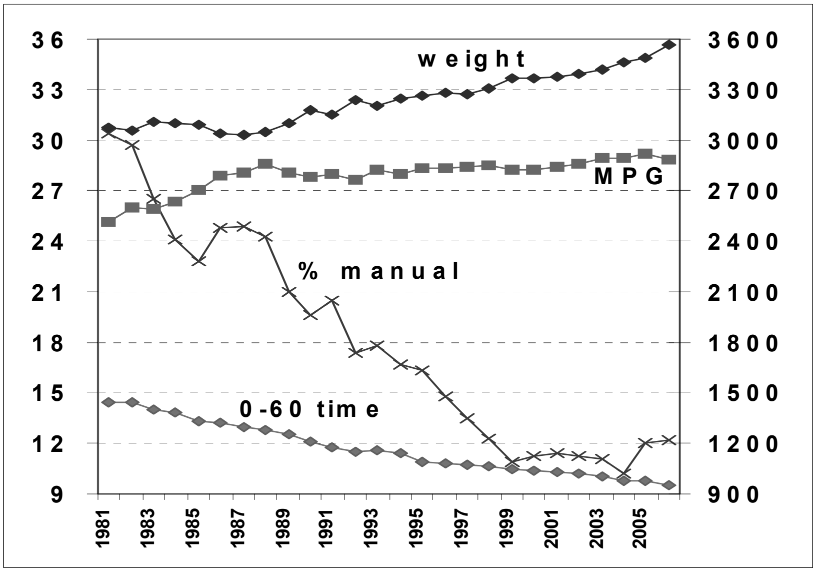
ANNEX

The tradeoff between fuel economy and other vehicle attributes

This tradeoff between fuel economy and performance is well illustrated by examining Toyota's stable of hybrid electric cars and the different decisions made by their designers about trading off fuel economy and performance. In the Prius, Toyota designers chose to use the hybrid technology primarily to increase fuel economy. They use a small, very efficient engine and use the added power of the electric motor to achieve performance similar to other vehicles in Prius's size category, with much better fuel economy (city/highway fuel economy of 60/51 mpg *vs.* 30/38 mpg for the smaller Corolla)[9]. In the Camry hybrid, the emphasis is still on fuel economy, but the designers chose to forgo downsizing the Camry's 4-cylinder engine, creating performance a bit better than the hybrid's conventional sibling (187 hp *vs.* 157 hp) but with clearly superior fuel economy (40/38 mpg *vs.* 24/33 mpg for the conventional 4-cylinder with automatic transmission). And in the Lexus GS450h, the designers pushed the tradeoff considerably more towards performance (5.2 second 0-60 mph, *vs.* 5.7 seconds for the GS 350 with the same engine), creating an ultra-powerful luxury car with fuel economy comparable to or slightly better than a less powerful car of the same size (25/28 mpg *vs.* 21/29 mpg for the GS 350)[10].

In the US , the tradeoff between fuel economy and other vehicle attributes has delivered a 2007 model year fleet of cars and light trucks that, over the past 20 years, has added a staggering array of fuel efficiency technologies, including: supercomputer design of vehicle body structures coupled with new lightweight materials and higher strength steels; significant improvement in aerodynamics and tyres; new engine technology, ranging from valves that adjust their timing and lift (degree of opening) in response to changing power demand, to fuel injection systems that can respond instantly to changes in cylinder conditions monitored by sophisticated sensors, and controlled by more onboard computer power than was available in the lunar module. And the net effect of this technology on fleet fuel economy has been…*zero.* Every bit of fuel economy *potential* represented by this technology has been traded away for other things. There is no ideal way to measure the impact of this tradeoff, but using a simple measure – "how efficient would the fleet have been had it remained at the average acceleration performance and weight of the 1987 fleet?" – the EPA has concluded that the tradeoff "cost" of the years 1987-2004 has been about 5.5 mpg or 22.5% for the combined car/light truck fleet (Hellman and Heavenrich, 2004)[11]. Figure A-1 shows the changes in average vehicle weight, 0-60 mph time, and percentage of manual transmissions from 1981 to 2006 for the US new passenger car fleet.

Figure A-1. **Changes in passenger car attributes, US new car fleet, 1981-2006**



Similar trends have occurred in European vehicle markets. From 1990 to 2003, average power for all light vehicles increased by nearly 30%, from 61 to 79 kW, while the share of 4-wheel drive vehicles tripled, from 2.6 to 6.3% of sales[12]. Average vehicle weight also increased substantially, with the ACEA reporting an increase of 10% during the period[13]. However, the European fleet was able to sustain a reduction in average carbon emissions during this period, compared to the US fleet's small increase in average emissions. A key difference between the US and European fleets appears to be the large increase in diesel share in the European fleet, from 13.8% in 1990 to 43.7% in 2003. This accounted for about a third of the fleet's emission improvement; the remainder of the improvement was primarily due to other technical improvements, with changes in vehicle size mix playing a small share (for the ACEA, the primary source of vehicles in the EU, "dieselisation" accounted for a 3.8% emissions reduction, other technical improvements accounted for an 8.3% reduction, and mix shift 0.3%[14]. Still, a substantial further reduction in emissions would have occurred – according to a cited ACEA study, the approximately 12% reduction between 1995 and 2003 could have doubled – had weight, power and other vehicle attributes not changed[15].

A short primer on vehicle energy use

All fuel-saving technology is designed either to reduce the power needed at the wheels to move the vehicle and power to run accessories, or to improve the efficiency by which the vehicle obtains power from its energy source – generally gasoline or diesel fuel.

Vehicles need energy to provide the power at the wheels:

- to overcome the force of inertia when they accelerate either from rest to a desired speed or from one speed to a higher one;
- to overcome the forces of air drag and tyre friction that would otherwise slow it down; and
- to overcome the force of gravity when climbing a grade.

Energy is also needed to power the accessories that maintain comfort (air conditioning, heating), provide entertainment (radio, CD player) or enhance safety (lighting).

Ignoring accessories for the moment, the forces a vehicle needs to overcome vary a great deal with the type of driving one does. On the highway, air drag is especially important because the energy/mile needed to overcome it varies with the square of speed – air drag at 70 mph is $(70/35)^2$, or four times what it is at 35 mph. The energy required to overcome tyre friction ("rolling resistance") is relatively constant with speed (though it does go up slightly at higher speeds) but varies directly with vehicle weight. And inertial forces, which also vary directly with weight, are a function of changes in speed – they will be low on a smoothly flowing freeway, and high if there is much slowing down and speeding up.

In the city, you are mostly going at slower speeds and air drag is low. Tyre resistance is just a bit lower than it was on the highway. But every time you stop at a red light or slow down for traffic and then accelerate, you are overcoming inertia – so inertial forces are high in city driving.

What this means is that weight reduction is an excellent way to reduce the energy needed by a vehicle, because weight is directly proportional to two of the three primary sources of energy use in driving (inertial losses and tyre rolling resistance). If a vehicle designer achieves a weight reduction of 10% and maintains constant performance by using a slightly smaller engine, fuel economy will be improved by about 6-7%, measured by the standard EPA fuel economy test, which assumes that 55% of driving is in the city and 45% on the highway, all of it fairly gentle[16]. Improving the efficiency of tyres and aerodynamic performance by the same 10% is less effective but will still achieve increases in fuel economy of about 2% for each (again, maintaining constant performance and measured on the EPA test).

Improving the efficiency of accessories will also help improve fuel economy, although much of this improvement will not show up on the EPA test, which does not include use of heating, air conditioning, lights or entertainment systems. A 10% reduction in accessory energy use could improve fuel economy by about 1%.

As noted above, the other way to improve fuel economy is to improve the efficiency with which the vehicle translates fuel energy into power at the wheels. An average passenger car or light truck powered by a gasoline engine loses more than 80% of its fuel energy between its fuel tank and its wheels in typical driving. The most losses come inside of the engine, through friction of air and fuel pumped through tubes and valves ("pumping losses"), friction of moving surfaces (e.g. pistons against cylinder walls), heat losses through cylinder walls, loss of heat in the exhaust, fuel used to keep the engine running during idling and deceleration, and so forth. Some of these losses arise because of design compromises caused by material limits, requirements of emission controls,[17] and limits to measuring capability and allowable complexity in engine adjustments.

Engine efficiency also depends on the transmission. Internal combustion engines can generate the power and torque needed to operate the vehicle at a wide variety of engine speeds; the transmission chooses the "best" speed as a compromise among fuel consumption, vibration and other factors, but is limited in its choice by the number of speeds in the transmission. This limitation is particularly important because engine efficiency can fall off substantially as the engine moves away from its most efficient operating mode. The more speeds in the transmission, the easier it is to keep the engine operating near its most efficient mode.

Finally, engines, especially gasoline engines, operate most efficiently at high loads, that is, when the power demanded from them is a substantial fraction of their maximum power. However, engines are “sized” to satisfy driving conditions such as accelerating from zero to sixty mph or from 50 to 70 mpg (highway passing) that require far more power than what is needed during average driving. In other words, engines are normally operated at a small fraction of their maximum power, with substantial penalties in efficiency. This opens up a strategy to improve fuel economy – find a way to artificially boost the power of a small engine for the limited time high power is needed, through turbocharging or supercharging (or use of the electric motor in a hybrid system), or shut down part of the engine at lower loads so that it behaves like a lower-powered one.

Although most losses occur in the engine, friction losses occur in the transmission and elsewhere in the driveline. Friction losses are reduced by improving engine oils, by making moving parts lighter, by substituting rolling surfaces for sliding ones, by developing special coatings for moving parts, and by improving manufacturing tolerances.

NOTES

1. The views expressed in this paper are those of the author only, and not of the Argonne National Laboratory or any other organisation.

2. Discussed in Gerard and Lave, 2003.

3. In other words, the last increment of added technology cost will be more than balanced by added fuel savings. Note that it might be possible to add technology to gain still higher fuel economy without having total added vehicle costs exceed total fuel savings…but the cost of the added technology might exceed the fuel savings associated with that technology.

4. For more information, see the Vehicle Technologies Program website: http://www1.eere.energy.gov/vehiclesandfuels/index.html
   The 50% weight reduction would be available for use in a leading-edge vehicle; the 2015 date does not assume that the new vehicle fleet could achieve such gains at this time.

5. Using the ADVISOR vehicle simulation model, developed by the National Renewable Energy Laboratory.

6. The 2030 midsized passenger cars obtained 5.5 L/100km for the naturally aspirated engine with conventional drivetrain; 4.84 L/100km for the turbocharged version; and 3.08 L/100km for the hybrid version. In CO_2 terms, these values are 121 g/km; 106 g/km; and 68 g/km.

7. Assuming the baseline 2005 diesel achieves a 35% higher volumetric fuel economy than the gasoline vehicle.

8. Fuel economy is extremely sensitive to driving styles: how gently one brakes and accelerates, how much the driver anticipates speed changes and avoids unnecessary braking; and the type of driving. As a result, multiple drivers using the same vehicle model typically will get a wide range of fuel economy results. Other factors that affect fuel economy results are average temperature and accessory use. Fuel economy values typically drop substantially in severely cold weather, for example.

9. Toyota, 2007. Corporate website http://www.toyota.com

10. Lexus, 2007. Corporate website, http://www.lexus.com

11. Hellman, C.H. and R.M. Heavenrich (2004), *Light-Duty Automotive Technology and Fuel Economy Trends: 1975 Through 2004*, US Environmental Protection Agency, EPA420-R-04-001.

12. P. Kageson, *Reducing CO_2 Emissions from New Cars*, European Federation for Transport and Environment, 2005.

13. Kageson, *op. cit.*

14. Kageson, *op. cit.*

15. Kageson, *op. cit.*

16. A key reason that the test driving cycle is so gentle is that the testing machines – dynamometers – available at the time the test was established had limited capacity to simulate more aggressive driving.

17. Because of extremely precise fuel control and advanced catalysts, most fuel economy penalties associated with emission controls have disappeared. However, stringent standards for nitrogen oxides have led to avoidance of the use of lean burn in gasoline engines, which creates an efficiency loss, and new standards for diesels may also cause some loss in fuel efficiency.

BIBLIOGRAPHY

Ahmad, S. and D.L. Greene (2005), “Effect of Fuel Economy on Automobile Safety: A Reexamination”, *Transportation Research Record: Journal of the Transportation Research Board, No. 1941*, Transportation Research Board of the National Academies, Washington, DC, pp. 1-7.

ECMT/IEA (2005), *Making cars more fuel efficient; Technology for real improvements on the road*, Paris, and Energy Conservation Center, Japan (ECCJ), *Smart Drive*, 2003.

Edmunds, D. (2007), “Explained: 2008 EPA Fuel Economy Ratings”, March 7. http://www.edmunds.com/advice/fueleconomy/articles/119812/article.html

General Accountability Office (2007), “Passenger Vehicle Fuel Economy, Preliminary Observations on Corporate Average Fuel Economy (CAFÉ) standards, GAO Highlights, March 6, http://www.gao.gov/highlights/do7551thigh.pdf

Gerard, D. and L.B. Lave (2003), *The Economics of CAFE Reconsidered: A Response to CAFE Critics and A Case for Fuel Economy Standards*, Regulatory Analysis 03-10, AEI-Brookings Joint Center for Regulatory Studies, September.

German, J. (2007), American Honda Motor Corporation: “Light Duty Vehicle Technology: Opportunities & Challenges”, PowerPoint presentation, Asilomar Conference on Transportation and Climate Policy, August 23.

Heavenrich, R.M. (2006), *Light-Duty Automotive Technology and Fuel Economy Trends: 1975 Through 2006*, US Environmental Protection Agency EPA420-R-06-011, July.

Hellman, C.H. and R.M. Heavenrich (2004), *Light-Duty Automotive Technology and Fuel Economy Trends: 1975 Through 2004*, US Environmental Protection Agency, EPA420-R-04-001.

Heywood, J. *et al.* (2003), The Performance of Future ICE and Fuel Cell Powered Vehicles and Their Potential Fleet Impact, Massachusetts Institute of Technology, Laboratory for Energy and the Environment, MIT LFEE 2003-004 RP, December.

IPCC (2007a), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press.

IPCC, (2007b), *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, April.

Kageson, P. (2005), *Reducing CO_2 Emissions from New Cars*, European Federation for Transport and Environment, Report T&E 05/1.

Kahane, C.J. (2003), "Vehicle Weight, Fatality Risk, and Crash Compatibility of Model Year 1991-99 Passenger Cars and Light Trucks", NHTSA Technical Report DOT HS 809 662, Washington, DC, October, http://www.nhtsa.dot.gov/cars/rules/regrev/evaluate/pdf/809662.pdf

Kalhammer, F.R. *et al.* (2007), *Status and Prospects for Zero Emissions Vehicle Technology; Report of the ARB Independent Expert Panel 2007*, prepared for State of California Air Resources Board, Sacramento, CA, April 13.

Kromer, M.A. and J.B. Heywood (2007), *Electric Powertrains: Opportunities and Challenges in the US Light-Duty Vehicle Fleet*, Sloan Automotive Laboratory, Massachusetts Institute of Technology, Publication No. LFEE 2007-03 RP, May.

Lexus (2007), corporate website, http://www.lexus.com

Lutter, R. and T. Kravitz (2003), "Do Regulations Requiring Light Trucks to be More Fuel Efficient Make Economic Sense? An Evaluation of NHTSA's Proposed Standards", Regulatory Analysis 03-2. AEI-Brookings Joint Center for Regulatory Studies, Working Paper 03-2.

National Research Council (2002), *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards*, National Academy Press, Washington, DC.

Office of Technology Assessment (1991), *Improving Automobile Fuel Economy: New Standards, New Approaches*, OTA-E-504 (Washington, DC: US Government Printing Office, October.

Owen, N.J. and R.L. Gordon (2003), *Carbon to Hydrogen Roadmaps for Passenger Cars: Update of the Study for the Department for Transport and the Department of Trade and Industry*, Ricardo Consulting Engineers, Shoreham-by-Sea.

Plotkin, S., D. Greene and K.G. Duleep (2002), *Examining the Potential for Voluntary Fuel Economy Standards in the United States and Canada*, Argonne National Laboratory Report ANL/ESD/02-5, October.

Plotkin, S.E. (2004), Fuel Economy Initiatives: International Comparisons, *Encyclopedia of Energy,* Vol. 2, Elsevier.

Ross and T. Wenzel (2002), *An Analysis of Traffic Deaths by Vehicle Type and Model*, American Council for an Energy Efficient Economy Report No. T021, March http://www.aceee.org/pubs/t021full.pdf

Small, K.A. and K. Van Dender (2004), A Study to Evaluate the Effect of Reduced Greenhouse Gas Emissions on Vehicle Miles Traveled", Department of Economics, University of California, Irvine, December 6.

Supreme Court of the United States (2007), No. 5-1120, Massachusetts *vs.* EPA, April 2.

Toyota (2007), corporate website http://www.toyota.com

Turrentine, T.S. and K.S. Kurani (2007), "Car buyers and fuel economy?", *Energy Policy* 35 No. 2, 1213–1223.

Van Auken, R.M. and J.W. Zellner (2003), *A Further Assessment of the Effects of Vehicle Weight and Size Parameters on Fatality Risk in Model Year 1985-1998 Passenger Cars and 1985-1997 Light Trucks,* Publication DRI-TR-03-01, Dynamic Research, Inc., Torrance, California.

White House release (2007), "Twenty in Ten: Strengthen America's Energy Security. http://www.whitehouse.gov/stateoftheunion/2007/initiatives/energy.html

HOW SHOULD TRANSPORT EMISSIONS BE REDUCED? POTENTIAL FOR EMISSIONS TRADING SYSTEMS

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1. INTRODUCTION

In developed countries, transport generates approximately 25-30% of emissions of CO_2, the main greenhouse gas (GHG), and these emissions are increasing sharply. There are two explanations for the increase in emissions from transport: the first is dependency on the internal combustion engine for transport with no wide-scale, economically viable alternative available in the medium term; the second is the sharp increase in vehicle-kilometres travelled, which seems to be an inherent feature of economic development.

One might well ask, given announcements that oil reserves will run out rapidly, whether we should not simply wait until reserves dry up to obtain a reduction in transport-related emissions. This said, rising oil prices are gradually making it more viable to exploit unconventional reserves, leaving aside innovations in technology that are reportedly opening up prospects for new fossil fuels (including fuels derived from coal, which is in plentiful supply world-wide). Hence, there is every reason to believe that the use of fossil fuels could continue on a large scale in the future.

Foresight studies show that, if our aim is to achieve ambitious emission control targets for transport within the next few decades, the policies we implement will have to be more determined: among other things, they should aim at reducing total consumption, that is to say, vehicle-kilometres travelled, not just unitary vehicle consumption (cf. ENERDATA and LEPII, 2005 for France, for instance).

Among the measures identified, carbon taxes and vehicle taxes are the most cost effective (OECD, 2007; Parry *et al*., 2007). However, the “fuel tax protests” of September 2000 in several European countries show that public opinion is very resistant to fuel tax increases (Lyons and Chatterjee, 2002). This resistance can also be explained by concerns about fairness, since many households depend on the car for day-to-day living and for getting to work. As well as this, fuel tax increases would require the international harmonization of fuel taxation in different countries, which seeing what has happened in the European Union, appears to be extremely difficult.

In the light of these difficulties, another instrument which combines economic incentives and regulation by quantity, namely, marketable or tradable permits (TPs), might be of interest. This category of instruments is part of a wider one, namely transferable permits. According to a general definition given by O. Godard (OECD, 2001), transferable permits cover a variety of instruments that range from the introduction of flexibility into traditional regulation to the organisation of competitive markets for permits. These instruments have in common: the setting of quantified physical constraints in the form of obligations, permits, credits or rights allocated to target groups of agents consuming scarce resources; and the permission granted to the agents to transfer these quotas between activities, products or places (offsetting), periods of time (banking) or to other agents (trading, hence “tradable permits”). These tradable emissions permits (or quotas[1]) are frequently referred to as “pollution rights”, implying that those who can afford to are allowed to purchase the right to harm the environment. However, the allocation of emission quotas does not involve the creation of “pollution rights” but the restriction of these rights, when previously they were unlimited. Making these quotas "tradable" therefore amounts to introducing flexibility and minimizing the total cost to the community of reducing emissions.

It is generally considered that tradable permits schemes with a large number of mobile sources involve huge implementation costs. We will argue that allocation methods and emission caps can be defined with no excessive complexity and that administrative running costs can be significantly lowered with a smart design. Adding the advantages of better acceptability and a more effective influence on behaviour given by the possibility of free allocation, TP schemes in transportation deserve a thorough exploration.

This report recaps, firstly, the theory about tradable permits (TPs) when compared with taxation and, secondly, the relevance of TPs in transportation: the current proposal by the European Commission for including aircraft operators in the Emissions Trading Scheme is briefly presented. Then a series of proposals elaborated from the author's works are covered: gasoline consumption by drivers of private vehicles, freight transportation, and tradable driving rights in urban areas. Finally, potential pitfalls and implementation issues are discussed.

2. THEORY

The economic theory behind pollution permit markets can be traced back to the work of Coase (1960) on external costs, followed by that of Dales (1968) on regulating water use, and the formalisation of pollution permit markets by Montgomery (1972).

A system of tradable permits equalises the marginal costs of reduction between all emission sources. Under some assumptions this is a sufficient condition for minimising the total cost of achieving a given emissions reduction objective (Baumol and Oates, 1988). This result is obtained independently of the initial allocation of rights: it should be stressed that this makes it possible to separate the issues of efficiency and equity.

However, Stavins (1995) has shown that when transaction costs are involved – the search for trading partners, negotiation, decision-making, follow-up and compliance with the rules – the initial allocation of rights affects the final balance and the total cost of reducing emissions. The authorities may therefore attempt to reduce these transaction costs; for example, by avoiding finicky regulations or by facilitating the activity of intermediaries between vendors and purchasers (Hahn and Hester, 1989; Foster and Hahn, 1995).

The use of transferable permits is not new. They have been used in the fisheries, and in the fields of construction rights and water pollution. The US "Acid Rain" scheme has been developed as a large-scale system of tradable sulphur dioxide emission permits (Godard, 2000). An appraisal of these experiments has made it possible to identify the principal criteria of success for such systems and the associated legal and institutional pitfalls (see below).

With regard to the quantitative reduction objective, the essential difference between taxes and permits lies in the fact that, in practice, the public authorities do not possess full information on the reduction costs for the different agents. With a permit-based approach, achieving the quantitative emissions reduction objective is guaranteed, but there is no guarantee with regard to the level of the actual marginal costs of reduction. On the contrary, in the case of the tax, the marginal cost of reduction for each agent is fixed by the tax level, but there is no guarantee with regard to the amount of emissions reduction.

This uncertainty makes it difficult for the regulator to make a choice, as errors regarding reduction costs for agents, particularly with regard to the distribution of efforts over time and between agents, may be very costly to the community. Nevertheless, a number of criteria may be of use when making this choice (Baumol and Oates, 1988).

A first criterion for the appropriateness of a quantity-based approach (i.e. emissions quotas) is whether the damage to the environment is in danger of increasing very rapidly or becoming irreversible when certain emission thresholds are reached or exceeded. In this case, tradable permits provide a relative advantage over the price-based (i.e. tax) approach: in a context of inherent uncertainty, quotas control reduces the cost of errors of anticipation of abatement benefits and costs (Weitzman, 1974). The problem of greenhouse gas emissions is a particularly good example of this situation, with a steep damage function while the abatement costs are considered as limited (Stern, 2006)[2]. Another example in the field of transportation is where congestion may, in the short term, result in hyper-congestion which generates large-scale waste for the community.

A second criterion is whether agents are more sensitive to quantitative signals than price signals, particularly if the price-elasticity of demand is low in the short or medium term, as is the case in transportation. Here again, a permit system is more appropriate.

For example, emissions from travel may be reduced by various means: changing driving style, reducing vehicle-kilometres of travel (by increasing the number of passengers in vehicles, reorganising trips or changing the locations of activities); by changing one's vehicle or changing mode in favour of one which consumes less energy. Some of these actions may be implemented in the short term, while others, such as changing one's vehicle, or one's place of work or residence, may take much longer. This results in elasticities which are generally low in the short term and considerably higher in the long term. For example, for fuel consumption, the price-elasticity values are between -0.3 in the short term[3] and -0.7 in the long term (Goodwin, 1988).

A third criterion, which is an important factor for the effectiveness of TPs, is the heterogeneity of the agents involved in the system. This means that the marginal costs of abatement must be sufficiently different between agents in order to allow benefits from trading permits, thereby making the market function effectively.

For instance, if we consider the use of the private car, the marginal abatement cost curves are highly varied and, in particular, rise as one moves from urban to suburban and then to rural settings. On two essential points, namely changes in the locations of activities and changes in transport mode, the possibilities for action differ very greatly in both nature and degree based on the residential locations of the individuals in question (urban, suburban or rural). Changes in the locations of activities in order to reduce the distances between different activities are much easier to make in urban areas than in suburban or rural locations, as a result of the density of available activities. Changes are possible in the short term for activities where the location imposes few constraints, such as shopping or leisure; reducing distances between home and work is easier in a conurbation which provides a high density of job and housing opportunities. Likewise, public transport which provides an alternative to the private car is more frequently available in urban areas.

Finally, last but not least, in political terms, systems where permits are allocated free of charge may be seen as a means of avoiding an additional tax, and this can enhance the acceptability of the new instrument. With this free allocation, economic agents have a supplementary incentive to save, whether emissions, trips or distance travelled, beyond their initial allocation of permits because they can sell unused permits and then obtain a tangible reward for their "virtuous" behaviour.

Nevertheless, the choice between taxation and permits requires a case-by-case analysis. A general solution to this problem of uncertainty with regard to the costs of emissions reductions has been proposed by Baumol and Oates (1988, pp. 74-76), on the basis of an idea developed by Roberts and Spence.

If the regulator does not put enough permits on the market (for a given year or a given sector), the free play of the permit market will result in an excessive price. The regulator can then introduce a payment in full discharge t (i.e. a "safety valve" or price cap): in lieu of buying permits at a price p which could rise to a too high level, the emitter could be discharged of his/her obligation to render permits by paying the charge t for each unit of emission exceeding the rights he/she holds. In this case, as soon as the price of permits exceeds the level t, it is in the interest of polluters to pay the payment in full discharge[4]. The upper bound of the permit price will therefore be equal to t. This is the hybrid solution which combines the allocation of permits and a payment in full discharge. It is to be applied when the regulator must make decisions either with regard to the temporal distribution of efforts (for example, annual objectives) or with regard to the distribution of this effort between the different actors or sectors. Of course this implies that the overall quantitative objective of emissions might be exceeded for one specific time period or sector: the corrections which afterwards would be needed, for instance, the level of t for the next period, are the responsibility of the regulator.

The main arguments against the use of permits in the transport system are the cost of administration and monitoring over a large number of mobile sources and the transactions costs of quota transfer. However, this issue happens to be similar in the case of road pricing and is now better addressed and effectively implemented, thanks to electronic technology which is affordable today. As we will see, this technology improvement can be of some help to minimise the operation costs of TPs.

Experiences in implementation of tradable permits markets (OECD, 1997; 1998) make it possible to identify some general criteria for success.

First of all, it is necessary to share a broad agreement on the need for doing something, on the system's effectiveness for improving the environment, and on its lower cost compared to other systems or solutions. Taking account of equity (in particular in the methods of allocation), and more generally of social and political acceptability, is of paramount importance.

The first major criterion is that of the simplicity and clearness of the system. The target must be clearly identified and the exchange unit must be defined, easily measurable and verifiable. The rules of allocation and exchange of quotas must be simple, so as to limit the transaction costs. The institutional and geographical borders of the market, as well as the participants, must be clearly identified.

A second criterion, not less major for the efficiency of the system, is the possibility of effective market operation. It is necessary to have a sufficient number of agents who are likely to take part in the market and who can pay the foreseeable price of the permits. Moreover, it is essential that the expected marginal abatement costs are sufficiently different so that benefits can be achieved thanks to the exchanges.

Lastly, the system's efficiency also depends on the credibility of emissions monitoring – the checking and the rigour of the sanctions. Moreover, in order to allow the economic agents to optimise their long-term behaviour, certainty as to the validity of the permits in the future is essential.

3. RELEVANCE IN TRANSPORT

The relevance of tradable permits in transportation can be assessed firstly, by identifying suitable nuisances, secondly, potential target activities for TPs and then matching the nuisances with these targets. This chapter identifies the relevant nuisances and targets and then compares the potential performance of TPs with a CO_2 tax at each of the points where TP systems could be applied.

3.1. Relevant nuisances

Two main criteria can be used to judge the appropriateness of transferable permit systems – the ability to impose a constraint, or a right, defined in quantitative terms within a specified space and time, and the ability of agents to transfer these quantitative obligations (Godard, in OECD, 2001). These criteria can be assessed against the main nuisances associated with transport activity, i.e. regional pollution, greenhouse gas emissions, noise and congestion.

In many instances it is possible to set precise and measurable targets for aggregate emissions. This is the case for greenhouse gas emissions where threshold effects may require a quantity-based approach and where global trading is possible.

Since several local or national health regulations prescribe limits for air pollutant concentrations[5], a quantity-based approach may also be relevant for this kind of emission. Space-time equivalents may be established for air pollution for which permits could be traded within a geographical area.

In all these cases, it is the sum of the individual outputs of agents that produces the nuisance. In contrast, this does not apply to noise whose level does not increase linearly with the number of individual emitters.

Congestion is another area where limits may be made explicit. If the local policy is not to increase road capacity, a quantity constraint could be imposed on road traffic. Strictly speaking, space-time equivalents of congestion cannot be defined very broadly, since an hour lost at a given time in a given location is not equivalent to an hour lost in another area or time. An efficient scheme would thus restrict trading of driving rights to the users of, say, a corridor during a limited time span. However, congestion generates network interaction effects: congestion on one section of road makes drivers choose another route in order to save time. Congestion also generates rescheduling interaction effects: congestion at one period makes some drivers decide to drive earlier or later. Because of these two kinds of interaction the trading of driving rights could be extended between different locations within the same urban network and between different times and even days. The equivalence between driving rights could be fine-tuned by weighting them differently according to the level of congestion (see below).

Another scarce resource, indirectly related to transport activity, is public parking space. Here again, if the local policy is to not limit the amount of public parking space, a quantity constraint could be imposed on its use. However, it is clear that for parking there is no broad interaction as in the case of congestion. The market would be restricted to small-scale areas (because generally two parking places are only equivalent when they are within walking range).

3.2. Potential targets for tradable permits implementation

The environmental impacts of transportation stem from:

- The technical characteristics of vehicles (energy source, vehicle unit consumption and pollutant emissions);
- The supply of transport infrastructure and services (price and quality of service for different modes of transport);
- The intensity of travel as a function of economic and social trends; and hence
- Land use through location of activities and its impact on distances travelled.

There is potential for controlling nuisances arising from transport in several but not all of these areas.

3.2.1 Unit vehicle emissions

The sheer number of automobiles constitutes a basic obstacle to decentralising emission permit systems in transportation. This is why most proposals to decentralise permits have stopped at the level of automobile makers, and have been targeted at unit vehicle emissions (Wang, 1994; Albrecht, 2000). This is where we find the most advanced use of permits (see, for instance, a review of the ZEV scheme in California in Raux, 2004). However, this approach yields several pitfalls. There is a measurement issue, for instance, with the (non-) inclusion of mobile air-conditioning systems. Moreover, this criterion cannot control for actual car use through the type of driving and even less the actual number of kilometres driven. This is why, for CO_2 emissions, end-user fuel consumption appears to be a more relevant target.

Regarding atmospheric pollutants, they are produced by the inefficient burning of fuel in vehicle engines and ineffective filtering of exhaust gases. This category includes nitrogen oxides (NOx), hydrocarbons (HC) and particulate matter. For example, in Europe, vehicle unit emissions are regulated by the Euro standards which apply to new vehicles put on the market. Table 1 gives the Euro values for private cars (class M1). It shows that between the Euro IV and Euro I standards the permitted levels for HCs and NOx vary in a ratio of 1 to 10 for petrol vehicles and 1 to 3 for diesel vehicles. Particulate emissions standards have so far only been imposed on diesel vehicles (a ratio of 1 to 6 between Euro IV and Euro I) but the Euro V standard, which was still under discussion at the end of 2007, will introduce limits for petrol vehicles too.

Standards of this type can thus provide a basis for regulating the intensity of vehicle use with reference to their pollutant emissions class. In practical terms, the number of rights required to use a vehicle, all other things being equal, could be varied according to the vehicle's emissions category. This type of modulation was used in the Ecopoints system, applied to lorries crossing Austria until the end of 2006 (for a survey of this experiment, see Raux, 2002).

Table 1. **European road vehicle emissions standards**

M1 petrol vehicles	**Date of application for new vehicles**	**HC (in CH4 equivalent)**	**NOx (in NO_2 equivalent)**	**Particulate matter**
		g/km	**g/km**	**g/km**
Euro I	1993	0.97 (HC+NOx)	0.97 (HC+NOx)	
Euro II	1997	0.5 (HC+NOx)	0.5 (HC+NOx)	
Euro III	2001	0.20	0.15	
Euro IV	2006	0.10	0.08	
M1 diesel vehicles				
Euro I	1993	0.97 (HC+NOx)	0.97 (HC+NOx)	0.14
Euro II	1997	0.7-0.9 (HC+NOx)	0.7-0.9 (HC+NOx)	0.08-0.1
Euro III	2001	0.56 (HC+NOx)	0.56 (HC+NOx)	0.05
Euro IV	2006	0.30 (HC+NOx)	0.30 (HC+NOx)	0.025

Source: Hugrel and Joumard, 2006.

3.2.2 Fuel standards

Some of the atmospheric pollutants result from the composition of fuels and therefore may be tackled by applying tradable permits to fuel standards. The use of lead as an additive in petrol is being phased out in developing countries and has been the subject of a successful application of TPs in the USA. The lead rights trading program between refineries between 1982-88 accelerated the phase-down of lead in gasoline until a complete ban came into effect in 1996 (for a survey of the literature on this case, see Raux, 2002). Sulphur dioxide (SO_2) emissions from vehicles are also covered by standards on the basis of the sulphur content of fuels.

3.2.3 Car ownership

In Singapore, a scheme of car-ownership rationing, involving auctions of a limited number of certificates of entitlement to purchase a new car, was initiated in 1990. The number of certificates is determined each year on the basis of traffic conditions and road capacity, and the certificates are issued each month (Koh and Lee, 1994). Chin and Smith (1997) showed quantity control of ownership to be a useful instrument, since automobile demand is inelastic and the social cost function is steep. Compared with price controls, quantity control reduces the welfare loss arising from any misperception of optimal equilibrium by the authority.

3.2.4 Car use

Some proposals involve setting quotas for vehicle-kilometres travelled (VKT) or trips within a given urban area for motorists that could be transferred among them as an alternative to pure congestion pricing, given the issue of acceptability (Verhoef *et al.*, 1997; Marlot, 1998).

A credit-based congestion pricing mechanism has been proposed by Kockelman and Kalmanje (2005) by which motorists would receive a monthly allocation in the form of credits (in principle, monetary), which could be used to travel on a road network or within a zone with congestion charging. The motorists would therefore have nothing to pay if they did not use up their allocation: beyond this allocation, they would be subjected to the congestion charging regime. Those who failed to use up their allocation completely would be able to use their credits later or exchange them for cash.

3.2.5 Parking use

Parking rights may also be considered as an indirect way of managing congestion. However, most road externalities are created by vehicles that move, while parking policy basically addresses vehicles that are stationary. For instance, an excessively restrictive parking policy in residential areas would generate additional vehicle traffic as a result of vehicles moving elsewhere to escape the policy. In areas that are similar to a CBD, in which jobs rather than residences are concentrated, the implementation of parking rights would interfere with or even duplicate driving rights with the same objective. These drawbacks mean that parking-rights markets do not merit further analysis (for a more detailed analysis, see Verhoef *et al.*, 1997).

3.2.6 Land use

In scattered settings, public transport is not viable so trips are usually made by car and distances travelled are longer. Land use is generally managed through regulation; however, there have been proposals for applying tradable permits to real estate developers on the basis of the travel volumes that their projects will generate (Ottensmann, 1998).

In order to do this, it would be necessary to identify traffic generators (for example, shopping centres, industrial or small business zones) and it poses many market organisation problems, in particular with regard to minimising transaction costs and making trading possible, not only within a conurbation but also between different conurbations.

3.2.7 End user fuel consumption

Regarding GHG emissions, the environmental effectiveness pleads for targeting as closely as possible to tailpipe GHG emissions themselves. Moreover, as seen above, the economic efficiency criterion implies equalising the marginal cost of CO_2 emissions' reduction, and therefore of reduction of fuel consumption. Targeting intermediate behaviours with specific quantitative objectives (i.e. type of vehicle, vehicle-kilometres and, for freight, tonne-kilometres, load rate or empty journeys) would not only be expensive in terms of information needed for the regulator but also a source of efficiency loss.

Taking into account the quasi-complete transformation of the carbon contained in fossil fuels into CO_2 during combustion[6], the more efficient solution consists in directly targeting consumption of these fuels.

Quotas of CO_2 calculated from the carbon contained in the fuel consumed by the end-user could thus be traded. For any quantity of fossil fuel bought (thus intended to be burned) by the motorist or the carrier, there would be an obligation to return to the regulating authority the corresponding quotas of CO_2 permits, which would then be cancelled.

3.3. Matching nuisance reductions to targets

The amount of distance travelled is one of the main drivers of nuisance levels, given current transport technologies, whether considering greenhouse gases, air pollutant emissions or congestion. Controlling land use is, in principle, an attractive way of reducing those distances, but its effects are controversial: it has still not been proven that it is possible to reverse the tendency to travel longer distances by making locations denser. However, one must recognise that the spatial concentration of activities yields more opportunities for cost-efficient transport alternatives, such as mass transit which is less energy consuming per passenger-km.

Car ownership is another indirect way of controlling car travel but the linkage with actual fuel consumption is very crude.

Other targets may have varied relevance according to the three types of nuisance: GHG emissions, regional pollution and congestion (cf. Table 2).

Table 2. **Appropriateness of TP targets for different nuisances**

Targets	**Nuisances**		
	GHG emissions	**Regional pollution**	**Congestion**
Land use	×	×	×
Car ownership	×	×	×
Unit emissions or vehicle technology	××	××	-
Fuel standards	××	××	-
End user VKT or trips	×	×	×××
End user VKT adjusted to emission category	×	×××	×
End user fuel consumption	×××	××	-

From × = low to ××× = high level of appropriateness.

For GHG emissions, targeting the fossil fuel consumption of end users with tradable permits is the most finely targeted incentive for reducing such emissions: end-users as the final decision-makers can modify, albeit with greater or lesser constraints, their travel choices, activity locations, or choice of vehicle or transport mode.

However, political resistance to rationing travel may suggest more indirect instruments are indicated. Among them, unit vehicle emissions (criterion of gramme of CO_2 per kilometre) and fuel standards, such as lowering of carbon content with bio-fuels. These targets are only one component of total GHG emissions. The other component is vehicle-kilometres travelled, which could also be controlled by tradable permits, but this has the same drawback as rationing travel while being less optimally linked to fuel consumption and hence to GHG emissions.

For regional pollutant emissions, the appropriateness of different targets is similar to the situation for GHG emissions. However, targeting fuel standards is particularly appropriate – they are, along with less polluting engine combustion technologies, another way of reducing harmful tailpipe exhaust emissions per kilometre driven. In contrast, targeting only VKT or trips has the drawback of rationing travel while being less optimally linked to pollutant emissions, since there is no incentive to shift to cleaner vehicles. This is why targeting VKT with an adjustment according to emission category may be a superior policy for local and regional pollutant emissions.

Regarding congestion, the most efficient and targeted incentive is on end-user VKT (or even trips on specific corridors or through an area). End-users as the final decision-makers can modify their travel choices, activity locations, or transport mode. However this has the basic drawback of rationing travel (as mentioned above).

3.4. CO_2 tax, upstream or downstream permits?

The instrument of taxation is widely used in the transport sector, essentially because of its tax yield. Excise duties levied in the European Union in 2002 varied widely in EU Member States, from €0.296 to €0.742 per litre for premium grade petrol and from €0.242 to €0.742 per litre for diesel oil (CEC, 2002). In France, fuel excise duties provided the central government with €27 billion in 2002 for a GDP of €1 522 billion. Although the current level of taxation might be considered high, it is not high enough to further reduce road fuel consumption.

The "tax rebellion" that took place in several European countries in September 2000 shows how sensitive public opinion is to fuel taxation (Lyons and Chatterjee, 2002). Central government is a focus for opposition, as it benefits from the tax, although it has little control over oil prices. Proposing a "CO_2 tax" in view of a GHG emissions reduction is likely to revive the debates on the use of fiscal revenues from the excises, which currently in the majority of European countries are not earmarked and play an essential part in the balance of public finances.

Although for the economists the impacts of taxes or permits on fuel demand are equivalent, the political perception of an instrument can be important. There is thus some interest in elaborating mechanisms which explicitly separate the objectives of generating fiscal revenue from the objective of reducing CO_2 emissions.

In order to minimise administrative costs, it seems relevant to set up the system of permits upstream, at a level where the actors are few: such as the fuel refiners or distributors, which already transmit the current excise duty to the ultimate consumer and return the product of the excises to central government. By requiring the producers and importers of oil, natural gas and coal to return the quotas, the system would cover all CO_2 emissions resulting from the combustion of the hydrocarbon fuels by end-users (Winkelman *et al*., 2000).

However, the potential for complete coverage by an upstream permit system has been undermined in Europe by distortions in the operation, since 2005, of the Emissions Trading Scheme (ETS) for energy-intensive, fixed industrial facilities (see Box). An upstream permit system would have to be established as a complement to the ETS if it were to function to its full potential.

Moreover, an upstream system is prone to two disadvantages:

The first relates to the risk of dilution of the incentive effect of permits on the final emitter, to implement the complete panoply of behavioural adaptations available to them. Indeed, whether the permits are acquired by auction or distributed free to the fuel suppliers, fuel suppliers would pass on opportunity costs[7] relating to these permits to their customers as a simple additional fee. In this case, the advantage *vis-à-vis* the current system of fuel taxation is null.

Box 1. **The European Trading Scheme**

Most developed countries agreed to quantitative, legally binding targets for reducing emissions of the six main greenhouse gases[8] in the 1997 Kyoto Protocol. The European Union committed to reducing its emissions by 8% on 1990 levels over the period 2008-2012 (the first commitment period)[9], sharing the burden among its Member States under the "EU bubble".

Keen to set an example for other, particularly industrialised, countries, the European Union took the lead in establishing a European emissions trading scheme (European Trading Scheme or ETS) at the enterprise level in Europe. At present, this system, which has been operating since 1 January 2005, applies only to CO_2 emissions from stationary combustion plants with a heating power of over 20 MW, in other words, to around 12 000 installations in the European Union. In practice, it applies mostly, but not exclusively, to the power generation industry and industries that are heavy energy consumers (mainly the ferrous metals, cement, glass, ceramics and paper industries). For the moment, it applies only to CO_2. Pursuant to the Directive establishing the ETS and to the subsidiarity principle, the responsibility for allocating quotas to the companies concerned lies with Member States: each State is required to submit its National Allocation Plan (NAP) to the European Commission[10].

An analysis of the implementation of the Directive in France (Godard, 2005) demonstrated that quota/allowance allocation had been particularly lax – in what was a classic example of the capture of public policy by big business – ostensibly so as not to undermine the competitive position of the companies concerned. The latter were subsidised by generous, free allocations, including some which had been intended for expanding the activities of new entrants, which implied virtually zero constraints for the companies concerned. In practice, the micro-economic incentive to trade, which makes a system efficient, was missing.

Despite this laxity, which was also the practice in other Member States, the pressure on the price of the allowance in the first months of operation took observers by surprise: the spot price for a tonne of CO_2 soared from EUR 8.5 to as high as EUR 30 in July 2005, fluctuating between EUR 20 and EUR 25 thereafter. Most buying was by electricity generators, owing to cyclical factors – the cold winter of 2005, increased use of coal, which emits more CO_2, in response to the rise in oil and gas prices. There was also some precautionary buying in view of uncertainties as to future economic growth and prospects for a tighter carbon cap (Alberola, 2006). For the year 2005, transactions totalled an estimated 12% of the 2.2 billion allowances allocated at European level.

At the beginning of May 2006, following the first declarations by Member States of actual emissions for 2005, the spot market price of an allowance plummeted to EUR 8.5, later picking up to around EUR 15 (during the summer of 2006). Since then, the market has collapsed again with prices crashing to less than EUR 1.

The second disadvantage appears in the event of free allocation of quotas to the fuel suppliers. If the permits are allocated free what would be the use of revenue accruing to polluters generated by this initial distribution? The fuel suppliers could transmit the opportunity costs relating to these permits which they would have received free: that would not call into question the economic efficiency of the system but certainly its acceptability, since those supporting the effort of reduction would not benefit from the revenue created by the free allocation. An upstream permits system thus seems, for reasons of political acceptability, incompatible with free allocation[11].

Lastly, the European Commission has said that it wished to include transport in the ETS gradually, starting with air transport (cf. Box 2).

Box 2. **EU plans to include air transport in the ETS**

Air transport is showing very rapid growth in traffic: in Europe, for instance, the annual growth in the number of flights has increased from 2.5% to more than 4% per year in the past ten years. Emissions of CO_2 from air traffic, which rose by 73% over the period 1990-2003, could cancel out the equivalent of more than one-quarter of the reduction that the European Union must achieve under the Kyoto Protocol (Wit *et al.,* 2005). According to a 1999 report by the IPCC, aviation accounted for only a small fraction (3.5%) of anthropogenic radiative forcing in 1992, but given the speed at which air traffic is growing, this percentage is set to increase rapidly. Furthermore, the report estimates that the full impact of aviation is two to four times higher than just that of CO_2 emissions, since the nitrogen oxides it generates lead to the formation of ozone and condensation trails, the effects of which are suspect but, as yet, little-known[12].

Although domestic air transport emissions are the responsibility of the States party to the Kyoto Protocol, the latter referred the issue of international air transport emissions to the International Civil Aviation Organization (ICAO). While the ICAO remains firmly opposed to any fuel tax on an international scale, it has agreed to the principle of an emission permit trading system for civil aviation, on the condition that the system is open to other economic sectors with no distortion of market access or allowance allocations.

Given the slow progress with negotiations at the ICAO, the European Commission issued a communication in September 2005 proposing to bring aircraft operators into the EU Emissions Trading System (ETS) for all flights departing from the European Union, whether or not the destination country was an EU Member State. Based on the study it had commissioned (Wit *et al.*, 2005), the Commission considered this to be a better approach than other options such as ticket or departure taxes and emission charges. It would only have a limited impact on the price of airline ticket costs (EUR 0 to EUR 9 per return flight within the EU).

Following a review of the practical implementation of the proposal and a resolution by the European Parliament in July 2006, the European Commission proposed a Directive to include aviation activities of airlines in the ETS in December 2006 (CEC, 2006). The Commission proposes to implement the programme for all flights departing from or arriving at EU airports as of 2012, beginning in 2011 with only flights (both domestic and international) between European airports. In contrast to the current ETS scheme, the method of allocating allowances will be harmonized across the EU, especially the benchmark for calculating allowance allocations, i.e. the ratio of total quantity allowances to the tonnes-kilometres achieved by the operators. The total quantity of allowances for allocation would be calculated on the basis of average CO_2 emissions for the aviation sector over the period 2004-2006. A set percentage of this total would be allocated free of cost (100% for 2011-2012) and the remainder would be auctioned. Each aircraft operator could then apply for a free allowance based on historical activity (tonne-kilometres). In addition, operators would be able to buy allowances from other sectors covered by the ETS.

This two-stage approach has come in for criticism from several stakeholders and from members of the European Parliament, mainly because they say it would create distortions in competition between airlines. As well as this, major disagreements persist on the total amount of allowances that should be allocated and the level of free allowances for airline companies. Lastly, the United States is vehemently opposed to the inclusion of non-European airlines in the programme.

In a study on the design of a GHG emissions trading system for the United States, Nordhaus and Danish (2003) ruled out a downstream system from the outset, judging that it would be too difficult to administer millions of sources. Like Winkelman *et al.* (2000), they argue the case for a hybrid approach which would combine an upstream procedure for fuel producers with a downstream procedure for automobile manufacturers. However, as German (2006) points out, an analysis of the detailed implementation of a hybrid scheme such as this shows that there are a number of difficulties.

One of the main problems is the risk of double-counting, both in terms of credits to automobile manufacturers for fuel efficiency improvements and in terms of allowances for fuel producers. This risk of double-counting arises mainly from the timing of calculations of allocations and credits: allocations for vehicle manufacturers are based on the entire lifetime of the vehicle, while those for fuel producers are for emissions in the current year. Generally, the incorporation of vehicle manufacturers in an upstream permit scheme would mean subtracting manufacturer efficiency allocations from annual allocations to fuel producers each year, which would require accurate monitoring of vehicle kilometres actually travelled, driving conditions that influence actual consumption, and vehicle scrapping. Furthermore, this type of programme does not cover the existing vehicle fleet, which is known to have a lifespan of around 25 years on average. In short, such a programme would be highly complex.

This is why it is of some interest to explore the possibilities of a fully downstream decentralisation of permit markets within the transportation sector.

4. TRADABLE FUEL RIGHTS FOR PRIVATE VEHICLES

Below, a proposal for “tradable fuel consumption rights” for motorists is described (based, with some alterations, on Raux and Marlot, 2005). In the case of France, private cars account for approximately three-fifths of automotive fuel sales (gasoline and diesel oil), the rest being consumed by light and heavy goods vehicles. We shall then evaluate this system both quantitatively and qualitatively.

4.1. A market for fuel rights

4.1.1 Obligation liability

As consumers of fuel and hence emitters of CO_2, motorists would be liable for the obligation to return the fuel rights to the regulating authority.

A consumer who purchases motor vehicle fuel (which will necessarily be burnt) will have to transfer the corresponding rights to the regulating authority. These rights will then be cancelled. The right corresponds to an authorisation to emit the CO_2 equivalent of a litre of fuel[13]. These rights may be held initially by the agent or transferred from another agent who holds rights or participates in the permit market.

4.1.2Allocation of rights

Free allocation of fuel rights could be made for car owners. To do this, a starting point can be an average consumption of 1 000 litres per car per year in France[14]. If we impose, say, a 10% reduction in this consumption, 900 rights should be allocated per car per year (i.e. rights to buy 900 litres at the regular price including current taxes). Since the allocation is on an annual basis, new incoming participants (e.g. individuals buying their first car) will get the same allocation as other car owners.

The increase or decrease of cars will, *ceteris paribus*, respectively decrease or increase the individual allocation on the following year in order to comply with the overall objective.

Since this kind of allocation may be debated as unfair for non car owners, another option could be to allocate fuel rights on a per capita basis (see Box 3).

Box 3. **An example of a per capita fuel rights allocation for France**

For example, starting in Year 1, the rights allocation would be of the order of 27 billion litres of diesel or petrol used by private cars in France for 2005, or per capita – child or adult living in France – rights amounting to 450 litres per year. Based on an average consumption of 8 litres per 100 km, that would work out at 5 600 km of travel by car per year or 22 400 km for a family of four. Car-pooling would therefore leave families some room for manoeuvre depending on their size. The rate by which rights allocations would be reduced each year would be announced several decades ahead and periodically adjusted by a regulatory authority, independent of the government in office.

Short-term travel behaviours are to a large degree determined by more long-term location choices – particularly residential ones. The regulating authority should therefore introduce and publicise a regular reduction in the number of rights that are allocated, with a rolling horizon of about a decade.

The rights would remain valid for an unlimited period, which may lead to hoarding and speculation. However, the CO_2-equivalent value of quotas held by an agent could be reduced in the following year in accordance with the rate of the reduction in free rights allocations, decided by the regulating authority.

4.1.3 Exchange mechanism

In order to consume more fuel than his/her free allocation, a consumer must purchase additional rights on the market. On the other hand, a consumer who does not use all his/her allocated rights could sell them. The possibility of selling unused rights provides an additional incentive for modifying one's behaviour, particularly for persons who can do so at low cost.

However, given the huge number of potential participants, the exchange would not be bilateral, but rather centralised through a stock exchange which would yield the daily value of right. Practically, participants would buy and sell rights through intermediaries, such as their usual bank operator, or buy them at the petrol pump (see below). This means perfect information for participants on the current price of the fuel right. Since transactions would be free on the market, there is no risk of a black market.

The trading of rights could take two possible forms:

- The more ambitious option would consist of a full market, those rights which are not allocated freely being auctioned. Financial intermediaries could be involved in trading and then propose rights to their clients. These auctions would produce an equilibrium price at which private individuals holding unused rights could sell them.
- A less ambitious option would try to not leave the management of fuel rights entirely to the market for reasons of acceptability: rights would be sold at a price fixed by the authority and at which the authority would buy back unused rights. This implies that the authority would

adjust this price on a yearly basis, while the level of CO_2 tax t would be fixed on a multi-year basis.

4.1.4 Monitoring, verification and penalties

The sale and purchase of rights would be supervised at national level by a regulatory authority. In order to reduce administrative costs and enforce reliable monitoring, fuel rights transactions will have to be validated as closely as possible to the time of fuel purchase, that is to say, when the motorist buys fuel at the pump. The rights which are awarded annually would be held on a chip card, recording rights debit and credit operations. This could be either a smartcard, compatible with the automatic teller machines (ATM) that are already installed at petrol stations, or a modification of the credit smartcards currently used. Rights could therefore be debited (or purchased at the current rate) when buying fuel. It would also be possible to purchase or resell permits in banks, using ATM bank distributors or the Internet.

4.1.5 A combined taxation and marketable rights system

It would be socially unacceptable to suddenly apply the fuel rights system to all motorists, so the implementation of the fuel rights market should be progressive and would coexist with the current taxation system. Moreover, taking part in the fuel rights system should be voluntary. Lastly, since rights transactions would be monitored when buying fuel at the pump it will not be possible to create an impenetrable administrative barrier between the two systems of taxation and fuel rights.

A possible solution is to set up the “safety valve” t referred to in Chapter 1 above (in fact, a “CO_2 tax”), which would be paid both by fuel consumers who wish to stay outside the rights market and those who are taking part in it but who have used up their allocation and are either unable or unwilling to purchase permits on the market. This tax would therefore constitute a price ceiling of permits on the market and would have to be calculated with reference to the country’s international commitments.

If the rights are allocated on a per capita basis, those people unwilling to cope with this system could immediately sell their rights. However, in the case where they buy fuel they would be liable to pay the “CO_2 tax”.

To sum up, the current fuel taxation system will be supplemented by the coexistence of two systems: the rights market on the one hand, and the extension of taxation with a “CO_2 tax” on the other hand. These two systems will make up the alternative proposed to motorists: the incentive to adopt the fuel rights system will be effective if the price of a fuel right is lower than the CO_2 tax.

4.2. Evaluation for the French case

An assessment of such a system of marketable fuel rights has been performed in the case of France. In this application, rights were supposed to be allocated to car owners. The quantitative results are based on empirical data collected in 1997, the most recent year for which data on the car fleet and fuel consumption was available at the time of the study.

4.2.1 Surplus distribution

Since we are evaluating two policy options to obtain a given objective of emission reduction, the differences between pure carbon taxation and tradable fuel rights lie in the distribution of surpluses between categories of motorists and between motorists and the central government (for details on methodology and results, see Raux and Marlot, 2005).

The quantitative exercise is performed with an objective to reduce fuel consumption by 10%. Given the uncertainty of the price response function of fuel consumers, we can only hypothesize values for the price-elasticity of demand which, as stated above, varies between -0.3 (short-term elasticity) and -0.7 (long-term elasticity). With the objective of reducing fuel consumption by 10% the tax would have to be adjusted accordingly.

Consumers must modify their behaviour in order to reduce fuel consumption, in particular by reducing vehicle-kilometres travelled. The difficulty of this adaptation will depend on the proximity of jobs, shops and services, and the supply of alternative transport modes to the car. An essential dimension therefore is the type of residential area. Four types of location are distinguished: the city centre, the suburbs, the peri-urban zone and rural areas (Hivert, 1999; Madre and Massot, 1994).

Because of the hypotheses needed concerning the different elasticities according to the type of residential location, the quantitative results summarised hereafter should only be considered as providing an order of magnitude for a possible distribution of surpluses. However, three main points can be stressed.

First, the comparison between taxation and permits involves the fiscal gain in the case of the tax and the fiscal loss for the central government in the case of fuel rights because of the free allocation. In the case of tax and with an elasticity of -0.3, which is the least favourable adaptation hypothesis, central government gains almost €5.1 billion (see Table 3) but “only” €1.2 billion with an elasticity of -0.7. This gain results from the newly paid tax even if the quantity of fuel consumed decreases. On the opposite with fuel rights the central government loses more than €1.7 billion of tax revenue. This is due to the reduction in the amounts of fuel consumed, which is not compensated for by an additional tax. As a matter of interest, the total tax collected on fuels amounted to approximately €30.5 billion in 1998, of which €23.6 billion came from excise duty. Thus the fiscal revenue loss in case of fuel rights would only represent about 5% of current fiscal revenue due to fuel consumption.

Table 3. **Distribution of surplus in case of tax and fuel rights**

	Total surplus motorists (mill. €)	**Total surplus central government (mill. €)**	**Average motorist surplus per vehicle (€)**
Tax			
e=-0.3	-7 198	5 107	-275
e=-0.7	-3 076	1 183	-118
Fuel rights			
e=-0.3	-374	-1 718	-14
e=-0.7	-161	-1 732	-6

Source: Raux and Marlot, 2005.

Second, in the case of the tax, motorists as a group lose between €3 billion (with an elasticity of -0.7, see again Table 3) and almost €7.2 billion (with an elasticity of -0.3). Moreover, whatever their type of residential location, all motorists “lose” to the benefit of society (between €118 and €275 on average per vehicle). With fuel rights, on the contrary, because of the free allocation these transfers are very much reduced. For each of the two elasticity values (-0.3 and -0.7), motorists as a group would lose, respectively, €374 million and €161 million, the annual loss per vehicle would be on average respectively €14 and €6.

Third, in the case of fuel rights, residential location plays a fundamental role: the main winners (see Table 4) are households living in the city centre or the suburbs who, on average, sell rights (they can more easily save fuel, therefore rights, by reducing their vehicle-kilometres travelled) while the households living in peri-urban areas are on average the largest purchasers. Between 1 billion and 1.4 billion rights would be exchanged (on the basis of one right for one litre of fuel): this figure is to be compared with annual fuel consumption of 26 billion litres. The orders of magnitude are of a few euros or tens of Euros of net gains or losses on average every year for each vehicle and between each category of residential location. Although these sums might seem small at first sight, it should be remembered that they are average results per category of motorists and may cover extremely varied adjustment behaviours.

Table 4. **Distribution of surplus according to location in case of fuel rights**

Location	**e=-0.3**		**e=-0.7**	
	Average motorist surplus per vehicle (€)	**Rights exchanges (millions)**	**Average motorist surplus per vehicle (€)**	**Rights exchanges (millions)**
City centre	9	870	1	577
Suburbs	3	546	0	453
Peri-urban	-41	-1 367	-16	-1 019
Rural	-16	-49	-5	-11
Total	-14	0	-6	0

Source: Raux and Marlot, 2005.

Finally, the cost of CO_2 saved can be roughly estimated. The net surplus loss for a 10% reduction of consumption, which is given in Table 3 (fuel rights case) is between €161 and €374 million. The quantity of tonnes of CO_2 saved, i.e. 10% of 26 billion litres, with an average of 2.5 kg of CO_2 emitted per litre, amounts to 6.6 million tonnes of CO_2. The cost of CO_2 saved is approximately €24 per tonne with the assumption of high elasticity (-0.7) and €56 with a pessimistic assumption of low elasticity (-0.3). The first figure has the same order of magnitude as the price of CO_2 per tonne in the first months of ETS, in both cases not including the administrative costs.

4.2.2 Administrative costs

The costs of setting up and administering the system would include: altering the software in the ATM at petrol stations so they can deal with the fuel right system (reading the balance, debiting); manufacturing and distributing chip cards, or installing the microcode software on existing bank chip cards during periodic replacement; the information campaign for this new system of transactions; managing the rights exchange market which could be included in the Stock Exchange. In view of the fact that the transactions and verifications required for the rights exchanges will be highly integrated with the current system of credit card transactions, these costs should be moderate. The maximum cost of implementation is estimated between 3 and 4 euros per card. Furthermore, operation could be covered by a fee charged on each right exchanged, a fee which would be very low in view of the high volumes involved.

4.2.3 Acceptability and equity issues

If we consider the development of more stringent objectives for emissions reduction in the future, fuel rationing seems unavoidable: this rationing can basically take the form of either price (tax) or quantities (permits) rationing. From this point of view, the issue of acceptability of rationing is an identical precondition for the two instruments and needs at least an information campaign and political willpower in order to introduce any emissions control measures. This is the first step which needs to be achieved. It is in this context of "accepted rationing" that we can evaluate the relative acceptability of permits.

If we again consider the French case study, this system, with a free allocation on a per capita basis, penalises high-income households more than the others: the data from 1997 (Hivert, 1999) show that the average per-kilometre mileage for each vehicle increases fairly steadily with income, from slightly more than 12 000 km for the lowest income brackets (less than 11 400 euros per year) to almost 16 000 km for the highest income brackets (more than 61 000 euros per year).

Lastly, the initial free allocation avoids imposing an excessive burden on consumers, particularly the least well off. The average annual consumption of cars varies from slightly more than 900 litres (for the lowest incomes) to 1 300 or 1 400 litres (for the highest incomes), while the proportion of mileage covered on home-to-work trips varies between 24% (for the lowest incomes) and 30 or even 39% for the highest income groups. These figures show that "necessary" travel would generally not be affected. However, this average data should not overlook the possible existence of situations of fragility, for example the "rural poor" who have no alternative but the car: such situations would require ad hoc compensation.

4.3. Conclusion

This system has the advantage of simplicity, as the unit of exchange is the permit for each litre of fuel consumed. The amounts consumed or exchanged are therefore monitored when fuel is purchased, and all persons who purchase fuel for private use can participate in the market; therefore, monitoring is straightforward as it only involves fuel purchases. The possibility of freely exchanging permits will discourage any tendency for a black market to develop.

The free allocation of emission rights creates an income which is distributed among the fuel consumers. In addition, these consumers are strongly encouraged to reduce their consumption as they can make a real and tangible profit from selling their unused permits.

5. TRADABLE FUEL RIGHTS FOR FREIGHT TRANSPORTATION

As previously explained, environmental effectiveness and economic efficiency pleads for directly targeting the consumption of fossil fuels. Targeting intermediate behaviours (tonne-kilometres, vehicle-kilometres, load rate or empty journeys) with specific, quantitative objectives would be, at the same time, expensive in terms of information for the regulator and a source of efficiency loss.

Here again, the design of a system of CO_2 emissions rights for freight transportation implies the identification of the agents holding those quotas and discussion of the method of allocation. This is followed by the issues of geographic and sector-based coverage of the scheme, and then monitoring and transaction costs. Based on this discussion a final proposal is presented, followed by concluding remarks on potential environmental and border effects.

5.1. Rights holders, obligations and allocation

Which entities will hold, exchange and have to return the rights for emissions generated? And, consequently, which actors will have to bear the emissions reduction burden? Freight transport activity, and its consequences as regards CO_2 emissions, results from an array of decisions taken by agents, shippers and carriers, with sometimes divergent economic logic. Added to this multiplicity of agents are as many different decision-making centres with unequal capacities of negotiation.

The targeting of fuel consumption naturally gives an incentive to carriers. However, the current operation of the logistic chain leaves them only limited margin for manoeuvre. Shippers, because of their requirements in terms of schedules, logistic constraints and required services, impose a framework with which the carriers must comply. Is it possible to involve the agents higher up the logistic chain in order to guarantee the effectiveness of the incentives?

For a firm carrying goods on its own, the problem does not seem insurmountable, given the integration of decisions within the firm. The firm will optimise its activity, including its industrial and geographical structure of production and distribution. For for-hire carriers, the question is a little more complex being given the current situation of the carrier's vassalage vis-à-vis the shipper. It would be appreciable to work out a system which makes it possible to share reduction efforts between shippers and carriers, taking into account their respective margins for manoeuvre.

One way to involve the shippers in the responsibility of fuel consumption would be to allocate to them a relevant mechanism of fuel rights. Two main types of initial allocation, namely auction or free allocation, could be proposed. The first has the advantage of avoiding complex computations that sometimes require expensive information to obtain. It also avoids implicating the authorities in a difficult negotiation with the agents, by letting the market arbitrate.

The auction of permits offers other advantages *vis-à-vis* the "grandfather rights" method of free allocation generally used. This latter method, which allocates rights proportionate with the past activity, gives a premium to "bad pupils"; i.e. those that use old and polluting technologies would obtain, other things being equal, more quotas than the more virtuous. Moreover, this method of free allocation encourages the entities to delay pollution reduction activities, since they can anticipate the time needed, several years in general, for the implementation of such a system: for instance, carriers could use "polluting" trucks in order to obtain a higher allocation. Lastly, the auctioning of the initial allocation also makes it possible to treat new entities entering the sector on an equal basis with the existing firms.

However, this auctioning is to be perceived as an additional tax, which would undermine its acceptability. This is why we explored the possibility of a free allocation. Several free allocation methods were tested by in-depth interviews with a sample of carriers and shippers (N=20, for details see Raux and Alligier, 2007). These methods included "benchmarking" allocation either to the carriers or to the shippers (with reference to the average ratio of total CO_2 emissions per tonne-kilometre of the freight transport sector), and a "grandfather" allocation to the shipper, based on their past individual ratio of CO_2 emissions per tonne-kilometre.

Many objections were raised by our interlocutors. The feedback from the carriers toward the shippers of information on consumption and vehicle-kilometres seems particularly difficult: the audits considered would be thus particularly expensive (even if they remain limited to the firms which would voluntarily adhere to the system). The standard of allocation according to an average ratio of quota per tonne-kilometre, even individualised by firm, appeared non-relevant and was disputed. The reporting character of this information and the fact of creating rent by this mechanism of free allocation, would make possible some fraudulent behaviour by agreements between carriers and shippers: even if they remained a minority, this would undermine the credibility of the mechanism.

As a whole, these drawbacks and the complexity of this mechanism of allocation justified the reserve, even opposition, of the majority of our shipping interlocutors.

So there would be no free allocation to shippers. However, some free allocation could be considered for transport operators, at least in the first years, in order to improve the acceptability of the scheme. For road hauliers this free allocation could be a "lump sum" allocation per vehicle in order to avoid complicated computations. For rail and river operators, which are far less numerous, this could be a kind of grandfather allocation, as is planned for air carriers in the current project of the European Commission (see above).

5.2. Sector-based and geographic coverage

The effective implementation of such a market for the freight transportation sector should be made at the European Union level at least, for obvious reasons of harmonisation of competition between the firms of the various Member States. This would imply in particular that the question of a free allocation or not and, if a free allocation is adopted, the choice of allocation method and computation are decided at EU level.

Environmental effectiveness implies the coverage of all freight transport modes, namely road, rail, river, maritime and air modes. This effectiveness should also cover the other transport sectors, in particular the private car, whether by a fuel rights market (see above) or by a CO_2 fuel tax for the sectors or agents not included in the fuel rights market.

It would be socially unacceptable to transfer suddenly from a system of taxation to a complete fuel rights system. The two systems must thus coexist, while creating a financial incentive to adhere to the permits system.

As mentioned above, a “CO_2 tax” would apply to the fuel consumers not wishing to take part in the fuel rights market. It would also apply as a “full discharge” payment to the participants to the rights market who would have exhausted their initial allocation and could not, or would not buy rights on the market. This CO_2 tax would constitute the upper price of fuel rights on the market and would make it possible for the regulating authority to limit the rise. The entrance into the fuel rights market would be thus on a voluntary basis.

The geographic coverage at EU level would make it possible to include all intra-European international freight transport, including air, river and sea transport. However, international air and maritime transport is not yet covered by the Kyoto Protocol. Regarding intra-European international air transport, the European Commission proposes its integration into the existing ETS (see above).

5.3. Monitoring and transaction costs

The system effectiveness relies on the possibilities of checking the emissions and managing the fuel rights market, without the transaction costs becoming prohibitive.

As seen above, shippers’ free allocation methods lead to costly information retrieval and the risk of fraudulent use of the system, which justifies their dismissal. The suppression of the free allocation option removes the costs of information retrieval and fraud control.

Regarding transactions, the transfer of quotas between shippers and carriers would be part of their contractual relationship, as currently with the carrying out of the transport services. These contractual relations are already the subject of legislative and regulatory provisions, without the need for intrusion by the authorities into the commercial relationship: thus, there will be no administrative extra cost from this point of view. In the same way, the exchanges of permits on the market would not be bilateral but would pass by a stock market: therefore, there would be no search cost for a partner for the exchange.

The monitoring would thus be reduced to the transfer of quotas to the regulatory authority at the time of fuel purchase. The purchases of fuel for trucks are done either at the pump or out of a tank on the carrier’s site. For the purchases from the pump, and particularly with the pumps reserved for the heavy trucks, the driver generally uses a magnetic or chip card. These cards, as for the ATM distributors, should have their software modified to manage the transfer of rights in proportion to the fuel bought. The participation of the carrier firm to the fuel rights market would suppose an exclusive use of chip cards when fuelling at the pump. As regards the supplies at the tank, the fuel supplier’s invoice should include the debit of rights to the carrier firm (or invoicing them if the firm does not take part in the fuel rights market). On the whole, the risks of fraud are particularly reduced.

5.4. Final proposal

The fuel tradable rights would be thus based on quotas of CO_2 calculated from the carbon contained in the fuel (mainly diesel oil for trucks, or gasoline) consumed by any freight vehicle user, i.e. a for-hire carrier or a shipper transporting on its own account: an obligation would be made to return the corresponding rights to the regulating authority, which would then be cancelled.

In principle, there should be no free allocation to shippers. However, in case of full integration in ETS, shippers holding ETS quotas could use them for transport.

A free allocation could be devised for transport operators in order to improve the acceptability of the scheme. Given the European scale, the principle of a free allocation or not and, if adopted, the choice of allocation method and calculation, would be decided at European Union level.

The for-hire carrier (or the transport organiser) would negotiate with the shipper in order to obtain (or be paid for) fuel rights in view of the achievement of transport operation. Carriers holding unused rights (after having transferred the required quantity referred to above to the regulating authority) could then sell them to the fuel rights market.

All freight transport modes would be covered, i.e. road, rail, river, maritime and air modes. Other transport sectors or agents not included in the fuel rights market (eventually private cars, depending on the extension of fuel rights market to them, see above) would be covered at least by a CO_2 tax. The geographical coverage would be at least at EU level.

Monitoring of quotas to be transferred to the regulating authority would occur at the time of fuel purchase, either at the pump or when filling a tank on the carrier's site.

The entrance into the fuel rights market would be on a voluntary basis. A "CO_2 tax" would apply to the fuel consumers not wishing to take part in the fuel rights market. Participants in the rights market who have exhausted their initial allocation could buy additional rights on the market or pay the CO_2 tax as a "full discharge" payment.

5.5. Potential environmental and border effects

Regarding the possibility of controlling the growth of road freight transport, and hence its CO_2 emissions, several counteracting forces are at work. For some goods, their values are so high that the variations of transport costs under consideration will have hardly any influence on distribution practices; the logic of inventory financial optimisation (holding costs) tends toward "zero stock" and "just-in-time" deliveries, and mainly outclasses the transport-environment optimisation logic; and the growing specialisation of factory production lines results in multiplied exchanges between production sites and thus kilometres travelled by intermediate goods.

These insights show that different sectors of the economy would have differing responses to either CO_2 tax or the emissions trading system. However at the macro level, observation shows that the sensitivity of behaviour to the fuel price is not null, given the recent developments in oil prices. For instance, total fuel deliveries in France, after a first decline in 2000, have been falling since 2002 (SESP, 2006) and this evolution is well correlated with that of the fuel price. This sensitivity affects private cars as well as heavy goods vehicles: total diesel oil consumption for the latter has stabilized since 1999.

Regarding economic impacts, is there a risk of holding a dominant position on the permits market? Could some agents have the capacity to distort competition and price mechanisms on the permits market? This risk is probably negligible: indeed, considering only transport, the multiplicity of agents and the dispersion of transport demand between them are such that no agent is likely to have sufficient power on its own[15].

The sector-based and geographic coverage and the mechanism considered make it possible to claim that there would be no discrimination as regards the marketing of fuel rights between firms of the 27 Member States of the European Union, whether they are shippers or carriers.

A legitimate interrogation remains, however: that of possible competition from carriers outside the European Union. In fact, the carriage of goods is less prone to economic distortion than the other branches of industry: freight will always have to be loaded in locations within the EU in order to be distributed for use in other locations within the EU, whether processing industries or final goods delivery locations. The only notable incidence would come from carriers being able to load fuel outside the European Union, not submitted to CO_2 taxation or fuel rights, and then transporting within the EU. This competition could be significant in the border countries, but limited through the trade-off between the weight of the carried fuel and the payload.

5.6. Concluding comments

Shippers using own-account transport have a direct incentive to minimise their fuel consumption, since they would have to surrender rights in direct proportion to the fuel consumed by their vehicles. Conversely, shippers using for-hire carriage are not directly subject to this restriction. This said, there are two factors that could influence the behaviour of the latter. Firstly, should they fail to make allowances for this constraint on carriers, there is the risk that the latter may gradually disappear, which would mean the economic balance would tip towards transport operators who managed to survive, and this alone might persuade reluctant shippers to compromise. The second factor is the increasing trend towards the inclusion of environmental aspects into corporate activity reports to shareholders and the public. This would give shippers an incentive to gear their activity so as to reduce shipment-related emissions.

For their part, hauliers and organisers of third-party transport could “bank” with the rights they negotiate on different orders from shippers. If they have made efforts to minimise their own fuel consumption, by grouping loads and reducing vehicle-kilometres or unitary vehicle consumption, for example, they would pocket the difference. In the same way, regarding railroad combined transport, the fuel consumption for the road transport haul to a rail terminal would be debited to combined transport organisers when they provide the transport service (as well as any diesel consumed on a rail transport leg). Lastly, rail transport operators would receive rights allocations, most of which they could sell on, depending on the degree of electrification of the network (and the share of nuclear or renewable energy used to generate their electrical power).

6. TRADABLE DRIVING RIGHTS IN URBAN AREAS

Congestion and pollution caused by automobile traffic are major and recurring concerns in urban agglomerations all over the world. Taking the economist's perspective, these phenomena reflect over-consumption of scarce goods, i.e. road capacity in the case of traffic congestion or clean air in the case of atmospheric pollution: this over-consumption is the result of the under-pricing of these goods. Thus the policy measure favoured by economists (Walters, 1961; Vickrey, 1963) is road user charging or congestion charging, which are both implemented by road tolls. In spite of the success of the London Congestion Charging Scheme (since 2003) or the successful experiment in Stockholm in 2006 followed by implementation in 2007, social and political resistance to congestion pricing is still strong in other cities.

Although it is accepted that introducing congestion pricing increases the welfare of the community as a whole, redistribution occurs (Baumol and Oates, 1988; Hau, 1992). In general, the situation of most motorists deteriorates; for a minority with high values of time it improves; while the government that collects toll revenues becomes wealthier. So, in general, there is little chance of a congestion charge being accepted, unless motorists are convinced that the government will distribute the resources collected efficiently and equitably.

In the light of these difficulties, TPs applied to these specific urban issues might be of interest. The allocation of quotas for trips or vehicle-kilometres to motorists within a given urban area has been proposed, with the possibility of these quotas being tradable (Verhoef *et al*., 1997; Marlot, 1998). A "credit-based congestion pricing" mechanism has been proposed by Kockelman and Kalmanje (2005).

This section will show the types of adverse impact this instrument may be appropriate for in urban areas and what targets may be set. To the best of our knowledge, none of the proposals quoted above is detailed enough for it to be possible to judge whether this type of measure could be applied in urban areas. In this context, however, "the devil is in the detail": from the specification of the implementation of TPs for urban travel demand management, the applicability of this type of instrument will be illustrated by referring to an example of implementation, along with elements of evaluation.

6.1. Specifications

What are the specifications for the implementation of tradable permit markets for urban transport demand management? The purpose is twofold: to limit the increase on the one hand of vehicle-kilometres travelled (VKT), particularly during peak periods, and on the other hand of atmospheric pollutant emissions from vehicles. The ideal, from an efficiency point of view, would be to target VKT with the ability to make distinctions on the basis of time and space (congestion) and the type of vehicle (atmospheric pollutant emissions).

However, the limited possibilities of affordable technology mean that a compromise must be accepted with regard to this objective. Therefore, we firstly need to take stock of technological possibilities at the present time and in the near future. Secondly, the specifications that TPs must satisfy to tackle congestion and pollution will be examined.

6.1.1 Existing and conceivable technologies and their costs

The most mature technology at the present time is roadside Electronic Toll Collection (ETC). This is based on an on-board electronic tag which uses Dedicated Short-Range Communications (DSRC) to dialogue with roadside readers. This procedure requires prior registering of both vehicles and drivers. A more sophisticated version involves debiting on the fly a preloaded smartcard or credit card that is inserted in the on-board unit (OBU). Objections with regard to the protection of privacy can be overcome by allowing the anonymous purchase of cards which have already been loaded with units. This kind of system is used in Singapore since 1998, with initially 32 gantries and 674 000 in-vehicle units distributed free of charge, with a total investment cost of USD 114 million (Menon, 2000). Annual operating costs stand at USD 9 million for roughly six million daily transactions in 2003 (Menon and Chin, 2004).

A second type of toll collection technology, based on a vehicle positioning system (VPS) using satellites (the international GPS system or the European Galileo system), is currently emerging. A well-known example is the TollCollect programme for lorries on the German motorway network. However, this technology needs an expensive on-board unit (currently between €200 and €400) while complex and costly manual procedures which duplicate the electronic system are required to process occasional users. Moreover, the possibility of permanently tracking vehicles raises obvious issues with regard to protecting the privacy of car drivers.

This is why, on the basis of these current technical possibilities and their present-day costs, the most immediate implementation would be based on roadside ETC (RS-ETC) and would cover all motorised vehicle trips in the zone covered by the traffic restriction scheme. In order to cover all the vehicle-kilometres travelled within the zone covered by the scheme, the second technology based on satellite vehicle positioning would be required.

6.1.2 Specifications of TPs to tackle congestion and pollution

In order to design these specifications a series of questions must be answered: they are briefly set out below.

The first relates to the specification of the unit to be traded. In view of the stated objectives, this will consist of driving rights (DR). It must be possible to make distinctions with regard to these driving rights on the basis of space and time (congestion) and according to the vehicle's emission levels (pollution). The mechanism for doing this and its parameters must then be specified.

The second question relates to specifying the entities which will hold and trade quotas and be obliged to return them on the basis of their emissions. This can consist of motorists or inhabitants.

The third question is how these quotas will be allocated: should they be allocated free of charge? If not, the entities affected by the scheme will have to buy all the permits they need on the market: in the event of the total available quantity on the market being small, it is equivalent to setting up a quota auction. Economically, this is the most efficient solution as it obliges actors to reveal their preferences. It is also consistent with the polluter-pays principle and creates a usable financial resource. However, as with congestion charging it immediately increases the financial burden on the actors involved: this would eliminate the essential acceptability advantage that driving rights could have over congestion charging. Consequently, at least some of the quotas would have to be allocated free of charge as a visible and immediate compensation in order to facilitate this instrument's acceptability.

If the quotas are allocated free of charge, to whom should they be allocated and with what distribution method? The problem is that although in theory these methods do not threaten the efficiency of the instrument, they ultimately determine the financial burden on the participating entities. Will these entities be vehicle owners or inhabitants? Choosing the latter would amount to compensating inhabitants for the consequences of congestion and pollution. This would involve those who drive little or not at all – pedestrians and public transport users – and not only motorists, which would improve the acceptability of the scheme.

Other issues relate to the period of validity of the quotas and the quota payment obligations. These parameters must be fixed in a way that maintains incentives to reduce consumption of driving rights, particularly during congested periods, and to reduce pollutant emissions.

Last, two questions must receive particular attention. The first is the possibility of keeping the transactions anonymous, which is an obvious factor for the acceptability of a new control mechanism. The second is how to deal with "border effects", in particular the management of occasional users and the anticipation of unforeseen behaviours which might undermine the effectiveness of the programme.

6.2. A system of tradable driving rights for urban areas

From the previous specifications, the features of the system can be designed: the unit to be traded with the computation of driving rights according to congestion and pollution levels; the allocation method; rights trading; period of validity of rights; and then tracking and checks of driving rights consumption.

6.2.1 The unit to be traded

The unit to be traded would be the *driving right* (DR). In the RS-ETC system, the unit of account for DRs would be the trip, while in the VPS-ETC system it would be the VKT.

An agency in charge of transportation in the conurbation and receiving its powers from the local elected authorities would fix the parameters of the programme. To do this, the agency would make use of a survey system including, for example, Household Travel Surveys and traffic count data (for example, from cordon traffic surveys).

The agency would specify the zones (on the basis of population density), the peak and off-peak periods, as well as the vehicle emission classes (using, for example, the Euro standards). These design issues are broadly similar to those of a congestion charging scheme.

These parameters would be used to compute the weighting of the DRs which would be charged to drivers. The DRs would be weighted on the basis of the level of congestion, but also on the basis of the size of the vehicle in *passenger car units* (PCUs) and its atmospheric pollutant emission class.

All the drivers entering and travelling within the zone covered by the scheme would be liable to return DR quotas to the agency on the basis of a computation method with the following principles.

A first kind of weighting could be set up with respect to standards of pollutants emissions (see for instance in Table 1 the vehicle emission standards in the European Union): the vehicle that pollutes the least (the Euro IV M1 petrol passenger car) would get the lowest weight while "dirtier" vehicles would get a higher and higher weight factor according to their Euro (III to I) class.

A second kind of weighting factor could be set up for congestion, making a distinction between the zone of travel (low/high density) and the time of travel (off peak periods/peak periods) as a result of the increase in the level of congestion in these zones and the larger population that is exposed to traffic nuisance in them.

These two weightings, which should be adjusted accurately on the basis of the estimated costs of congestion and pollution, could be combined to derive a public rule for the number of DRs to be returned to the regulating authority. These weightings obviously assume the capacity to identify vehicles on road on the basis of their Euro category (see "Tracking, checks" below).

6.2.2 Allocation

The proportion of the driving rights allocated to the inhabitants of the urban zone would be estimated initially by the survey system described above. These DRs would be distributed free of charge equally between all the inhabitants. Data would serve as a basis for the elected representatives to decide what they think it is fair to allocate free of charge to inhabitants. Each inhabitant would have a DR account with the agency, and this account would initially be credited with this free allocation.

The driving rights which are not allocated would be sold by the agency. This means those motorists who live outside the conurbation and business users (for example, those making deliveries for firms, tradesmen, doctors, etc.), those making through trips, and those inhabitants of the urban zone who have used up their remaining DRs would be able to purchase DRs. The sale of these rights by the agency would resemble conventional congestion charging.

As driving rights are allocated to individuals but used by vehicles, there is an obvious incentive for carpooling.

6.2.3 Rights trading

Regarding the trading of rights, a careful approach would be to not leave the management of driving rights entirely to the market: rights which are not allocated free of charge would be sold at a price fixed by the agency, the same price at which the agency would buy back unused rights.

However, nothing would prevent a holder of unused rights from transferring them (or even give them free of charge) to an acquaintance. In practical terms, this would involve simply notifying the agency that rights have been transferred from one account to another (for example, by making an electronic Internet transfer). Obviously, there would be no black market as sale and purchase would be unrestricted.

Likewise, small business users would be able to use the rights allocated to them as residents of the conurbation for either their private or their business trips. Lastly, it might be possible for families to combine the rights accounts of their members to form a joint account to which the DR smartcards of the family members would be linked.

6.2.4 Period of validity

At the start of the scheme, each resident in the urban zone would, for instance, obtain a free allocation amounting to several weeks of rights, so that from the outset they would each be able to use the rights they are allocated variably from one week to another. Next, at the start of each week, the resident would be allocated rights for a period of seven days, thus giving the rights holder the flexibility to distribute them over the week as he/she wishes from the outset. These rights would be valid for one year after they have been allocated. Unused rights could be sold back to the agency at any time, even after their validity has expired.

The balance of a resident's DR account should never be negative. Put another way, as soon as a resident's rights have been completely used up, he or she would have to buy the necessary additional rights at the market price.

The risk of over-consumption of rights at certain periods during the day, the week or the month would be quite limited for a number of reasons. First, the rate at which DRs are used up increases with the level of congestion and pollution: there would be an opportunity cost for each right since those used up during a congested period will not be used elsewhere or at another time. Next, the use of these rights would be associated with another (transport) expenditure in order to perform an activity whose net utility would have to be positive in order for it to take place. Last, as the agency would be able to buy back unused rights, residents would have no incentive to make additional trips to use up their rights.

6.2.5 Tracking, checks

As said above, the VPS-ETC, i.e. a satellite-based vehicle positioning system, is currently prone to some drawbacks which prevent it from a very near-future implementation in urban areas. This is why a DR collection system would take the form of RS-ETC.

The on-board unit could be provided free of charge to motorists in order to encourage electronic transactions as much as possible, thus easing traffic flow through the checkpoints. This equipment would identify the type of vehicle and in particular its Euro class. It would permit the automatic debiting of the required number of DRs from a smartcard while vehicles are travelling.

The DR smartcards would be distributed free of charge to those who choose to have the on-board equipment. The cards would be credited with the DRs allocated to or purchased by the motorist.

The number of vehicle detection gantries should be minimised by using natural barriers (for example, rivers or railway lines) and the road network topology (i.e. single ways). The main difficulty is then to detect car "trips"[16], since traffic would be monitored only by detection of vehicles when passing a gantry. The solution would be to link the right to drive to a period of, say, one hour after the first detection by a gantry. That is to say, if the car is detected again within this period of one hour, it would be considered as the same trip and no supplementary DR would be debited. Trips of more than one hour's duration would be longer-distance trips and then it would be fair to debit one more DR.

In order to improve the acceptability of the scheme, a maximum daily number of DRs to be debited would be set, following the example of the maximum daily charge in the Stockholm congestion charging trial.

For coping with occasional users, potential malfunctions or violations must be detected with the help of *video enforcement systems* (VES), as previously quoted. The VES can be used to fight the fraudulent use of on-board units by randomly checking the suitability of the tag against the Euro class of the vehicle with the help of the vehicle registration database.

The VES can also be used to detect vehicles not equipped with on-board units, either because they only drive occasionally in the zone (for example, visitors) or because they refuse to have an on-board unit of any type. This was the policy of the Stockholm congestion charging trial. After having being detected, the driver can pay the charge within a given period (for instance, two weeks, as in the Stockholm case). The payment and recovery mechanism for the invoice could be similar to that in the London or Stockholm schemes (unsolicited payment by Internet, telephone or in shops, before a potential fine and recovery by a specialised firm).

In order to minimise the amount of such potential malfunctions, a financial incentive can be offered to register and obtain the on-board unit. This incentive could be that the regular fee for driving through the scheme area for one day while not being registered would be the equivalent of the maximum daily number of DRs debited applicable to registered users (see above).

6.2.6 An example of implementation

This kind of scheme has been devised for the Lyon urban area (1 200 000 inhabitants, including the inner city of Lyon-Villeurbanne with approximately 600 000 inhabitants) and assessed with computation of various economic surpluses (for details on methodology and results, see Raux, 2007).

The implementation of DRs would be based on an RS-ETC system, as described above, which would regulate the number of trips. For the sake of simplicity, in the first years of the scheme no particular weighting would be applied to DRs according to the Euro standard. The debiting of DRs would be effective only in periods of higher traffic, for instance, between 6 a.m. and 7 p.m. from Monday to Friday: this would be a proxy for weighting DRs according to congestion.

With a limited objective of only capping , for reasons of acceptability, the current total number of trips made by car during the first years of the scheme, TDRs amounting to this level would be allocated for free between the Lyon-Villeurbanne inhabitants: in this case, most of the potential surplus (92%) gained by the local government in the case of conventional road pricing would instead be redistributed between motorists and inhabitants of the inner city. A small proportion of this surplus (8%), corresponding to the share of external traffic without a free allocation of TDRs, would constitute revenue for the local government.

6.3. Concluding comments

Barriers to the implementation of TDR are mostly the same as for conventional urban road pricing, as the purpose of both instruments is to regulate transport externalities and hence travel intensity. These barriers have already been identified in the literature (see Jones, 1998; Schlag and Teubel, 1997).

The issue of the legal feasibility of regulating urban car travel with TDR is broadly analogous to the one for area or cordon road pricing. The national legal framework must be made compatible if needed, which is not yet achieved in many countries, including France.

One of the main barriers to implementation of regulation appealing to the market is equity concerns, summarised as “the poor won’t be able to travel any more”. At this point there is a noticeable difference between TDR and road pricing, since part of the TDR can be allocated for free: this is a guarantee for a minimal travel capability which is not affected by the pricing of rights on the market, even for those drivers who are unwilling or unable to abandon their car. Regarding acceptability, this free allocation is an advantage for TDR over road pricing. The second advantage is that with this free allocation, individuals have a supplementary incentive to save, whether trips or distance travelled by car, beyond their initial allocation of driving rights because they can sell unused rights and then obtain a tangible reward for their "virtuous" behaviour.

Geographical equity is also a crucial issue when drivers living inside the charging zone obtain free allocations while those living outside would have to buy driving rights. In the London congestion charging scheme, where discount fees are delivered to inhabitants, or for cordon schemes such as in Oslo or Stockholm where those driving inside can do so for free, this issue has been resolved by agreements between local governments on charging and surrounding areas on the allocation of revenues from pricing. A similar agreement must be reached in the case of TDR.

More generally, the allocation of free TDRs creates rights concerning the urban rent which are shared among the inhabitants rather than being captured by the local government. These characteristics make free TDRs essentially different from conventional urban road pricing, with even special discounts for some users.

Conventional congestion charging involves a transfer from motorists to the community, which is able to use the revenue as it judges best, while the free allocation of tradable driving rights confines a certain proportion of the transfers to within the group of motorists and the population. This loss of revenue for the public authorities represents the price that must be paid for the acceptability of congestion charging, and this price may seem very high.

A possible strategy would be to introduce a capping mechanism on free allocation and keep this quantitative level constant from year to year. As demand increases with the growth of the agglomeration, purchases of the additional TDRs required would provide revenue for the transport authority. Thus transport users would reveal their preferences, providing a signal to the community to invest in a cost-efficient manner in developing the supply of transport, but not necessarily road transport.

Finally, TDRs could coexist with tradable fuel rights schemes: while the latter target the consumption of fossil fuel at the country level, TDRs are restricted to urban zones and target congestion and atmospheric pollution. TDRs are, of course, an alternative to conventional congestion charging. Existing parking control systems could, however, be maintained.

7. POTENTIAL PITFALLS AND IMPLEMENTATION ISSUES

Europe's experience with the ETS has identified the pitfalls to be avoided: this section shows how the above proposals can respond to these concerns. Opening up these fuel rights markets to other countries or sectors of the economy is a second issue addressed. Lastly, the issue of the co-ordinated launch of these different markets is discussed.

7.1. Pitfalls to avoid in the light of the European Emissions Trading Scheme

The experience gained from the first phase of the ETS (2005-2007) has been instructive in many respects: much criticism has been levelled at the ETS in particular (cf. Open Europe, 2007) and at emissions trading markets in general with respect to their ability to meet the challenge of curbing greenhouse gas emissions.

A first criticism often encountered is that this "market" never actually worked in the first place, as can be seen from the collapse in the price of the permit per tonne of CO_2 in 2006, from the point when Member States first began to declare their actual emissions, which turned out to be lower than the initial allocations. Furthermore, when it became clear that the allowances held in this first phase would not be valid for the second phase (2008-2012) the market price plummeted again. On the contrary, all of this shows that the market played its equilibrium price-setting role perfectly given the surfeit of, by then, worthless allowances.

The over-generous allocation of allowances which precipitated the collapse of the market price can be put down to Member States, most of which clearly sought to favour their own industries: the latter captured the decision-making process after intensive lobbying (Godard, 2005).

One possible way of counteracting these effects would be to centralise decisions on allocations at European Union level, reversing the subsidiarity principle. That is why, should there be a market with free allocation of fuel rights for freight transport, we propose that not only the principle but also the calculation of the free allowance be centralised. However, there are grounds for fearing that centralising these decisions in Brussels may not make them immune to intensive lobbying by industry organisations, or to a degree of opacity in the European decision-making process.

Lastly, another criticism: the costs of administering and declaring emissions would be high for small emitters, i.e. structures managing only a few stationary installations (for example, a boiler in a hospital).

It may legitimately be said that these failings stem essentially from the principle and method of free allocation adopted. The above proposals on fuel rights are aimed at avoiding these failings.

In the case of fuel rights for drivers, the principle of a set free-of-charge allocation is proposed. As it is a set allocation, it avoids the need for complicated calculations that are costly to administer on an individual basis. The simplicity of the allocation principle proposed and the transparency of the calculation, as well as the fact that it applies to the entire population, reduces any risk of government decision-making being captured by private interest groups.

For freight transport, it is proposed that there be no free allocation to shippers, which eliminates any reason to lobby for allocations and the adverse consequences that might have. Clearly, this principle runs counter to the free allocation principle applicable currently in the ETS, to which fuel rights programmes will have to conform one way or another: moreover, several authoritative voices are questioning the principle of free allocation in the ETS today and are arguing for allocations to be auctioned. On the other hand, as stated previously, fuel rights could be allocated as a set allowance free of charge for road freight vehicles: in order to reduce the risks of escalating allocations if Member States pursue a beggar-my-neighbour policy, the flat-rate allocation method should be regulated in detail at European Union level.

As a general rule, the principle of set, cost-free allocations, which avoid complicated calculations, sharply reduces the administrative costs of these programmes. There would still be the costs of monitoring emissions and managing fuel rights transactions, which the proposals above have sought to keep as low as possible.

One last and more basic problem is the volatility of the price of CO_2 observed on the European market. This volatility is compounded by uncertainty about the shape that the ETS will take after 2012. Price volatility runs directly counter to the need for a clear and continuing long-term signal on CO_2 prices which can steer the required investment decisions in the right direction to achieve significant reductions in emissions over several decades. This said, the problem is not specific to tradable permits as an instrument, it also affects tax instruments. Whatever the incentive instruments used, strong political will must emerge if a long-term signal is to be sent.

7.2. International and cross-sector issues

Should the fuel rights market for the transport sector be operated at a national or an international level?

Tradable fuel consumption rights for private vehicles could at first operate mainly on a domestic basis: it would be viable in view of the generally short distances involved in car trips and if we ignore the impact of “tank tourism” at borders. The risk of the latter should be quite limited for countries whose neighbours are also committed to reducing their emissions within the EU bubble: these countries will also have to implement either a “CO_2 tax” or a permit system. However, the autonomy of each central government regarding fuel taxation is limited by the behaviour of its neighbouring countries, as shown by the current difficulties in fuel taxation harmonization within the EU.

On the other hand, tradable fuel consumption rights for freight transportation should operate at EU level, given the high intensity of international competition in this sector. It should be underlined that implementation of TPs for transportation, like ETS, does not need the unanimous approval of the EU Member States, unlike fiscal policy.

Should the fuel rights market for the transport sector be closed or open to the cross-sector permits market?

By closing the market, i.e. preventing CO_2 emission permits to be bought by transport users from, say, ETS or to be sold by transport users to the ETS, governments or the EU can manage a different level of abatement burden in the transport sector when compared with other economic sectors.

In general, if markets are closed to each other, the marginal costs of reducing CO_2 emissions are likely not to be the same in different sectors. Distortions of this type will reduce the efficiency of the policy. Although this could be justified regarding the transport sector for a variety of social or political reasons, closure of the market should be considered as a temporary measure. Ultimately, the permits market system should be open, that is to say that everyone in the country emitting GHGs in different sectors of activity would be able to exchange rights on the same market.

Quite clearly, downstream tradable permits markets would replace any upstream permit market for energy producers. They would also render pointless and redundant a tradable permits market for automobile manufacturers based on unitary emissions from the vehicles they sell. True, vehicle buyers would be confronted with a degree of rigidity in energy-efficient supply in the short term. This is a constraint which could be alleviated by two measures. First, the reduction in rights allocations each year could be very gradual in order to facilitate initial changes in driver behaviour. Second, the announcement of a mechanism for reducing allocations over several years would send a clear, long-term signal to car manufacturers, so they would rapidly develop highly energy-efficient vehicles: in fact, manufacturers would be relatively certain that these vehicles would find customers, in contrast to the situation at present.

7.3. Phased, co-ordinated implementation

Let us first stress that fuel rights markets in the transport sector could be phased in. The fact that a market is open does not mean that it will gain the support of all of the stakeholders overnight. Rights transaction operations – for instance, debiting procedures at the pump – will require physical modifications which inevitably take time. This said, the necessary modifications might well happen quickly as fuel distributors will wish to attract customers who want to participate in the rights market.

If stakeholders are free to enter the market, the incentive for them to do so will implicitly be the existence of a "CO_2 tax", provided that the latter, driven by governments, remains higher than the price of fuel rights on the market. The other role of the "CO_2 tax" is to ensure fair treatment while avoiding finding ways around emission reduction requirements.

For political and practical reasons, the different fuel rights markets could be introduced separately, i.e. on different dates for the freight transport and private car sectors. The crucial point is that as soon as at least one of the markets is introduced, a general "CO_2 tax" is established for all of the players not yet concerned. To ensure the acceptability of these measures, the tax should be reasonably low to begin with, with increases to be phased in over several years announced in advance. This will mean that both markets will have to be established within a short timeframe.

8. CONCLUSION

Decentralised permit markets in the transport sector have advantages, in theory, given the need to reduce transport nuisances and, in particular, to include the sector in the global effort to reduce CO_2 emissions. They also allow us to separate the issue of the economic efficiency of nuisance reduction programmes from the issue of their equity.

Their application to the problem of congestion and atmospheric pollutant emissions in urban areas seems feasible and effective at reducing kilometres travelled, while encouraging the use of cleaner vehicles. The free allocation of driving rights to the residents of the area concerned, rather than generating toll revenues for local authorities, is perhaps the price we have to pay to make this type of regulation acceptable and applicable in practice.

As regards CO_2 emissions, the free allocation of fuel consumption rights is a more pragmatic response to concerns about fairness than taxation alone. Moreover, given the current high levels of fuel taxes, for example, in Europe, this type of allocation would make more acceptable a programme to ration fuel by quantity rather than price.

In addition, the free allocation would provide a strong incentive to reduce fossil fuel consumption because of the tangible advantages to be gained by anyone who cuts their consumption to a level below their initial rights allocation.

The basic objection to the implementation of decentralised rights markets in the transport sector is that the costs of implementation would be much too high for the desired results, given the very large number of actors concerned. The proposals set out above, for both private vehicle users and freight transport, are intended to reduce these costs as much as possible: they avoid complex allocation calculations. The only remaining costs are those of monitoring emissions and managing fuel rights transactions by electronic procedures for purchases at the pump.

Admittedly, the cost of operating fuel rights markets would be higher than simply extending current taxes on fuel. That may be the price to be paid for the actual implementation of a programme to reduce emissions by transport users.

NOTES

1. The terms “quota”, “permit” or “right” are used interchangeably in this report.

2. However, some other economists argue the opposite (see, for instance, Nordhaus, 2006).

3. I.e. a 10% increase in price would lead to a 3% reduction in fuel demand.

4. This does not apply to the current European Trading Scheme, as the penalty is not a payment in full discharge.

5. Primary gases, in the case of air pollutants such as CO_2, SO_2, NO_x and VOCs. Secondary chemical reactions, such as ozone formation, may also be considered.

6. In France, for instance, the combustion of one litre of gasoline emits, on average, 2.401 kg of CO_2, while this figure is 2.622 kg of CO_2 for one litre of diesel oil (*source:* ADEME).

7. As the permits will have a value on the market, the opportunity cost for a fuel supplier would consist in not selling on the market the permits received for free, or not recovering their value in the form of extra costs to their consumers.

8. These six greenhouse gases are: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO_x), hydrofluorocarbons (HFC), perfluorocarbons (PFC) and sulphur hexafluoride (SF6).

9. The aim of the Protocol is an average reduction of 5.2% for industrialised countries as a whole, while the Rio Convention aspired to a reduction of 50%.

10. In contrast, the Directive set a standard penalty in the event of a firm exceeding its allocation; payment of the penalty tax of EUR 40 per tonne of CO_2 does not release the offending firm from its obligations.

11. Except taxing this revenue, from which arises a new complexity.

12. For a detailed review of the physics and chemistry of air transport emissions and a discussion of possible ways of measuring them, cf. Wit *et al*. (2005).

13. Strictly speaking, this value should vary according to the type of fuel: diesel fuel contains more carbon than gasoline; gasoline with ETBE can have different emissions than gasoline without ETBE. A conversion factor would apply for each kind of fuel. For the purpose of simplicity of exposition and evaluation, in this paper we have assumed that one rights unit corresponds to one litre of any fuel.

14. Based on the mileages and unit consumption figures which are reported in the panel survey (13 719 km on average, and slightly less than 7.5 l/100 km), average annual consumption is 1 022 litres (Hivert, 1999).

15. For example, Arcelor-Mittal, the first European shipper, generates less than 1% of the tonne-kilometres in France (personal communication).

16. The option of driving *day* rights is dismissed because it is not sufficiently linked to travel intensity and period.

BIBLIOGRAPHY

Alberola, E. (2006), Prix des quotas de CO_2: premiers enseignements. *Lettre trimestrielle de la Mission Climat de la Caisse des Dépôts*, No.°5, January.

Albrecht, J. (2000), The diffusion of cleaner vehicles in CO_2 emission trading designs, *Transportation Research Part D*, 5:385-401.

Baumol, W. and W. Oates (1988), *The theory of environmental policy*, Cambridge University Press, Cambridge, 299 p.

CEC (2006), Proposal for a Directive of the European Parliament and of the Council of 20 December 2006 amending Directive 2003/87/EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community, COM(2006) 818, Commission of the European Communities, Brussels.

Chin, A. and P. Smith (1997), Automobile Ownership and Government Policy: The Economics of Singapore's Vehicle Quota Scheme, *Transportation Research Part A*, 31: 129-140.

Coase, R. (1960), The Problem of Social Cost, *Journal of Law and Economics*, 3: 1-44.

Dales, J.H. (1968), Land, water and ownership, *Canadian Journal of Economics*, 1: 797-804.

ENERDATA, LEPII (2005), *Étude pour une prospective énergétique concernant la France*. Report for the DGEMP, Paris.

Foster, V. and R. Hahn (1995), Designing more efficient markets: Lessons from Los Angeles' Smog Control, *Journal of Law and Economics*, 38:19-48.

German, J. (2006), Reducing Vehicle Emissions through Cap-and-Trade Schemes, in: D. Sperling and J. Cannon (eds.), *Driving Climate Change. Cutting Carbon from Transportation*, Elsevier, 2006, 89-105.

Godard, O. (2000), L'expérience américaine des permis négociables, *Économie Internationale*, 82: 13-43.

Godard, O. (2005), Politique de l'effet de serre – Une évaluation du plan français de quotas de CO_2, *Revue française d'économie*, XIX(4), 147-186.

Goodwin, P.B. (1988), *Evidence on Car and Public Transport Demand Elasticities, 1980-1988*, TSU Ref. 427, Oxford, June.

Hahn, R. and G. Hester (1989), Marketable permits: lessons for theory and practice, *Ecology Law Quarterly*, 16: 361-406.

Hau, T.D. (1992), *Economic fundamentals of road pricing: a diagrammatic analysis*, The World Bank Policy Research Working Paper Series, No. 1070, December, 96 p.

Hivert, L. (1999), Le parc automobile des ménages. Étude en fin d'année 1997. Rapport de convention INRETS-ADEME. INRETS, Arcueil, June.

Hugrel, C. and R. Joumard (2006), *Directives et facteurs agrégés d'émission des véhicules routiers en France de 1970 à 2025*, Report LTE No. 0611, INRETS, June, 160 p.

Jones, P.M. (1998), Urban Road Pricing: Public Acceptability and Barriers to Implementation, in: K.J. Button and E.T. Verhoef (eds.), *Road Pricing, Traffic Congestion and the Environment. Issues of Efficiency and Social Feasibility*, Cheltenham: Edward Elgar Publishing, 263-284.

Kockelman, K.M. and S. Kalmanje (2005), Credit-Based Congestion Pricing: A Proposed Policy and the Public's Response, *Transportation Research 39A*: 671-690.

Koh, W.T.H. and D.C.K. Lee (1994), The vehicle quota system in Singapore: an assessment, *Transportation Research Part A*, 28: 31-47.

Lyons, A. and K. Chatterjee (eds.), (2002), *Transport Lessons from the Fuel Tax Protests of 2000*, Ashgate, Aldershot.

Madre, J.L. and M.H. Massot (1994), Comment décrire l'étalement urbain à partir des nomenclatures de l'INSEE ? Internal note, INRETS, Arcueil.

Marlot, G. (1998), Réguler la congestion par des permis négociables: une solution au dilemme efficacité/acceptabilité. 8th WCTR, Antwerp.

Menon, A.P.G. (2000), ERP in Singapore – a perspective one year on, TEC, February.

Menon, A.P.G. and K.K. Chin (2004), ERP in Singapore – what's been learnt from five years' operation? TEC, February.

Montgomery, W.D. (1972), Markets and licenses and efficient pollution control programs, *Journal of Economic Theory*, 5: 395-418.

Nordhaus, R.R. and K.W. Danish (2003), *Designing a mandatory greenhouse gas reduction program for the US Pew Centre on Global Climate Change*, Arlington, VA., May, 66 p.

Nordhaus, W.D. (2006), After Kyoto: Alternative Mechanisms to Control Global Warming, *American Economic Review*, Vol. 96, No. 2, May, 31-34.

Organisation for Economic Co-operation and Development (OECD) (1997), *Putting Markets to Work. The Design and Use of Marketable Permits and Obligations*, Public Management Occasional Paper 19, Paris.

OECD (1998), *Lessons from Existing Trading Systems for International Greenhouse Gas Emissions Trading,* OECD Environment Directorate, Paris.

OECD (2001), *Domestic Transferable Permits for Environmental Management. Design and Implementation*, OECD, Paris.

OECD (2007), *Cutting Transport CO_2 Emissions. What Progress?* OECD-ECMT, Paris.

Open Europe (2007), *Europe's dirty secret: Why the EU Emissions Trading Scheme isn't working*, Open Europe, London, August, 57 p.

Ottensmann, J.R. (1998), Market-based exchanges of rights within a system of performance zoning, *Planning and Markets*, 1.

Parry, I.W.H., M. Walls and W. Harrington (2007), Automobile Externalities and Policies, Discussion Paper 06-26, *Resources for the Future*, Washington, 37 p.

Raux, C. (2002), The use of transferable permits in the transport sector, in: OECD (ed.), *Implementing Domestic Tradable Permits. Recent Developments and Future Challenges*, OECD, Paris.

Raux, C. (2004), The use of transferable permits in transport policy, *Transportation Research Part D*, Vol. 9/3, pp. 185-197.

Raux, C. (2007), Tradable driving rights in urban areas: their potential for tackling congestion and traffic-related pollution. Working Paper. http://halshs.archives-ouvertes.fr/halshs-00185012/fr

Raux, C. and L. Alligier (2007), A system of CO_2 tradable permits applied to freight transportation: Is it feasible, could it work out? World Conference on Transport Research, June, Berkeley, 14 p.

Raux, C. and G. Marlot (2005), A System of Tradable CO_2 Permits Applied to Fuel Consumption by Motorists, *Transport Policy*, 12, 255-265.

Schlag, B. and U. Teubel (1997), Public Acceptability of Transport Pricing, *IATSS Research*, 21, 134-142.

SESP (2006), *Les comptes des transports en 2005* (tome 1). www.statistiques.equipement.gouv.fr

Stavins, R. (1995), Transaction costs and tradable permits, *Journal of Environmental Economics and Management*, 29: 133-148.

Stern, N. (2006), *Stern Review on the Economics of Climate Change,* Executive Summary, http://www.hm-treasury.gov.uk/d/Executive_Summary.pdf

Verhoef, E., P. Nijkamp and P. Rietveld (1997), Tradable permits: their potential in the regulation of road transport externalities, *Environment and Planning B: Planning and Design*, Vol. 24, 527-548.

Vickrey, W. (1963), Pricing in urban and suburban transport, *American Economic Review: Papers and Proceedings*, 53 (2), May, 452-465.

Walters, A.A. (1961), The theory and measurement of private and social cost of highway congestion, *Econometrica*, Vol. 29, No. 4.

Wang, Q. (1994), Cost savings of using a marketable permit system for regulating light duty vehicle emissions, *Transport Policy*, 1: 221-232.

Weitzman, M.L. (1974), Price *vs.* Quantities, *The Review of Economic Studies*, Vol. 41, No. 4, October, 477-491.

Winkelman, S., T. Hargrave and C. Vanderlan (2000), *Transportation and Domestic Greenhouse Gas Emission Trading*, Center for Clean Air Policy, April, 32 p.

Wit, R., B. Boon, A. Van Velzen, M. Cames, O. Deuber and D. Lee (2005), *Giving wings to emission trading. Inclusion of aviation under the European Emission Trading System (ETS): design and impacts*, Report for the European Commission, DG Environment, 245 p.

THE DESIGN OF EFFECTIVE REGULATIONS IN TRANSPORT

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1. INTRODUCTION

Motor vehicles have been recognized as an important contributor to air quality problems for over 40 years, almost as long as air pollution itself has been considered a public health problem instead of simply a nuisance.

Attempts to control mobile emissions began in the United States, Japan and northern Europe around 1970, amid growing concerns about unhealthy air. Until about a decade ago, direct public health impacts were the focus of auto emissions policies, which were designed to reduce emissions of the so-called "conventional" pollutants, carbon monoxide (CO), volatile organic compounds (VOCs), oxides of nitrogen (NOx) and lead, substances that either alone or upon reaction with other pollutants can cause respiratory disease, elevated cardiovascular disease risk, high blood pressure, photochemical smog formation, reduced visibility and acid deposition. Of these, the most serious (and fortunately the easiest to deal with) was lead, an additive that raised octane levels in gasoline. Today, gasoline is lead-free in most of the developed world and is being steadily phased out almost everywhere else.

More recently, these local air quality concerns were joined by a newly emerging problem to which vehicles are a major contributor – global warming. Motor vehicles emit a substantial share of global CO_2, including roughly 32% of total US emissions[1]. Although the policy response so far has been very limited, many knowledgeable observers believe that implementation of more vigorous CO_2 policies, especially in developed countries, is only a matter of time.

This paper will trace the development of modern regulation of emissions, both local and global, from motor vehicles. To illuminate the principal themes of this story the focus will be on the experiences of the United States and Europe. Among those themes, three stand out – questions that sooner or later must be considered in the development of any environmental policy.

First, the theme of *federalism*. In every country, governments are constituted at various levels of aggregation, from local to national. Which level of government is the most suitable for attacking a given public problem? If different levels of government can fairly claim to have a role in addressing the problem, how will the various responsibilities be assigned and coordinated? In order to develop an effective and efficient public policy, the governments must have both the right incentives and the capacity to do so.

Finding the right level of government to address an environmental problem is a tradeoff between two competing considerations. The government's jurisdiction must be large enough to "internalize the externalities", as an economist would say. That is, if either the environmental evil or the policy remedy has effects that extend beyond its borders, then the policy-maker's incentives will very likely be inappropriate. For example, policies to control emissions of stationary-source air pollutants may not be stringent enough if most of the effects of pollution are experienced in neighbouring jurisdictions. At the same time, the level of government must be appropriate to the problem. Smaller, more local, units of government are more likely to know the preferences of their citizens, yet less likely to have the expertise and experience to deal effectively with particular problems.

The second pervasive theme here is the choice of *policy instrument*: the specific mechanisms used to achieve the environmental objective. It is common to pose two polar types: direct regulation and economic incentives (EI). Rather than commands or requirements, EI instruments provide penalties or rewards to encourage behaviour that will improve environmental quality. Another way of putting the difference is this: with direct regulation, there is a bright line that determines whether behaviour will be tolerated. With EI, the relationship between performance and consequences is continuous and gradual. There is no bright line, just steadily increasing rewards for better performance.

Direct regulation and EI approaches can be compared in many ways: for an extensive discussion, see Harrington, Morgenstern and Sterner (2004). Here, the focus will be on a couple of distinctions that are particularly telling for motor vehicle policies and that are prominent in the discussion below. Most importantly, EI are generally more cost-effective, in that at the same cost of a regulatory instrument, they deliver more environmental improvement. A less well-known advantage of EI is that more information is revealed to policy-makers about the actual cost of regulation, both before and after the regulation is imposed. Under direct regulation, such cost information is rarely forthcoming and is often available only from the parties being regulated, who have little incentive to be truthful. On the other side, there were fears, especially among regulators or environmentalists, that the greater flexibility and discretion granted to polluters by EI approaches would compromise their effectiveness. In addition, direct regulation was seen as more straightforward and simpler. EI required either introduction of taxes, usually beyond the jurisdiction of environmental authorities, or the construction of novel, artificial markets in pollutant reductions.

Thus, despite these apparent advantages, until about fifteen years ago the novelty of EI approaches and the distrust of regulators ensured that the environmental policies actually chosen were heavily dominated by direct regulation. This observation is especially true in the United States, where a great volume of new federal regulation to promote environmental quality was enacted during the 1970s, none of which could be characterized as economic incentives. Since then, however, there has been a remarkable surge of interest in EI approaches in environmental policy. Since at least 1995, whenever new environmental policies are proposed, economic incentive instruments have frequently been suggested and have generally received a respectful hearing.

Instrument choice is about more than just rewards, penalties and requirements, however. It is also about which activities should be rewarded or penalized and how and where performance is to be measured. The most economically efficient instrument must penalize, and therefore be able to measure, the activity by an economic agent that directly causes the damage. For motor vehicles it would be ideal to place a fee on vehicle emission rates or accumulated vehicle emissions directly, and even better if the fee rate varied by time and place, since the impact of emissions depends on circumstances. Such fees operate on every relevant margin: the number of vehicles, how much they are driven, how drivers drive them and how much of the emissions produced are captured by the emission control systems. Thus, vehicle manufacturers would have the appropriate incentive to reduce the emission rates of their vehicles; refiners would have an appropriate incentive to produce fuels that minimize emissions; and motorists would experience directly in their pocketbooks the emission consequences of their driving and trip-taking behaviours and alter them accordingly. In addition, such a tax instrument would operate on all vehicles on the road, whereas the policies that are actually implemented tend to affect only new vehicles.

However, measuring emissions of vehicles in use in a practical manner is not technically feasible for some pollutants, notably the conventional pollutants NOx, VOCs, CO and particulates. This was true in the early 1970s when emission regulations were first appearing, and it is still true today. A second-best alternative would be to use periodic emission tests to estimate emission rates together with mileage to estimate emissions. As discussed further below, though, policy-makers have avoided this approach. In most jurisdictions the primary regulatory instrument to control conventional pollutants is a maximum standard on the emission rates of new vehicles.

For the main global pollutant, CO_2, matters are very different. The amount of CO_2 generated is determined almost exactly by the amount of carbon in the fuel. The amount of CO_2 discharged is the same as the amount generated, as CO_2 abatement is technically not feasible in vehicles. Thus, measurement of carbon used (or, if all fuels have the same carbon content, the measurement of fuel used) is the proper performance measure for this pollutant. Despite this, regulation of global pollutants from vehicles is frequently an emission rate regulation.

The third theme is *policy interactions*. Local and global air pollution are not the only social problems associated with motor vehicle use. Traffic congestion, accidents and oil dependency are also matters of concern and, to various degrees, grist for the policy mill. Of course, government policies at different levels can also interact. Typically, legislative and regulatory initiatives have dealt with environmental, safety and other externality issues in isolation, without considering their effect on other vehicle-related concerns. The question is, how important are these interactions? Do policies interacted to deal with one have an appreciable adverse effect on others? Are opportunities for jointly effective policies being missed?

Fourth, *economic considerations*, including the costs of compliance, the direct and indirect burden of those costs, their effects on regulatory stringency, and through these mechanisms, their political consequences, will be considered. The "cost" of something is a deceptively difficult concept and rarely more so than when dealing with the costs of environmental regulations, which can rarely be directly observed. Not surprisingly, the estimated *ex ante* costs of regulations usually have greater influence on events than estimates of actual costs made after the regulation has been implemented. Therefore, the accuracy of these cost estimates is an important public policy consideration and partially justifies consideration of policy instruments where cost information is revealed automatically.

2. VEHICLE EXTERNALITIES

Many observers have tried to quantify the external costs of motor vehicle use, and these efforts have been fairly controversial. For one thing, industry advocates and conservative commentators often complain that the calculations are unfair because they leave out the benefits of vehicle use. Therefore, before turning to the external costs of auto use, let us consider the private benefits – and costs – of vehicle use. Not only will this digression help explain why vehicle benefits seem to be neglected in policy discussions, but it will help put the valuation of the externalities in perspective. First, we note that the private cost of owning and using a vehicle is high – so high, in fact, that vehicular transportation now accounts for 18% of expenditures among American households (BLS, 2001). According to the American Automobile Association, the per-mile cost of driving is about 56¢/mile. The AAA assumes the vehicle is an average new car, and 73% of the costs are fixed (depreciation, insurance and financing), leaving an average variable cost of vehicle use to be around 15¢ per mile. Barring a major drop in fuel prices, these variable costs will in all likelihood increase with vehicle age, as maintenance expenses increase and the vehicle passes out of warranty. In Europe, the costs of vehicle use are even higher than in the US, owing to higher fuel and vehicle prices. On either side of the ocean, then, vehicle ownership and use is obviously a very costly proposition.

Despite the high costs, driving remains the principal mode of household transportation, in Europe almost as much as in the United States. This is illustrated in Table 1, which shows the mode split between passenger cars and ground transit (rail or bus) in the United States and selected EU countries. As expected, the US tops the chart at 96% passenger cars. But the Netherlands, United Kingdom and Norway are not far behind at 87%, and the only country in the table at less than 75% is the recently-added Czech Republic.

Table 1. **Indicators of car use**

	Mode split: motor vehicle *vs.* bus or rail transit	**Vehicle ownership**	
		2002	**Saturation**
United States	96	812	852
Netherlands	87	477	613
United Kingdom	87	515	707
Norway	87	521	852
Sweden	83	500	825
Switzerland	78	559	803
Czech Republic	70	390	819

Source: Eurostat, FHWA Highway Statistics, Dargay *et al.* (2007).

Table 1 also shows total vehicle ownership per 1 000 of population in these countries, both in the year 2002 and at "saturation". The saturation estimates were developed by Dargay *et al.* (2007), who show that country vehicle ownership rates depend very strongly and robustly on per-capita income. The relationship is S-shaped: at very low and very high income levels, car ownership grows slowly. In the former case the slow growth reflects not only the low population of potential buyers, but perhaps also the lack of infrastructure (roads, fueling stations, etc.) to support vehicle ownership. But as income grows, it seems, everyone wants a car.

The saturation level depends on population density and degree of urbanization, and for most European countries the estimate is above 700 vehicles per 1 000 population. It should be noted that comparable saturation rates apply in developing countries as well. The vehicle fleet in China, for example, is predicted to grow from its current 16 vehicles per 1 000 population to 807. This estimate is much higher than others for developing countries, but the strong tie to income is reasonably persuasive.

The high level of vehicle ownership, together with the high cost of ownership can only mean one thing: the private benefit of vehicle ownership is very high indeed. All the evidence suggests that the desire for convenient, on-demand private personal transport is universal and, once it becomes affordable, irresistible. Its main urban alternative, bus and rail transit, is competitive for work trips to the urban core, but for other types of trip it is simply less convenient, unless population densities are very high. And again, for any trip by car its marginal benefits must exceed its marginal costs; otherwise the trip would not be made. These marginal costs will of course be highly variable, but the average variable operating costs, estimated above to be about 15¢ per mile, are a reasonable lower bound[2].

To come back to the main point, motor vehicles do provide large benefits to users. However, these benefits are private benefits, and nearly anyone can obtain them if he is willing to pay for them. There may be some public benefits to motor vehicle use, but few come to mind. The external effects of motor vehicle use – those that fall on non-users – are almost exclusively bad, and they are not easy to avoid. In particular, there are few markets where those affected can take private actions to eliminate their exposure to these externalities. If there is to be a response to auto externalities, it has to be collective.

Table 2. **Range of reported external costs in cost-of-driving studies[a]**
(Cents per mile)

	Low[a]	**High[a]**	**JEL[c]**
Air pollution	1	14	2.3
Climate change	0.3	1.1	0.3-3.5
Congestion	4	15	5-6.5
Accidents (external)	1	10	2-7
Energy security	1.5	2.6	0-2.2

Notes:

[a] Harrington and McConnell (2003). Combination of the studies surveyed by K.T. Analytics (1997) and Gomez-Ibanez (1997).

[b] “Low” and “high” are respectively the second lowest and the second highest estimates reported in the articles surveyed.

[c] Based on a survey of the economics literature. See Parry, Walls and Harrington (2006) and citations therein for further discussion.

The main vehicle externalities are shown in Table 2. Columns 2 and 3 of this table give the upper and lower bounds save one of a set of externality studies primarily from the grey literature. The estimates reflect many studies and it is often not clear what the assumptions are underlying the estimate. This accounts for the broad range in cost estimates. The fourth column gives results from a more selective set, mostly from published economics articles, where it is clear what the assumptions are.

To allow externalities to be compared with one another, it is necessary to express them in common or at least convertible units, and it is most natural to express them in terms that are consistent with indicators of vehicle use. The most common indicator of vehicle use is vehicle miles/kilometres travelled (VMT or VKT). It is important to keep in mind, however, that this is a unit of convenience and may obscure the enormous variation in these estimates of external costs. It is very misleading to suppose that, say, *x* miles of driving activity always produce *y* in damages. The enormous range in estimates may become clearer following an explanation of how each of the external cost estimates in the table below are calculated.

Conventional pollutants. The externality is generated by emissions, mostly from the tailpipe. To get from emissions to damages, one must estimate the effect of the emissions on air quality, the effect of air quality on health, and then value the change in health endpoints. The marginal effect of emissions on air quality is difficult to estimate quantitatively and depends critically on location, and there is rarely good data on actual vehicle emissions anyway. Even in this case, it is heroic to assume a fixed relationship between miles driven and damages, since that relationship will depend on the vintage of the vehicle and its abatement equipment as well as the time and place the vehicle is driven. Likewise, the effect of air quality on health depends on population density, the age distribution, personal habits and time spent outside, and existing dose-response functions are subject to large uncertainties. The degree of uncertainty is enormous in the valuation step as well.

Global pollutants. For a given type of fuel, the principal greenhouse gas of interest, CO_2, is produced in fixed proportions to the carbon in the fuel consumed, because there is no technology on the horizon that will enable CO_2 abatement technology on the vehicle. Also, all units of CO_2 emitted are safely assumed to have the same climate consequences. Therefore, the relevant margin for estimating CO_2 damages is fuel consumption, or better, carbon content of fuel consumed. It is a little more complicated if biofuels are involved, because the only carbon that should be counted is that in the fossil fuel used in its production. When the carbon use estimates are converted to per-mile units, as in Table 2, additional assumptions are required about the average fuel economy of all vehicles. Still, getting from vehicle use to GHG emissions is subject to much less uncertainty than is the case for conventional pollutants. However, converting GHG emission estimates to estimates of changes in climate, and the valuation of the climate changes, is extremely uncertain.

Congestion. In the table below, congestion costs (chiefly lost time but, in principle anyway, also the annoyance of driving in stop-and-go traffic and the uncertainty in estimating arrival times) are estimated at 5-6.5¢ per mile. The lower number is taken from a Federal Highway Administration Capacity study. The upper number was calculated at RFF as follows. First, total travel time for one day for all motorists in a metropolitan area (Washington, DC in this case) is estimated using a simulation model of local travel behaviour. This is compared to what the travel time would be if the cost of travel were slightly reduced and the total travel increased. This procedure gives the change in welfare that would accompany a small increase in total vehicle use in Washington, DC. The estimate is extrapolated to other American cities using the ratio of total travel demand in those cities to the available highway capacity. The per-unit congestion cost is determined by dividing the sum of congestion costs in all cities with populations exceeding 100,000 by the total estimated VMT in the nation for one weekday.

This procedure calculates congestion costs at the margin, but it also tacitly assumes no congestion on non-urban highways. While congestion is likely to be lower on such roads, it is not zero. Therefore it is likely that the estimate is low, notwithstanding the fact that it is higher than other unit estimates of congestion costs. A larger point is that the representation of congestion costs on this unit cost basis is especially problematic, since it is likely that there is an inverse relationship between the length of a trip and the congestion experienced by or caused by the traveller. But it is useful as a static number for comparison purposes.

Accidents. The entries in the table should refer only to external costs of accidents; injuries or property damages incurred by the driver should be excluded. They definitely are excluded for the studies supporting column 4, but some studies in the broader collection represented in columns 2 and 3 may refer to all accident damages, internal or external. Compared to estimation of emission damages, accident damages are relatively straightforward. There is good accident data, at least when fatalities are involved, and those accidents probably represent the large majority of economic damages from accidents. Valuing the health effects of accidents is no more difficult than valuation of health effects of pollution.

Energy security. Energy security is now a particular concern for both the US and the EU, especially in transportation with its high level of oil use. Dependency on oil imports from potentially hostile sources (the Middle East and Russia) is said to be a problem for at least three reasons: price volatility, price manipulation and implications for national security. For none of these reasons is the case for externality airtight, however. Oil prices are volatile, to be sure, and economies can be damaged by volatility in oil prices. However, it is not clear that a marginal reduction in US or EU reliance on imports can affect the volatility. Oil is fungible, and a supply disruption anywhere from any cause will unsettle markets everywhere, regardless of the dependency level. The national-security justification is questionable because defence expenditures are unlikely to be marginal. Perhaps the most important national security concern is the flow of petrodollars into terrorist organisations, but in this case the problem is not the level of oil imports, but the level of imports from hostile countries that tolerate such organisations.

Comparing the estimates, it appears the most economically significant externalities are congestion and accidents. However, they are also the ones that are most familiar. Almost everyone has experienced congestion first-hand and most have some experience with accidents as well. Even in the worst case, congestion and accidents will affect us individually or in small groups. In contrast, energy supply disruption or significant climate change will affect everyone if they occur, and the possibility, especially for climate change, of disruption on a national or global scale cannot be dismissed. In other words, the mean values of these large-scale externalities perhaps should be tempered by keeping in mind the variances, which are virtually unknowable.

3. LOCAL EMISSIONS

Since 1970, when the modern environmental movement was in its infancy, the principal approach to reducing emissions from motor vehicles has been emission standards for new vehicles, in units of mass per unit distance. Describing these vehicle policies, which developed rather differently in the US and Europe but have ended up close to the same place, is the main purpose of this section. In addition, extensive regulations have been adopted governing fuel quality, with the twin purposes of: (i) reducing the quantity and toxicity of fuel constituents that, when used in vehicles, cause environmental quality problems directly; and (ii) ensuring coordination with new vehicle regulations, which often required fuels with particular qualities. While the fuel stories are interesting and instructive, they are not included in this review.

Other policies for control of local emissions have been developed, including vehicle inspection and maintenance (I/M), vehicle scrappage and no-driving days. Some of these policies have seemed to be rather cost-effective in certain local applications, but all have suffered from a difficulty in determining what their true emission reductions are. In any case, the emission reductions from these policies are small relative to the reductions brought about by the vehicle emission standards. They will not be considered further here.

3.1 Local emissions policies: United States

Before 1970, air quality, to the extent that it entered public policy at all, was primarily under the jurisdiction of the states and, except for California, had nothing to do with motor vehicles. The federal government's role was limited to research and financial support. The centralisation of environmental policymaking is primarily the result of a series of landmark statutes that were passed between 1969 and 1980[3]. It is not clear that these centralising moves were part of a grand plan; rather it appears to have been prompted by more *ad hoc* concerns. First, there *were* some environmental problems that crossed state lines. More importantly, there was an air of crisis at the time, a concern that environmental problems had to be dealt with right away. Most of the states had, in the minds of many, demonstrated that they could not act quickly enough or forcefully enough to deal with the multitude of environmental problems facing the country. It was said that the federal government was the only level of government powerful enough to stand up to the large corporations that were presumably the primary source of environmental degradation. In particular, federal authority over environmental policy would avoid the much-feared "race to the bottom" – polluters' shopping around for lenient states willing to sacrifice environmental quality for new jobs and economic growth.

For air quality, the national policy was set in the Clean Air Act of 1970, which mandated the setting of uniform ambient standards, plus a set of technology-based regulations for new sources, both stationary and mobile. The states' role was to do what needed to be done, over and above the federal technology regulations, to meet the ambient standards. These standards were initially supposed to be met in 1975, although the deadline was almost immediately pushed back to 1977. After almost forty years, this remains the basic approach to air quality planning. Although the air is a lot cleaner today, the ambient standards have still not been met, largely because they have been tightened significantly and new pollutants have emerged as problems. The task has proved to be a much bigger and more complicated job than originally anticipated.

California was the only state that had established emission reductions before 1970 for new cars. It retained this under the new Clean Air Act and indeed its vehicle standards were more stringent than the federal standards. The impetus for the insertion of federal authority into what had been a concern of the states came in part from the nascent environmental movement (the first Earth Day was held in 1970), but also from the vehicle manufacturers themselves. Manufacturers were not in favour of more stringent emission regulation – far from it – but they feared even more a patchwork of disparate and possibly contradictory emission regulations from the states, which, in a national industry enjoying significant economies of scale, might severely complicate vehicle design and production decisions. So manufacturers supported federal regulations, but then sparred with Congress and the EPA over their stringency and scheduling. The ensuing emission standards required two-way catalysts (to control CO and VOCs) by 1979 and three-way catalysts by 1983.

California continued to be a trendsetter, developing new "Low Emission Vehicle" (LEV) standards that went into effect in 1990. The LEV standards were considerably tighter than the then-current California Standards. They also introduced some flexibility by allowing manufacturers to meet a fleet average standard, rather than requiring each vehicle to meet the same standard. The federal government followed suit shortly thereafter. In 1991 the new Clean Air Amendments put in place "Tier 1" standards, equivalent to the California LEV standards, that came into effect in 1994, followed by Tier 2 standards, for which implementation began in 2004. Tier 2 coupled very stringent emission standards with new ultra-low-sulfur fuel standards that were required in order for the emission control systems to operate properly. Vehicles are placed in "bins" according to emissions. A certain percentage of each manufacturer's vehicles are supposed to be in each bin, and each year the percentages in the more stringent bins increase until implementation is complete in 2009.

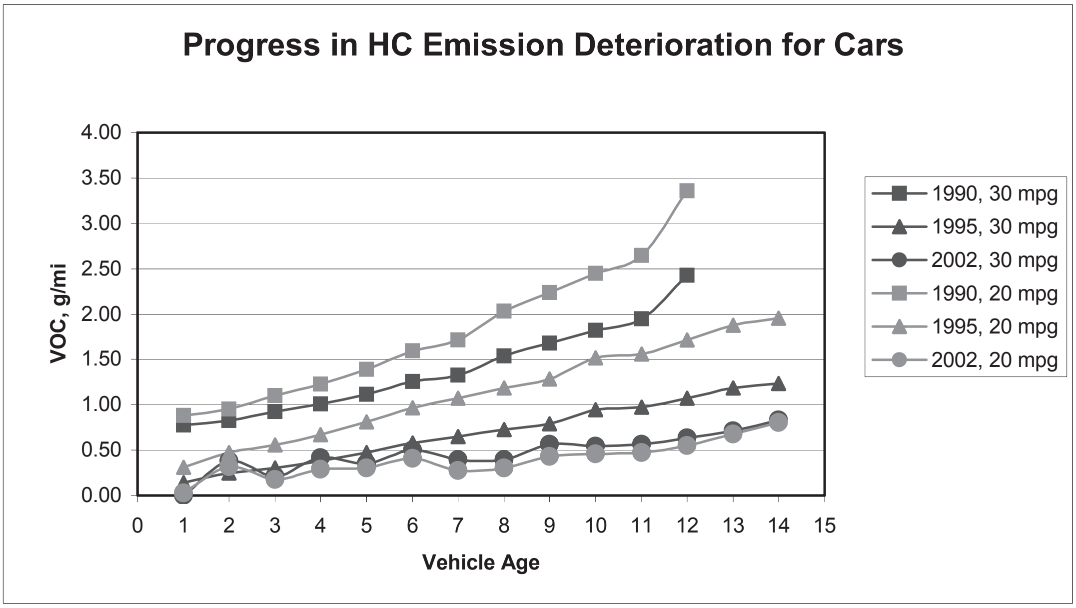
However, there was another part of the California LEV program that was not so successful: the Zero Emission Vehicle (ZEV), vehicles without tailpipe or evaporative emissions – a requirement that at the time could only be met by 100%-electric vehicles (EVs). The ZEV mandate required of each major manufacturer a 2% ZEV fleet penetration by 1998, 5% by 2001 and 10% by 2003. It was an attempt to force the development of battery and electric vehicle technology and, it was hoped, make EVs widely available. To meet the volume requirements, it was anticipated by manufacturers that the high initial cost of ZEVs would be subsidized by all other vehicles until innovation and economies of scale brought down the price. However, the increase in the cost estimates was so dramatic that this became impossible – from a 1990 estimate of $1 350 per vehicle by 2000 to $5 000-$10 000 in 1995 to an estimate made in 2000 for 2003 vehicles of $20 000 per vehicle (NAS, 2006). Throughout the period, CARB was watering down the program, not only the fleet requirements but by introducing the concept of a "partial ZEV" that did not have zero emissions. The program lapsed when it became evident that the battery technology had not progressed nearly fast enough to make the electric vehicle a viable commercial alternative.

California's LEV program has been a major influence on the federal emission standards. The LEV itself led to the development of emission technology that was more durable and robust and that allowed drastic reductions in new vehicle emissions at modest cost; and its success led to the federal promulgation of similarly stringent standards. The ZEV experience, however, had a less happy outcome. While it did advance technology in some areas it failed in its stated purpose, and what technical advances it did achieve came at high cost to manufacturers. It should be noted that despite the failure of the ZEV, California's LEV program is an example of one of the chief advantages of federal systems like the US and EU, first pointed out in 1932 by Justice Brandeis of the US Supreme Court: "*It is one of the happy incidents of the federal system that a single courageous State may, if its* *citizens choose, serve as a laboratory; and try novel social and economic experiments without risk to the rest of the country*."

Warranties. Along with emission standards, EPA regulations also extended the mandatory warranty on emission control systems (ECS). In the early 80s there were no special requirements on the warranties on the ECS, and they were no longer than the warranties on other parts or systems. Since 1995, however, the minimum warranty has been 24 months or 24 000 miles, and specified major ECS parts – catalytic converters, electronic emissions control units and onboard diagnostic devices – have a warranty of eight years or 80 000 miles.

Better technology and, perhaps, better warranties have made ECS much more reliable and durable, and the improvement can be seen in the trends in emissions from same-age used vehicles at different times. Figure 1 below shows the average hydrocarbon emissions in grams per mile as a function of vehicle age. The data are required emission test data taken from the vehicle Inspection and Maintenance (I/M) program in Arizona in 1990, 1995 and 1992. Previous work (Harrington, 1997) had shown that emissions from vehicles with poorer fuel economy tended to deteriorate more quickly, so emissions are shown for 20 mpg (0.1181 km/l) and 30 mpg (0.0787 km/l) vehicles. As shown, vehicles of the same age have much lower emissions in the newer vintages. Also note that the role played by fuel economy in emission deterioration, strong in 1990 and 1995, had disappeared in 2002. Similar results obtain for CO and NO_x; see Parry *et al.* (2005).

Figure 1. **Progress in HC emission deterioration for cars**



3.2 Local emission policies: Europe

The modern environmental movement and the regulatory responses to it arrived in Europe at about the same time as in the US, but regulation of vehicle emissions was slower to develop. Before the European Union existed in its current legal framework, the European Commission exercised more of a convening function than a regulatory function in the development of vehicle emission regulations.

Regulations were adopted one country at a time, and there was wide variation among member countries. By 1990, over 98% of new gasoline vehicles sold in Germany and The Netherlands had three-way catalysts, while comparable figures in France, Italy and the UK were 3.2, 0.7 and 3.9%, respectively. In addition, the adoption of catalyst technology was relatively slow. In developed countries outside the EC, emission abatement in vehicles was embraced more quickly, including elsewhere in Europe. In Norway, Sweden, Switzerland and Austria, all non-EC countries, 100 percent of new vehicles were required to have three-way catalysts in 1990 (Boemer-Christiansen and Weidner, 1995). In the US, as noted above, all new vehicles had three-way catalysts by 1983.

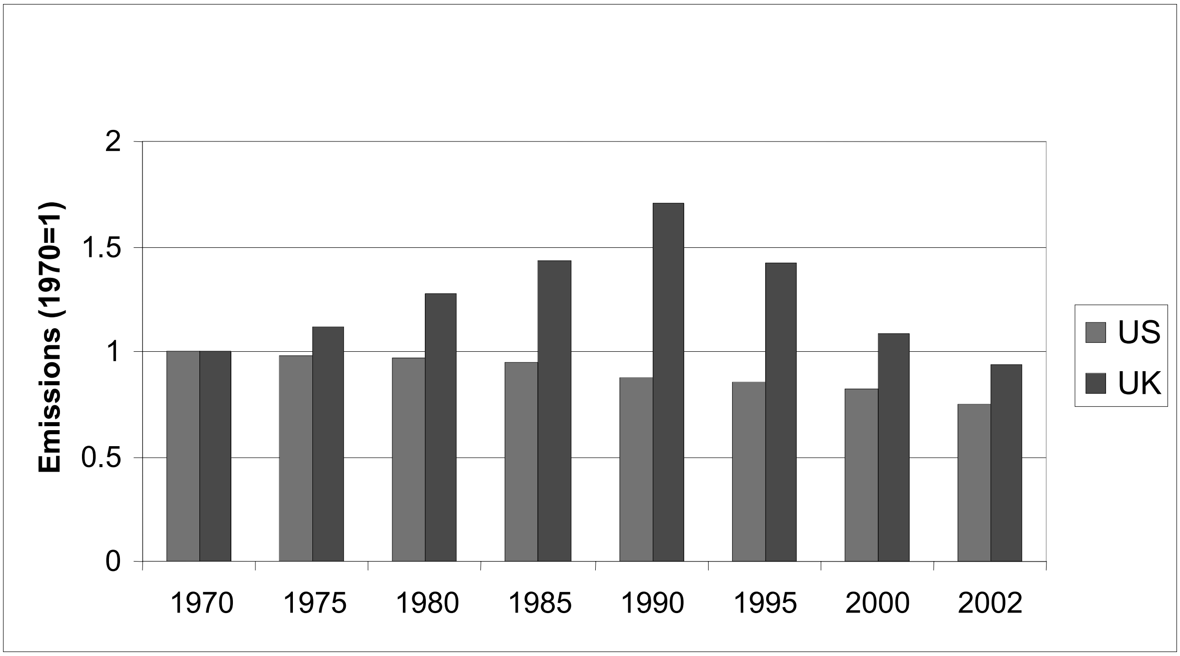
There were at least two reasons for the relatively slow response compared to the US and Japan. First, there was a very different perception of the most serious pollution problems. In the US ground-level ozone was seen as the greatest health threat among air pollutants, and tackling ozone demanded reductions in volatile organic compounds (VOCs) and oxides of nitrogen (NO_x). Mobile sources were by far the major anthropogenic source of the former. In Europe, ozone was considered a less urgent problem, perhaps on account of the lower frequency of hot, muggy "ozone" days there. Europe, and Germany in particular, was more focused on the ecological effects of acid deposition, concerns that turned their attentions to stationary source emissions of SO_2, NO_x and particulates. Not surprisingly, significant reduction in acid rain precursors occurred in Europe as much as a decade before the US. Within Europe, though, control of vehicle emissions tended to be pursued in those countries concerned about acid deposition and not in countries that were not. The UK in particular was usually upwind of major continental sources and receptors, and may have perceived lower benefits and greater costs than most other countries from any European-wide regulation of motor vehicle emissions.

In addition, there was a disagreement between Germany and the UK over the stringency of the standards and whether end-of-pipe abatement technology would be required. Germany favoured more stringent standards requiring catalytic converters, but Britain supported a more lenient "lean burn" technology that did not have the fuel economy penalty associated with converters. To get low NO_x emissions with the engines then available, the air-fuel mix had to be so lean that the engine suffered from reduced power, misfires and high HC emissions (Boemer-Christiansen and Weidner, 1995, p. 40). In other words, technology developments seemed to favour the use of catalytic converters.

Nonetheless, there was a European agreement on vehicle emissions in 1991, and an EC directive issued in that year specified emission reductions requiring three-way catalysts for all new vehicles, beginning in 1993. These were the Euro 1 standards, and since then there have been a steady succession of tighter emission regulations for both gasoline and diesel vehicles, culminating in Euro 4, which went into effect in 2005 and Euro 5, which will be fully implemented in 2009. It is difficult to compare US and EU standards – different emission test cycles, different pollutants or pollutant definitions in some cases – but apparently by the end of the decade the US and EU standards will be approximately the same.

Figure 2 below compares the relative change in total estimated US NO_x emissions with those in the UK from 1970 to 2002. The figure reflects the regulatory history, with US emissions declining slowly from their 1970 total throughout the period, with moderate reductions in emission rates being offset by the substantial growth in the passenger car fleet and in annual vehicle use over those years. In the UK, on the other hand, emissions grew much more rapidly between 1970 and 1990, then fell much more sharply as the EU emission regulations gradually diffused across the fleet.

Figure 2. **Total NOx emissions: US *vs.* UK**



4. GLOBAL EMISSIONS

Growing concern about global climate change has directed the attention of policymakers and analysts worldwide to all major sources of greenhouse gases (GHG). The transportation sector is one such source, and within this sector motor vehicles are now coming under particularly careful scrutiny. In the United States, which leads the world in motor vehicle use both in total and per capita, motor vehicles account for about 20% of CO_2 emissions. In other countries motor vehicle use is growing rapidly, especially in the developing world. Accordingly, the search is on for efficient and equitable policies to reduce emissions of greenhouse gases from motor vehicles. Reducing CO_2 emissions essentially means reducing fossil fuel use in vehicles, and there are only three ways to do that:

(i) Reduce the amount of vehicular travel.
(ii) Switch to alternative fuels with lower greenhouse gas emissions.
(iii) Improve fuel economy in vehicles.

For the most part, the policy proposals to address the issue have been limited to (ii) and (iii). Thus the US has had fuel economy standards for new light-duty vehicles since the worldwide oil crisis in 1979 and, after a long period of stasis, has enacted legislation to raise them significantly. And Europe has had a voluntary fuel economy program for manufacturers in place for about a decade and is now proposing to make it mandatory. In addition, on both sides of the Atlantic efforts are underway to use public funds to jump-start a large alternative fuels industry. In the US this has taken the form of large subsidies to fund both pilot and commercial-size plants to produce ethanol.

These policy initiatives have proceeded, even though a comprehensive policy, attacking all margins on which fuel consumption can be reduced, is technically feasible and economically attractive. The availability of such a policy is very different from the case of local emissions, where, as noted above, an efficient policy was not feasible because there was no way to measure emissions of vehicles in use. For global emissions, however, such an efficient policy is feasible, and in fact something close to it in form is already in use in almost every country in the world. The relevant price instrument is a fuel tax. Nearly all the carbon in gasoline is emitted as CO_2, and most of the rest is emitted as carbon monoxide (CO), an even more potent greenhouse gas. This, together with the fact that the location and timing of greenhouse gas emissions do not matter, means that a tax on the carbon content of fuel would be an almost ideal instrument against global warming – "almost" because an ideal instrument would set the tax rate equal to the marginal damages in Table 2. A tax with this property is called a Pigouvian tax.

The familiar gasoline tax, which is in use in nearly every country, could be easily converted to a carbon tax, and even the relatively low fuel taxes in the US (which average about 40¢ per gallon) would exceed the marginal damages of carbon emissions reported in Table 2. However, in many countries, including the US, fuel taxes are earmarked for road construction. There is a rather arcane argument among economists whether fuel taxes could be considered a Pigouvian tax under these circumstances, depending on whether one believes the amount of road building is truly contingent on the tax revenues. If it is, then the tax revenues cannot be said to be internalizing the externality, since they are used up in the provision of infrastructure. In most European countries the issue is moot, inasmuch as fuel tax revenues are much higher than required for transport and make a substantial contribution to the general fund. European fuel taxes, it seems safe to say, are a true Pigouvian or even supra-Pigouvian tax. That is, according to the estimates of external damages of driving presented above, most Europeans are already internalizing the carbon externality.

Of course, the global warming debate is not being driven by estimates of damages in either Europe or North America. Steps are already being taken in Europe to improve vehicle fuel economy directly, perhaps by direct standards on fuel economy, as in the US. If policy-makers and the public want larger reductions in fuel use than Europe's high taxes currently bring about, it could be because of concerns about oil dependency, although as noted in Table 1, those externalities are not very large either. Perhaps the answer is that the estimates are lacking credibility, or perhaps that what people are really worried about is not the mean but the extremes of the value distribution.

There is one other possible explanation for the preference for fuel economy standards rather than fuel taxes, and that is skepticism about whether the "market" for fuel economy really works. One of the most persistent and effective skeptics is David Greene of the Oak Ridge National Laboratory in the US, and in recent testimony before Congress he explains why. First, surveys of new car buyers suggest that they are willing to pay for no more than 2-3 years of fuel economy improvements. In addition, manufacturers believe that consumers have at most a three-year horizon for fuel economy improvements, and they design their vehicles accordingly. Third, even if consumers wanted to value fuel economy properly, it is not that easy to do so. A vehicle is a bundle of attributes that consumers value – fuel economy, reliability, power, leg-room, etc. – and consumers are rarely presented with choices that hold all the other attributes except fuel economy constant, so that consumers can easily see what fuel economy "costs".

On the other hand, econometric studies of consumers' purchase decisions for new vehicles consistently show that the implied willingness to pay for fuel economy is at least equal to what can be justified by the lifetime fuel savings. The most recent and one of the most sophisticated studies with such findings is by Train and Winston (forthcoming). More research is needed to resolve this apparent anomaly between what consumers say and what they actually do.

Table 3. **Statistics on vehicle and fuel use, US and EU (EU-15)**

	2002		**% Change, 1995-2002**	
	EU-15	**US**	**EU-15**	**US**
Population (millions)	380.4	288.4	2.0%	8.3%
LDVs per capita	0.488	0.766	14.8%	5.5%
Fuel economy (litres/km)	0.066	0.096	-13.2%	0.8%
Fuel economy (mpg)	35.6	24.7	15.2%	-0.8%
Passenger-km/vehicle	21 929	18 853	-2.3%	-0.4%

Sources: ORNL(2004), Eurostat, Shore (2005).

Some trends in vehicle ownership and use are shown in Table 3. Not surprisingly, vehicle ownership in the US far exceeds that in Europe, but the EU's car fleet is growing faster. This is consistent with the Dargay *et al.* model described above. Fuel economy in the EU is much better, but it is rather a surprise to find the use per vehicle to be slightly higher in Europe. (This will bear some further looking into to make sure there is no problem here.). Except for this last item, the numbers reflect the somewhat lower incomes and much greater cost of vehicle ownership and use in Europe. It is of particular interest that fuel economy increased substantially in the EU but not the US between 1995 and 2002, presumably a reflection of the higher fuel prices, which exert a constant pressure to improve fuel economy. Despite those higher prices, however, between 1995 and 2002 the increase in vehicles per capita in the EU nearly offset the gains in fuel economy and passenger use per vehicle.

4.1 Biofuels

In the short run, there are few ways to achieve substantial reductions in vehicular fossil fuel use. Exotic new vehicles, such as fuel cell or all-electric vehicles, may eventually be part of the solution, but the technology is not yet developed sufficiently. Greater penetration of more fuel-efficient conventional vehicles, such as hybrids or diesel vehicles, can produce fairly quick but limited results, the limit being that they continue to use fossil fuels, just a bit more efficiently than conventional vehicles. The attraction of biofuels is that they require at most modest changes to existing vehicles. In addition, biofuels can, with some exceptions, make use of the existing fuel distribution network.

Both Europe and the United States have made extensive commitments to increasing production of ethanol and biodiesel, the most important biofuels, in the last decade. Biofuels make up a very small share of liquid fuels used in transportation – about 1.3% in the US and 0.7% in the EU in 2006 – but they are growing rapidly. As shown in Table 4, US ethanol production tripled between 2000 and 2006, while biodiesel production, essentially non-existent in 2000, approached 2 million tonnes in 2006. Corn is the principal feedstock, accounting for over 90% of ethanol production. In Europe, hardly any biofuels were produced in 2000; by 2007, production exceeded 10 million tonnes, with planned expansions amounting to an additional 25 million tonnes. The production pattern is the reverse of what is found in the US, with biodiesel being by far the dominant fuel. The principal feedstock is rapeseed oil, responsible for more than 90% of biodiesel production.

Table 4. **Trends in production of biofuels, US and EU**
(in million tonnes)

Year	**US**		**EU**	
	Ethanol	**Biodiesel**	**Ethanol**	**Biodiesel**
2000	5.25	0.007	0.2	0.7
2002	7.0	0.05	0.4	1
2005	10.9	0.25	0.8	3.2
2006	15.2	1.75	1.2	4.9
2007	–	–	2.9	8.4
Additional planned or under construction			7.0	16.6

Sources : Kutas *et al.,* 2007, Koplow, 2006.

This dramatic increase in biofuels production was produced by the generous use of subsidies. In the US, ethanol was first subsidized in 1978 through an output subsidy of 40¢ per gallon (at a time when fuel cost about $1.00-$1.50 at the pump). From that time until the present, ethanol has continued to enjoy an output subsidy that varied between 40 and 60¢ per gallon, and is currently 51¢/gal. In the meantime, the output subsidy has been joined by a plethora of other instruments, including (i) an import duty of 54¢/gal on ethanol intended for use in transportation, supposed to keep Brazilian cane ethanol out of the US market; (ii) product content rules, mandating a minimum biofuel content; (iii) support for feedstock producers; and (iv) consumption subsidies, such as credits for "clean" vehicles and privileges such as the ability to use HOV lanes. While the federal government was first to subsidize biofuels, individual states followed with their own policies, and today 28 states offer subsidies of various kinds for biofuels (Koplow, 2006).

European subsidization of biofuels began around 1992 as part of the reform of the Common Agricultural Policy (Kutas, 2007). Subsidies applied to ethanol and biodiesel equally, but biodiesel production was quicker off the mark, presumably because diesel was an imported item while gasoline was produced in surplus and exported. As in the US, action has not been limited to the central government, but individual countries have also enacted their own subsidies. As in the US, production in the first decade was modest by today's standards, but took off after around 2002.

The Global Subsidies Initiative has made an attempt to aggregate all the multifarious subsidies that benefit biofuels for the countries that are important biofuel producers. Table 5 uses data from the reports for the US and EU, and displays the subsidy intensity, which can be thought of as the amount by which the subsidy distorts the various markets affected. The authors of these reports calculate, in each case, at least two scenarios based on different assumptions. With one exception, the numbers in Table 5 reflect the midpoint of those scenario estimates. That exception is US corn ethanol, for which one of the scenarios generates more CO_2 than is generated by the amount of oil it displaces. The figure in the table represents the other scenario only. In the US case, the authors also make a rough calculation for cellulosic ethanol, which has a cost per CO_2 equivalent of about $150, but that estimate is rather suspect since there is no commercial production of cellulosic ethanol yet. In addition, in the US report it proved impossible to find data to construct an estimate for biodiesel.

Table 5. **Estimated biofuel subsidies, various units**

Total support	**US**		**EU**	
	Ethanol[a]	**Biodiesel**[a]	**Ethanol**[a]	**Biodiesel**[a]
\$/gal	1.25	1.35		
€/litre	0.23	0.24	0.74	0.50
\$/MM BTU	14.90	11.50		
€/GJ	9.83	7.49	35	15
\$/gal. fossil equivalent	1.70	1.47		
€/litre fossil equivalent	0.31	0.27	1.10	0.55
Subsidy/market price	36%	49\$	110%	70%
\$/tonne CO_2 equivalent	545	NA	990[b] 4680[c]	310[d] 1008[d]
€/tonne CO_2 equivalent	378	NA	687[b] 3250[c]	215[d] 880[e]

Sources: Koplow (2006), Kutas *et al.* (2007).
Notes:
a. Exchange rate: €1.00=\$1.44
b. sugar beet feedstock
c. grain feedstocks
d. used cooking oil feedstocks
e. canola oil feedstocks.

All the measures in Table 5 suggest that biofuels production is costly and not very efficient, but perhaps none more so than the cost-effectiveness of carbon reduction. Even the Stern (2006) Review, which puts damages from future warming at 5-20% of World GDP, has a current social cost estimate of \$311 per ton, which is dwarfed by most of the estimates in Table 5, especially the European estimates.

4.2 CAFE

In the United States, gasoline taxation to mitigate global warming has very little purchase with politicians, and little wonder, considering how unpopular gas taxes are with the general public. These taxes are widely perceived as unfair to the poor and to those whose circumstances and life choices have locked them into a high-mileage lifestyle. And their effectiveness is challenged, not only by the public but also by some economists, who argue that the low price elasticity of motor fuel will require very large tax increases to have the desired effect (e.g. Greene, 1991). Indeed, recent studies find the elasticity of motor fuel to be lower than ever, perhaps a reflection of the low relative price of fuel, at least until recently (Small and Van Dender, 2005).

Instead, the favoured approach is likely to be mandated fuel economy standards for new vehicles powered by fossil fuels. Since 1979 motor vehicles in the US have been subject to fleet-weighted corporate average fuel economy (CAFE) standards. At the time of enactment the principal justification was a concern about a scarcity of motor fuel and fear of a reliance on imported oil. Today these concerns have abated somewhat, but the policy is still strongly favoured by environmentalists as a way of curbing emissions of greenhouse gases. From 1991 to2005 the CAFE standards have required fuel economy in new cars and light trucks to be 27.5 and 20.7 mpg (0.087 and 0.114 l/km), respectively. In 2005, the standard for light trucks was raised about 10%, to be implemented between 2008 and

2011. In addition to raising the standard, the National Highway Traffic Safety Administration (NHTSA), the government agency responsible for the CAFE standards, introduced a new approach to CAFE that was significantly different to the old CAFE in several ways, which we discuss further below. And in December 2007, after many years of effort, Congress passed legislation to raise the CAFE standards to 35 mpg (0.676 l/km), to be achieved by 2020.

Because CAFE stands out as the principal alternative policy to higher fuel prices to control greenhouse gas emissions in the transport sector, and because it offers so many examples of the unintended consequences of policies, it will be the focus of the discussion below.

Between 1978 and 1991 the CAFE standards increased from 18 to 27.5 mpg for cars and from 17.2 (in 1979) to 20.7 mpg for trucks. Over that same period, the fuel economy of new vehicles sold in the United States increased from 19.9 to 25.1 (US DOE, 2000). Most observers agree that this increase was caused by CAFE (NRC, 2002), and a recent econometric study of vehicle fuel use by state found CAFE to have had a strong effect on fuel economy (Small and Van Dender, 2006). One of the points of contention is the "rebound effect," which prevents an increase in fuel economy from causing a proportional decrease in fuel use. The size of the rebound effect has steadily fallen along with the elasticity of travel with respect to fuel price. Small and Van Dender (2006) found the long run rebound effect to be 0.22, and when they allow it to vary over time, they find that in the most recent period it falls to 0.12. The rebound effect is real but fairly small.

There is less consensus concerning other effects of CAFE, including its effect on highway safety and its role in several profound changes in the US motor vehicle market since 1980. These controversies are due partly to problems inherent in fuel economy standards in general, and partly to the details of the particular CAFE standards adopted.

Details of CAFE Policy

CAFE established separate standards for cars and light trucks, and the timetable of gradually increasing car standards was specified in the legislation itself. For trucks, standards were established later by regulation. At the time, most trucks were commercial and farm vehicles, and business and agricultural groups argued successfully that severe restrictions would adversely affect profits and productivity. Federal policy also favoured light trucks by exempting vehicles exceeding 8 500 pounds from any CAFE standards and by exempting trucks from the "gas guzzler" tax imposed on cars. The upshot was that the CAFE standards for trucks were much more lenient – and remain so today.

The difference between car and truck standards was rendered especially important by another aspect of the CAFE policy, little noticed at the time: the definition of *car* and *light truck.* Manufacturers managed to get trucks defined in a very liberal way, such that a vehicle was considered a truck if it had no hump behind the front seat and if its rear seats could be removed without the use of tools.

The fuel economy standards were also "fleet-weighted" by manufacturer. This approach allowed manufacturers much more flexibility than a set of model-specific standards and hence lowered the costs of meeting a particular fuel economy standard. Thus a manufacturer could still sell "gas guzzlers" as long as their sales were offset by sales of enough subcompacts that the average fuel economy met the standards. To prevent manufacturers form shifting production (and employment) abroad, where small-vehicle capacity and expertise were high, a manufacturer's imports (from outside North America) were considered separately from domestic production.

Several writers have pointed out that the CAFE policy, in principle at least, creates some unusual and even perverse incentives. Vehicle manufacturers have three general strategies for meeting the CAFE standards: (i) adopt fuel-saving innovations in new vehicles; (ii) modify vehicle characteristics to reduce fuel use (mainly, reduce vehicle weight); and (iii) use pricing to affect the mix of vehicles sold. That is, a manufacturer can improve its CAFE rating by raising the price of big cars and lowering the price of small cars. This third alternative was not much discussed during the legislative deliberations over CAFE, but it is the only alternative available in the short run. Such a fleet-mix strategy would affect not only the mix of vehicles but also the number of vehicles sold, and if sales increased, then aggregate fuel use would rise even as average fuel economy improved. In the event, however, this possibility proved to be more hypothetical than real, but it is a possibility.

A more serious market structure question involves cars and light trucks. Between 1980 and 1998, sales of new light-duty vehicles that were classified as trucks increased from 21.4 to 47.3%. Part of the growth could be attributed to the growing popularity of pickup trucks in both commercial and household applications. But far more important was the introduction of mini-vans and sport utility vehicles (SUVs), new families of vehicle that were classified as trucks for regulatory purposes but had many of the characteristics and appeal of passenger cars. By 1990, what had been only a farm or commercial vehicle had become a household vehicle as well.

The growth of the light truck market is a fact; the role of CAFE in that growth is less certain. The disparity between car and light truck CAFE standards is certainly a strong incentive for manufacturers to look for ways to sell trucks to car buyers, and the loose definition of a truck certainly created opportunities to do that. However, other events were occurring simultaneously. As the recent NRC report points out, during the 1980s the full-size light-duty truck category was dominated by domestic US manufacturers, and they naturally sought to expand sales in that category.

CAFE policy has also suffered from a lack of policy coordination in the matter of giving credits to vehicles that use alternative fuels. Several manufacturers have developed "flex-fuel" vehicles, which are capable of running on either gasoline or 85% ethanol (E85). To encourage the further production of these vehicles, there is a section of the CAFE regulations that allows such vehicles to be treated very leniently by CAFE policy. Essentially, for determining fuel economy of such vehicles, a large fraction of fuel is assumed to be renewable and not counted in the fuel economy calculation, giving these vehicles very impressive fuel economy ratings. This provision was supposed to have been accompanied by an E85 subsidy to ensure that its price at the pump was less than that of gasoline. However, that subsidy was delayed getting out of Congress, so for a long time after these vehicles were introduced, supplies of E85 were difficult to find and were in any case more expensive than gasoline. The result was that these flex-fuel vehicles burned gasoline almost exclusively, a very perverse outcome.

CAFE and Highway Safety

Probably the most important and controversial issue involving CAFE is its putative effect on highway safety, an issue discussed at length by two National Research Council reports (NRC 2002, 1992). The mechanism is weight. Numerous studies, reviewed in both reports, have found a significant negative correlation between vehicle weight and the probability that an accident will result in serious injury or death. Crandall and Graham (1989) connected these results to CAFE in a quantitative way. They estimated that CAFE reduced vehicle weights by an average of 18%, or about 500 pounds. A 500-pound reduction in average vehicle weight was estimated to cause a 14 to 27% increase in occupants' fatality risk.

There was and still is some controversy at this point about whether it was vehicle weight that was actually protecting occupants. Weight is highly correlated with vehicle length and volume, and it could be that those variables are the critical ones. Both are plausible, as two different physical principles are at work. When two vehicles of different weights collide head-on, the deceleration is proportionately lower in the heavier vehicle[4]. Deceleration is also lower in larger vehicles because the greater volume provides greater "crush space" – the ability of vehicle components to absorb the energy of impact and not transmit it to the driver. The simple physics implies that: (i) in one-vehicle collisions, mass doesn't matter but crush space does; and (ii) in multivehicle collisions, it is not mass *per se* but the disparity in the masses of the vehicles that kills.

The realization that weight disparity was important gave new significance to the observed shift in fleet composition toward trucks. Whereas vehicle safety studies had hitherto concentrated on the safety of the occupants of the vehicle, concern was growing over the fate of occupants of the other vehicle in a crash. The recognition of this externality, together with the controversial article by Crandall and Graham, motivated new work by the National Highway Traffic and Safety Administration on the question (NHTSA, 1997). In this study, the effects of weight on accident severity were categorized by vehicle type. A 100-pound weight reduction increased fatalities by about the same amount for cars and trucks (actually, slightly more for trucks) in accidents involving stationary objects, a confirmation of intuition. A 100-pound reduction in car weight increased the fatality risk by 2.63% in a collision with a light truck. However, a similar reduction in trucks *reduces* fatality risk by 1.39% in a collision with a car. Taking all types of accidents and their incidence into account, the study found that reducing car weight increases fatality risk by 1.13% per 100 pounds, while reducing truck weight reduces fatality risk by 0.26% per 100 pounds. These results remain controversial, and NRC was not able to achieve unanimity on this point.

In its discussions of safety, the NRC committee considered only the effects of differences in weight. But the rebound effect also has obvious safety implications. Indeed, the rebound effect may look small when only fuel consumption is considered, but once its effects on conventional pollutants, accidents, and traffic congestion are brought into the discussion, its effects might not look so small any more.

Finally, it should be kept in mind that CAFE also can affect highway safety through the rebound effect. This effect depends on the assumption, which seems reasonable, that the risk of having an accident increases with mileage driven.

CAFE innovations

The new CAFE rules introduced by NHTSA in 2005 depart from the existing structure of CAFE in at least two significant ways. First, an effort is made to reduce the incentive for manufacturers to adopt a strategy of weight reduction to meet CAFE standards. NHTSA developed an "attribute" standard, in which a vehicle's CAFE target was determined by a function of a particular vehicle attribute. In this case, the attribute was the "footprint," essentially the area of the rectangle made by the tyres.

The second innovation arose in the particular way the attribute function was developed. NHTSA took a large collection of fuel economy technologies, many of which had been examined for cost and fuel economy improvement by the National Research Council (NAS, 2002). For each vehicle model it added the technologies one by one until the marginal benefits of raising fuel economy, in terms of fuel savings, equalled the marginal cost of further reductions. This procedure associated a fuel economy rating with each vehicle's footprint. Having done this for each vehicle, they fitted a curve through the points to get their function, which related fuel economy to the footprint. In other words, the footprint function embodied an explicit notion of weighing marginal benefits against marginal costs. As far as the author knows, this is the first time in American regulatory experience that regulators made use of benefit-cost analysis during the design of a regulation, rather than tacking it on at the end.

Target fuel economy ratings were thus assigned to each vehicle model of each manufacturer. Taking a sales-weighted average of the fuel economy targets of all vehicles generated a specific fuel economy target for each manufacturer, tailored to its unique fleet structure. These individualized targets are the CAFE standards that each manufacturer has to meet.

Several rationales, some stated and others unstated, were offered for NHTSA's development of the new attribute standard. The first was a desire to elicit improvement in fuel economy from some manufacturers, chiefly Asian, that hitherto have had to do little to meet the CAFE standards. In addition, the footprint-based attribute standard would reduce the incentive for manufacturers to meet the CAFE standards by down-weighting and thereby raising the risk of more severe injuries in accidents. The RIA contained an extensive discussion of the recent data on the accident outcomes when one vehicle is considerably heavier than the other, concluding that the disparity of weights was an issue only if the heavier vehicle exceed 5 000 lbs. It also took note of the questions that some had raised concerning whether the accident risk was related to weight or size. By choosing footprint, NHTSA was attempting to prevent size reduction from being a compliance strategy. While size and weight are highly correlated, they are not perfectly so, and manufacturers still retained the option of reducing weight if the core size was unchanged.

One other possible if unstated rationale is a concern about the effect of CAFE on American manufacturers. The market strengths of Ford, GM and Chrysler are in larger vehicles, just the ones that would be facing the largest potential change from a CAFE standard of the old structure. These companies have suffered substantial losses of market share in the past few years and still face serious disadvantages in the market because of pension and healthcare requirements for older and retired workers. Thus the new attribute standard may have had a political purpose along with its other objectives.

Finally, although the algorithm incorporated BCA in a clever way, its procedure was not without limitations. For one thing, NHTSA has subsequently faced (and lost) a legal challenge to this procedure, because the only benefit considered was the motorist's fuel costs. The court ruled that in addition the effects on global climate change have to be considered. The second limitation is that the costs that are considered are the cost estimates made prior to promulgation. Actual costs could be very different. In fact, as discussed in the next section, it is most likely that they will be lower.

4.3 Fuel economy policies in Europe

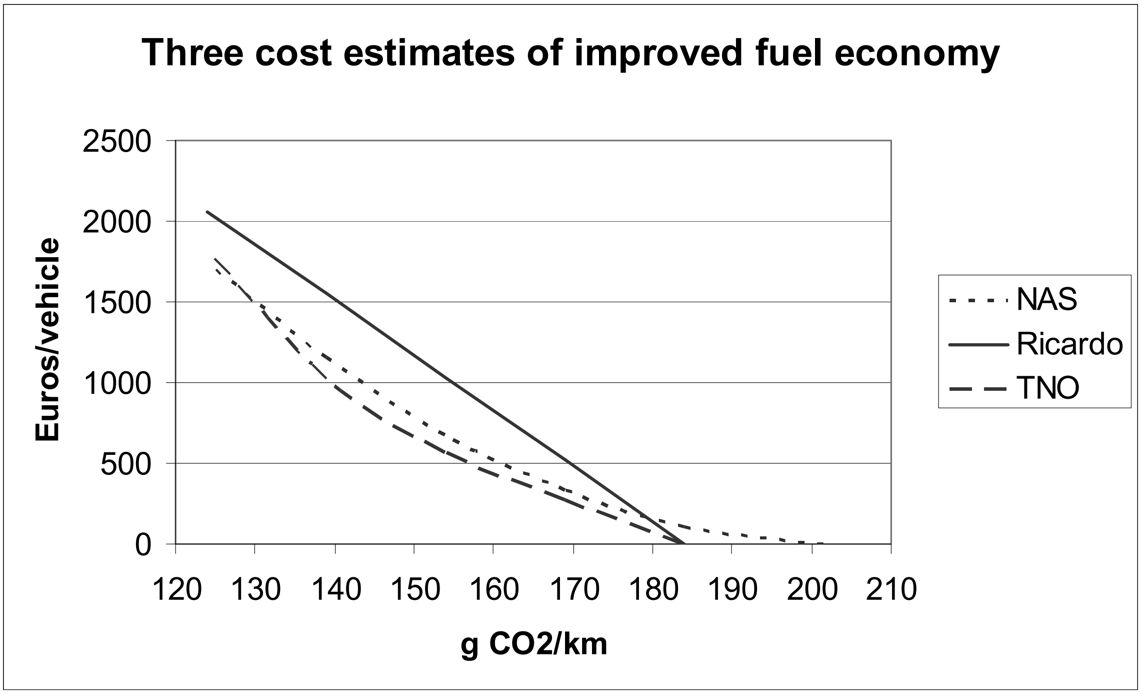
In 1998, the EC negotiated a voluntary agreement with the European Automobile Manufacturers Association (ACEA), obligating its members to reduce CO_2 emission rates of vehicles sold in Europe (An and Sauer, 2004). The goal was an industry-wide, average CO_2 emission rate of 170 g CO_2/km by 2003 and 140 g CO_2 (39.5 mpg) by 2008. With one year to go, emissions among European vehicles now average about 160 g CO_2/km (34.6 mpg), a rate of improvement of about 1.5% per year, half the 3% per year that would have been required to meet the 2008 target (Economist.com "Collision Course", December 19, 2007). It is now clear that the voluntary standard is not going to be met in 2008, and in response the EC has proposed a new mandatory target of 130 g CO_2/km (42 mpg) with a deadline of 2008. According to the *Economist,* this proposal has split the European car industry. Manufacturers of primarily small vehicles, such as Renault and Fiat, are not too concerned, as their vehicle fleets now average around 145 g CO_2/km, already within striking distance of the new standard.

German manufacturers, especially those that cater to the luxury market, are the most threatened by the new rules.

5. THE COST OF FUEL-ECONOMY STANDARDS: PROBLEMS OF OBSERVATION

There is a great deal of interest now in increasing vehicular fuel economy standards in both the United States and Europe. Analysis of new standards, including the preparation of cost estimates, has become a cottage industry. Three such estimates are reproduced in Figure 3. The first was produced by a committee of the National Academy of Sciences (US) for their 2002 study of improved fuel economy. The NAS generated cost estimates for ten different vehicle types by applying particular fuel-saving technologies to those types. These estimates were converted to quadratic cost functions in Fischer *et al.* (2004). What is presented is the estimate, converted to euros (in 2007 purchasing power) and carbon intensity, for a mid-sized vehicle in the American market. The other two estimates represent the average vehicle in the UK fleet. They were produced by the European consultancies Ricardo and TNO and used in the development and assessment of the United Kingdom's energy strategy (DTI, 2007).

Figure 3. **Three cost estimates of improved fuel economy**



It is remarkable how closely the NAS estimate, once converted, matches up with the other two, especially the estimate by TNO, and especially when one considers that the NAS estimate was an extrapolation far beyond existing US fuel economy ratings in 2002 (or today, for that matter). That is perhaps due to a fortuitous choice of assumptions in converting the US estimate, or to a lack of change in the cost estimates since 2002, or to an indication of the extent to which analysts are influenced by other analysts.

In any case it is worth keeping in mind that these are cost estimates, not actual costs, and therefore subject to error. If cost estimates are used to make regulatory decisions, then errors in those cost estimates could propagate and produce regulations that are less effective and efficient than they might otherwise be. Indeed, studies comparing government estimates of the costs of regulation with actual costs estimated after implementation show that the *ex ante* estimates tend to overestimate the actual costs. (How different regulation is from government investment projects, especially in infrastructure and defence, for which costs are famously underestimated.) If cost estimates are too high, then it is possible that regulation is not as effective as would be justified. That is particularly true in the case of the US attribute standard, inasmuch as it relies so closely on BCA in the design of the final regulation.

Naturally, we have very little experience with the accuracy of estimates of the cost of fuel economy regulations. In Europe, vehicles have not been subject to fuel economy regulations, although the high fuel prices have assured that they would be much more efficient than their American counterparts. In the US, there has been no change in fuel economy regulations since 1991, so there has been no occasion for a comparison of *ex ante* and *ex post* fuel economy regulations. Nonetheless, it should be possible to use the actual data on fuel economy and other attributes, plus the sticker price for various vehicles and use a regression to estimate the marginal willingness to pay and the marginal cost of each attribute (they are assumed to be equal in equilibrium). However, when researchers have tried to do that, as often as not they have found the cost to be negative. The problem is that one does not observe all combinations of vehicle attributes. Indeed, poor fuel economy is more likely to be found in luxury and high-performance vehicles with higher sticker prices. That is, with the limited set of data found in actual production vehicles, the cost of fuel economy cannot be reliably isolated.

With relatively little actual information on the cost of fuel economy, perhaps some insights are available from studies on local pollution regulations. There is in fact considerable experience with estimating the cost of local pollution abatement technologies, but it offers a mixed message on regulatory cost estimates. Researchers have conducted studies of both vehicles and fuels and, on the whole, the latter are much more conclusive. One reason is that in both Europe and the US, fuel standards for emission reductions have been applied in some countries or in some metropolitan areas and not others, which means that analysts can observe product prices with and without the regulation. For vehicles, on the other hand, vehicle standards are applied throughout the EU or US, so that observation of the incremental effect on vehicle prices is impossible.

As far as the author is aware, regulatory cost comparisons are uncommon in Europe, because until recently there were few analyses of the costs of regulation during rulemaking. Requirements for regulatory impact analysis, the engine for driving such analyses in the US since 1981, have only appeared in Europe much more recently. The difficulty is illustrated by a review of the UK air quality strategy (AEA Technology, 2004), commissioned by the UK Department for Environment, Food and Rural Affairs (DEFRA). The mobile-source section reviewed the vehicle regulations Euro 1, 2, 3 and 4, plus a number of fuel quality regulations. Necessarily, the authors limited their attention to an *ex post* analysis conducted in 2001 and to the policies that could have produced significant emission reductions by that date. For vehicles, their analysis was limited to Euro 1. Unfortunately, however, it was impossible for the authors to rely on existing documents for the comparison of vehicle costs.

For Euro I technology there was no regulatory impact analysis (RIA) providing an estimate of *ex ante* costs, while for Euro 2 technology the authors were unable to find an existing *ex post* study. Although an *ex ante* Euro I estimate could not be found, the authors reported on the cost substituted other information from both European and American sources. The former included industry estimates of £400-£600 per vehicle for catalytic converter technology, reported by the Stockholm Environment Institute (SEI, 1999), and an estimate of £350 per vehicle in a report (not cited) commissioned by the UK government. The authors also mentioned that a prominent manufacturer sold catalytic converters to the industry for less than £50 per unit, but that did not include other components of the ECS or the cost of installation. These Euro 1 estimates were really not very conclusive.

In the US, the longer tradition of RIAs provides more *ex ante* studies to choose from, both for California standards and for federal standards. In California, Cackette (1998) found estimates prepared by industry and the California Air Resources Board (CARB) of the cost of California low-emission vehicle (LEV) regulations from the early 1990s. Industry estimates ($788 per vehicle) greatly exceed CARB estimates ($174 per vehicle), with the latter being a little higher than actual data from 1998. Actual costs were estimated to range from $75 to $152 for a limited selection of models. It is not clear how the actual cost estimate was calculated. For ultra-low-emission vehicles (ULEV), Cackette found estimates by individual firms. The GM estimate of this rule was "up to" $1 000 per vehicle, while the estimate submitted by Honda was only $300. CARB's estimate was $250.

However, not all estimates of California were overestimates. As noted above, CARB projected cost and availability of the ZEV, but unfortunately the technology has never emerged to allow the vehicles to be produced at reasonable costs.

The most comprehensive *ex post* assessment of motor vehicle standards and comparison with *ex ante* estimates was produced by Anderson and Sherwood (2002), who analyzed six fuel regulations and ten vehicle standards. Unlike the fuel regulations, it was impossible to use vehicle price changes to estimate the cost of individual rules. Not only were regulations becoming effective simultaneously with several other vehicle regulations, but many regulations were phased in over several years. For example, Tier 1 standards for light-duty vehicles were phased in so that 40% of vehicles had to comply in 1994, 80% by 1995, and 100% by 1996. Instead, AS use the cost estimates to estimate a pattern of expected cumulative cost increases for all vehicles from 1994 to 2001. They compare this trend to the BLS price trends for motor vehicles. They find that, by 1996, EPA had overestimated the cumulative cost of the vehicle rules by about $150 per vehicle and by 2001, by about $100 per vehicle, indicating some minor amount of cost underestimation between 1996 and 2001. AS attribute this outcome not to underestimation of the cost of later regulations, but to changes in the price of precious metals in 1997 and 1998 that affected the cost of catalytic converters required by vehicle emission standards adopted prior to 1996. Correcting for the unanticipated change in precious metals prices, it appears likely that the costs of most of the regulations were overestimated by EPA; nonetheless, for the purposes of the tally below, all the vehicle emission regulations enacted during the 1990s will be lumped together and counted as one.

A final and probably needless comment at this point: the estimates from industry sources again were serious overestimates (a cumulative $500 per vehicle by 2001) of the actual compliance costs, although most of the error appears attributable to a single regulation, the estimate of the costs of on-board diagnostic systems (OBD) required in 1996.

6. FURTHER THOUGHTS ABOUT POLICY

Above, we have reviewed three sets of policies, one to address local pollutant emissions from vehicles and two to address emissions of CO_2. Here are some final words about each.

The local pollutant policy is the use of emission standards for new vehicles. This was not the only mobile-source policy put in place over the last forty years; indeed, to make emission standards work required at least one major change to fuels, and that was the removal of lead from gasoline. Once gasoline was lead-free, however, the fuel standards did achieve by far the greatest part of the emission reductions, and new cars today are very probably 98-99% cleaner than new cars in 1970. Their emission control systems are also far more robust and durable than ever. The remaining vehicular emission problems are no longer found in light-duty vehicles but in heavy-duty, on-road vehicles and non-road vehicles. New regulations have been promulgated to address each, but it is too early to tell how they will do. Another mobile source pollution problem that still resists solution is the problem of maritime emissions. In coastal cities in the US and western Europe, other emission sources have been reduced so much that emissions associated with the port have become one of the main sources of pollutants.

We also considered policies encouraging the replacement of fossil fuels with biofuels in order to reduce CO_2 emissions. A wide range of policies has been implemented in the US and the EU to further this goal. Some have been pure subsidies of outputs, others subsidies of outputs, and others regulations, say, to require consumption of the biofuels produced. Determining the overall effect of these subsidies is not easy, but some recent work suggests that the cost of forcing these new technologies is very high and, perhaps in some cases (notably US ethanol), they may encourage technologies that produce more CO_2 than they displace. If nothing else, these programs demonstrate that the task of reducing fossil fuel use in transportation is extremely arduous. And yet, that task is likely to be necessary if some current fears about the severity and speed of climate change are to be guarded against. The question is whether subsidies, as politically popular as they generally are, are the best way to do that.

We hope to discourage use of one fuel by extreme encouragement of another. If it were possible, it would probably make more sense to discourage the use of fossil fuels directly by taxing them rather than subsidizing their competitors. A tax on fossil fuels would automatically encourage the production of those competitors, but it would also encourage other actions that would reduce CO_2 emissions, e.g. reducing car use and buying more fuel-efficient vehicles. (Or, instead of a tax, an alternative would be to bring motor vehicles into the evolving cap and trade program for stationary sources. Probably the best way to bring in vehicles would be to impose and “upstream” cap and trade policy, which would not require individual motorists to trade carbon permits for the privilege of using their vehicles. Permits would be held by refiners who would have to surrender a permit in order to sell a quantity of fuel. As far as the motorist is concerned, it would act like a tax, except that the price of fuel would probably be more variable.)

A tax on fossil fuels would also avoid a real danger of the apparently excessive subsidies we see in the US and the EU today, and that is the creation of a community of beneficiaries that will resist any serious change to the policy, even if it becomes obvious that it is not a good idea. Once a thousand biofuel plants are built, encouraged by a web of subsidies out of proportion to the public benefit, there could be major issues of stranded costs that will make policy change very difficult.

Finally, there is the CAFE policy to improve fuel economy in vehicles. The US has had a mandatory CAFE policy in place for thirty years, and the majority view, the author would say, is that it did have some effect in improving overall fuel economy and reducing fuel use in the US, not in absolute terms certainly, but compared to what fuel use would have been in the absence of CAFE. There is also broad agreement that, to a significant degree, the problems of CAFE were not inherent, but were attributable to the particular details of the American policy. In particular, separating vehicles into car and truck groups for averaging purposes might have worked better if it had not been rather easy to build vehicles that appealed to households as cars but which were considered as trucks for regulatory purposes. The incentive to do this was heightened by the large difference between the car and truck standards. CAFE might also be improved by greater flexibility for manufacturers. Already, CAFE permits fuel economy "trading" within a manufacturer's fleet of vehicles. It might improve the cost effectiveness of the program to allow trading across manufacturers. In addition, what it would certainly do is make the cost of CAFE more transparent, as the price of the CAFE credits would become known.

NOTES

1. Source: The US Greenhouse Gas Inventory, USEPA 430-R-05-003, April, 2005.

2. This estimate only counts the costs of vehicle use. The cost of elapsed time to the driver and other occupants of the vehicle is ignored.

3. Including the National Environmental Policy Act (1969), the Clean Air Act of 1970, the Federal Water Pollution Control Act Amendments of 1972, the TOSCA, CERCLA, RCRA.

4. Conservation of momentum requires that if, for example, two vehicles, one twice the mass of the other, collide head-on while travelling 45 mph, the velocity immediately after the crash will be 15 mph in the direction travelled by the heavier vehicle. Thus the change in velocity in the heavier vehicle is 30 mph; in the lighter, 60 mph.

BIBLIOGRAPHY

AEA Technology (2004), “An Evaluation of the Air Quality Strategy”, Report prepared for DEFRA.

An, Feng and Amanda Sauer (2004), *Comparison of Passenger Vehicle Fuel Economy Standards and GHG Emission Standards Around the World,* Pew Center on Global Climate Change.

Anderson, John and Todd Sherwood (2002), Comparison of EPA and Other Estimates of Mobile Source Rule Costs to Actual Price Changes, SAE 2002-01-1980.

Boemer-Christiansen, Sonja and Helmut Weidner (1995), *The Politics of Reducing Vehicle Emissions in Britain and Germany,* Madison, N.J.: Fairleigh Dickinson University Press.

Brandeis, Louis (1932), *New State Ice Company v. Liebmann*, 285 US 262, 311.

Cackette, Tom (1998), “The Costs of Emission Controls”, Presentation at MIT Workshop on New Vehicle Technology, MIT, June.

Crandall, R.W. and J.D. Graham (1989), The Effect of Fuel Economy Standards on Automobile Safety, *Journal of Law and Economics,* 32: 97–118.

Dargay, Joyce, Dermot Gately and Martin Sommer (2007), Vehicle Ownership and Income Growth, Worldwide: 1960-2030, *The Energy Journal,* 28(4).

Department of Trade and Industry (UK) (2007), “Synthesis of the Analysis of the Energy White Paper”, May.

Fischer, Carolyn, Ian Parry and Winston Harrington (2004), *Economic Impacts of Tightening the Corporate Average Fuel Economy (CAFE) Standards*, Resources for the Future, Washington, DC. Report prepared for the Environmental Protection Agency and the National Highway Traffic Safety Administration.

Gomez-Ibanez, J.A. (1997), Estimating Whether Transport Users Pay Their Way: The State of the Art, in: D.L. Greene, D.W. Jones and M.A. Delucchi (eds.), *The Full Costs and Benefits of Transportation,* Heidelberg, Germany: Springer-Verlag, Berlin, Chapter 3.

Greene, D. (1991), Short-Run Pricing Strategies to Increase Corporate Average Fuel Economy, *Economic Inquiry* 29(1): 101–14.

Greene, David (2007), “Policies to Increase Passenger Car and Light Truck Fuel Economy”, Testimony before the US Senate Committee on Energy and Natural Resources (January 30).

Gruenspecht, H. (2001), Zero Emissions Vehicles: A Dirty Little Secret, *Resources,* 142: 7–10. Resources for the Future, Washington, DC.

Harrington, Morgenstern and Sterner (eds.), *Choosing Regulatory Policy,* Washington: RFF Press.

K.T. Analytics, Inc. and Victoria Transport Policy Institute (1997), Review of Cost of Driving Studies. Paper prepared for the Metropolitan Washington Council of Governments.

Koplow, Doug (2006), Biofuels: At what cost? Government support for ethanol and biodiesel in the United States. Global Subsidies Initiative, International Institute for Sustainable Development.

Kutas, Geraldine, Carina Lindberg and Ronald Steenblik (2007), Biofuels: At what cost? Government support for ethanol and biodiesel in the European Union. Global Subsidies Initiative, International Institute for Sustainable Development.

National Highway Traffic Safety Administration (1997), *Relationship of Vehicle Weight to Fatality and Injury Risk in Model Year 1985–93, Passenger Cars and Light Trucks*. NHTSA Summary Report DOT HS 808 569, Springfield, VA: National Technical Information Service.

National Research Council (2002), *Effectiveness and Impact of Corporate Fuel Economy (CAFE) Standards.* Washington, DC: National Academy Press.

National Research Council (2006), *State and Federal Standards for Mobile Source Emissions.* Washington, DC: National Academy Press.

Oak Ridge National Laboratory (2004), *Transportation Energy Data Book*.

Parry, Ian, Margaret Walls and Winston Harrington (2007), Motor Vehicle Externalities, *Journal of Economic Literature,* 45(2), June.

Shore, Joanne (2005), "The Road Ahead for Light-Duty Vehicle Fuel Demand". Presented at Energy Information Administration, July.

Small, Kenneth and Kurt Van Dender (2006), The Effect of Improved Fuel Economy on Vehicle Miles Traveled: Estimating the Rebound Effect Using US State Data, 1966-2001.

Train, Kenneth and Clifford Winston (Forthcoming), "Vehicle Choice Behaviour and the Declining Market Share of US Automakers", *International Economic Review.*

USEPA (2005), US Greenhouse Gas Inventory, EPA-430-R-05-003, April.

A FULL ACCOUNT OF THE COSTS AND BENEFITS OF REDUCING CO_2 EMISSIONS IN TRANSPORT

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INTRODUCTION

Among economists and policymakers more generally, a fuel efficiency standard for cars and the fuel tax have been the subject of extensive debate. The major benefits from stricter fuel efficiency standards and higher fuel taxes are the reduction of greenhouse gas emissions and the reduced oil dependence. The major costs are the increased production cost, the reduced comfort and the negative impact on mileage-related externalities (congestion, accidents) due to the rebound effect.

In this contribution, we use a wider framework than Harrington (2008), Plotkin (2008) and Raux (2008) to discuss the CO_2[1] emission reduction in transport. In Section 1 we analyse, for the EU, the effects on welfare and CO_2 emissions of pricing all transport activities depending on their full social costs. In Section 2, we go beyond the transport sector and compare the options to reduce emissions in the transport sector with the possibilities and costs to reduce emissions in other sectors of the economy. In Section 3 we take a world view and analyse the impact of two types of international climate negotiations on the emission reduction strategy in the transport sector.

The GHG reduction ambitions differ strongly across the world. It is normal that this translates into different CO_2 reduction policies in the transport sector. This is the first reason why this contribution focuses more on EU policies than on American policies. A second reason is that the EU has been a forerunner on high fuel taxes for cars and ambitious CO_2 reduction targets.

The EU has high fuel taxes and is considering strong fuel efficiency standards. These fuel taxes are not called carbon taxes but act as a high carbon tax of Euro 200-300 per tonne of CO_2. The EU has very ambitious overall GHG emission targets (up to -50% in 2030 compared to the 1990 level) but is considering at the same time a strong reform of its transport policies, possibly moving away from fuel taxes.

This raises several policy questions. First, what are the impacts of a strong reform of the transport pricing policy on overall welfare and how will this affect the overall CO_2 emission reductions? Second, if one gives up the principle of high fuel taxes in the transport sector, how will one be able to meet ambitious GHG emission targets in the economy? The first question will be dealt with by considering the transport sector globally, trading off the different modes and the different types of externalities. For the second question, we put the emissions of all sectors in a country on the same basis and assess the role of the transport sector in reaching the national GHG emission target in the most efficient way.

In the second part of this contribution, we take an international cooperation view of the policies to reduce CO_2 emissions. As climate change is a world issue, the costs and benefits for any region reducing emissions in the transport sector or in other sectors, depend in the end on whether one's effort is part of an international agreement or not. At present, the EU has developed a double strategy of cooperation ("tit for tat": large cuts in emissions if the world joins them, small efforts if they are alone). We look at the implications of the two scenarios for the costs and benefits of CO_2 emission reductions in the transport sector. In the same section, we also pay attention to the potential of technological cooperation.

In this contribution, we use three types of numerical model analysis that are very different. In order not to confuse the reader, we define them briefly in Table 1. The three types of modelling exercises are internally consistent. First, they all use similar exogenous assumptions on economic growth and oil prices. Second, the carbon values that result from the exercise at world level and the exercise at energy sector level are of the same order of magnitude as the exogenous carbon value used in the model for the transport sector.

Table 1. **Frameworks of analysis used in this contribution**

Research Question	**Scope**	**Model used**
Effect on CO_2 emissions of pricing all modes of transport depending on their external costs	Transport sector with its different modes in 2020 Carbon price is exogenous	TREMOVE-II Partial equilibrium model of the transport sector applied to EU-27 + 4 countries
What is the potential contribution of the transport sector to a cost efficient reduction of CO_2 emissions in a country?	All energy use in a country 2005–2050 Carbon price is endogenous	MARKAL-TIMES Partial equilibrium model of the energy sector, applied to Belgium
What is the expected price of CO_2 emissions in different types of international agreements?	World economy 2005-2050 Carbon price is endogenous	GEM-E3 General equilibrium model of the World economy

1. WHERE DOES EUROPE GO IN TERMS OF PRICING AND REGULATING EMISSIONS? MOVING FROM FUEL TAXES TO KM CHARGES

There is a long-standing debate in Europe on the need to introduce new policy instruments in the transport domain. Starting with the Fair and Efficient transport pricing doctrine launched in 1998, there has been an emphasis on pricing reform that makes all modes pay their full external costs. External costs include here climate change damage, other air pollution and noise damage, accidents and external congestion costs.

This is exactly what many economists have been advocating for years, and what has been at the core of the fuel efficiency standard debate. In the fuel efficiency debate, the effects of stronger standards on the CO_2 emissions but also on the mileage-related externalities (accidents, congestion) were an important consideration. An important drawback of a stricter fuel efficiency standard is the rebound effect that increases costs of congestion and accidents, and this is an economic efficiency loss when transport taxes do not internalise these mileage-related externalities. Abolishing the fuel efficiency standard and the high fuel price and replacing them with better targeted instruments looks like the obvious way forward.

What can we expect in the larger EU, if there is a full internalisation of all the external effects, as economics prescribes? A recent exercise by the GRACE research consortium[2] is probably one of the most complete analyses of the effects of such a policy change[3]. The TREMOVE model was used to examine what the effects would be on emissions (CO_2 and conventional) of a drastic change in pricing policy. The model runs year per year from 1995 to 2030 and represents the transport market equilibrium. It is to be considered a medium-term model, as it keeps track of the vehicle stock turnover and takes location as given. The alternative pricing scenario is defined in Table 2. The analysis covers 31 countries (the EU-27 + Switzerland, Norway, Turkey and Croatia).

Table 2. **Scenario description**

	Cars	**Trucks**	**Other modes**
Reference	Current tax system + regulation for conventional emissions	Current fuel taxes + regulation for conventional emissions + Eurovignet	Unchanged policies
CO_2 tax + km charge	CO_2 tax + flat km tax that covers all other externalities and is differentiated by country and type of vehicle	CO_2 tax on fuel + flat km tax that covers all other externalities and is differentiated by country and type of vehicle	Prices cover variable costs

The TREMOVE model[4] represents the transport activities in a country as an aggregate of the activities in three types of zone: metropolitan, urban and non-urban. For each zone, one represents all modes of passenger transport and freight transport. Road freight and passenger transport interact via congestion and a distinction is made between peak and off-peak traffic. Passengers' preferences differ depending on the motive (professional, commuting, leisure), and choices are made taking into account preferences, money and time costs. For freight, different types of transport (unitised, bulk…) are distinguished and modal choice depends on the time and money cost of the different alternatives. The private cost of transport consists of the price set by the suppliers (equal to the marginal resource cost if not subsidized) plus all the taxes, charges and tolls. The choice of consumers and firms between different sizes of vehicles and different types of fuel is represented using logit functions. The logit functions are based on present prices, and a real interest rate of 4% is used. Urban public transport supply is characterised by a Mohring effect: an increase in demand allows to improve frequencies and to reduce waiting times. The capacity of the infrastructure is represented via aggregated speed flow functions.

The model computes equilibrium on each transport market (this means for each zone) via iterations on the time costs and the demand levels. The model is calibrated so as to match an exogenous unchanged policy or "reference" scenario. Of interest is the fact that the model computes, for a given transport equilibrium, all the external costs and all tax and charge revenues. Welfare is defined as the sum of consumer surplus, producer surplus minus total external costs plus the value of tax revenue[5]. In our case, the model is used for counterfactual analysis: what is the effect on welfare of modifying taxes, charges or regulations such that they better match the different external costs?

In the reference scenario, the main instruments for pricing transport are all kinds of vehicle tax, a high fuel tax plus a km charge for trucks. The investment and operation costs of public transport are heavily subsidized in some of the countries. Conventional emissions are controlled by the different

EURO regulations for cars and trucks. The CO_2 emissions are controlled by a "voluntary" fuel efficiency standard, and it is assumed that technological progress continues to reduce average fuel consumption slightly. Most of the taxes are not connected at all to the different types of external cost. There is one exception: the fuel tax (in fact a CO_2 tax) is twice as large as the climate change damage (by assumption, equal to 80 Euro/tonne of CO_2). Overall user prices for most modes are too low; even the variable public transport prices are heavily subsidized.

Figures 1 and 2 show the mismatch between current taxes and marginal external costs for passengers and for freight transport by mode. Both figures represent averages for the EU-27 + 4 for 2020 in the reference scenario. The figures take into account the greening of the car stock resulting from the introduction of the different EURO regulations, and results from the assumption that in 2009 an average CO_2 emission rate of 140g/v-km is reached for new cars. Figure 1 shows that air transport does not pay its marginal external costs (noise, air pollution): the left column is larger than the right column (here 0). The high fuel tax and other car taxes, on average, are insufficient to cover the marginal external costs of car use. These are averages that cover widely different situations: marginal external costs for road transport are much larger in the peak in urban areas than in rural areas. Passenger rail also generates external costs but its variable costs are subsidized so that the tax column becomes negative. Figure 2 gives a general picture of the external costs and current taxes for different freight transport modes. On average, the charges and taxes for IWW (inland waterways), large trucks and rail freight do not cover their marginal external costs.

Figure 1. **Marginal external costs compared to taxes for 2020 – passenger transportation in reference scenario**

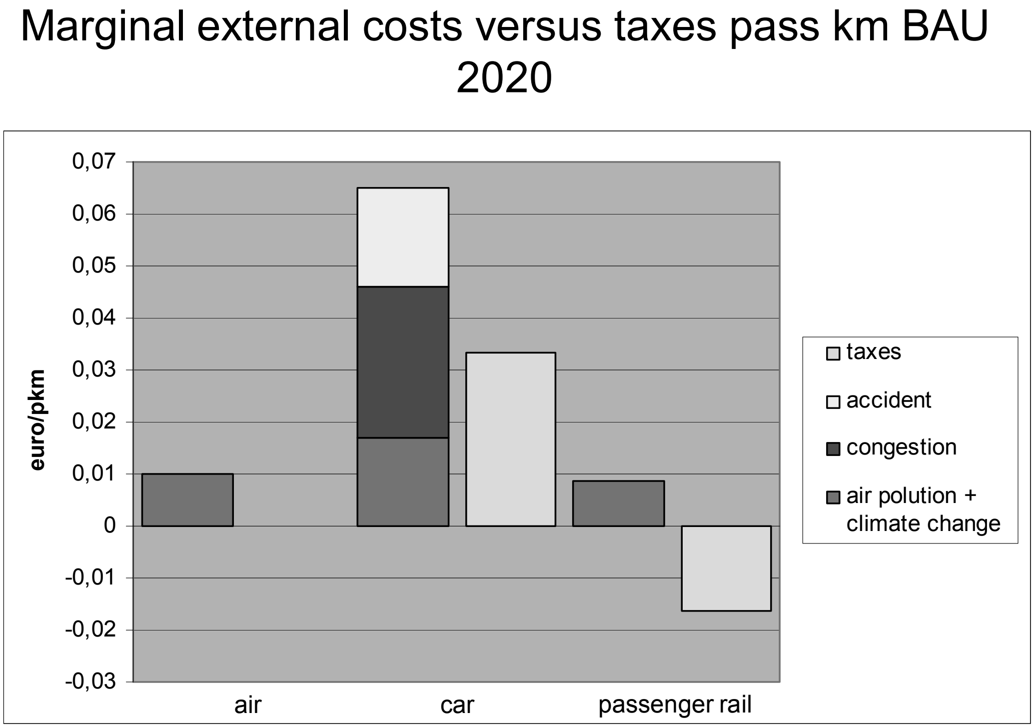
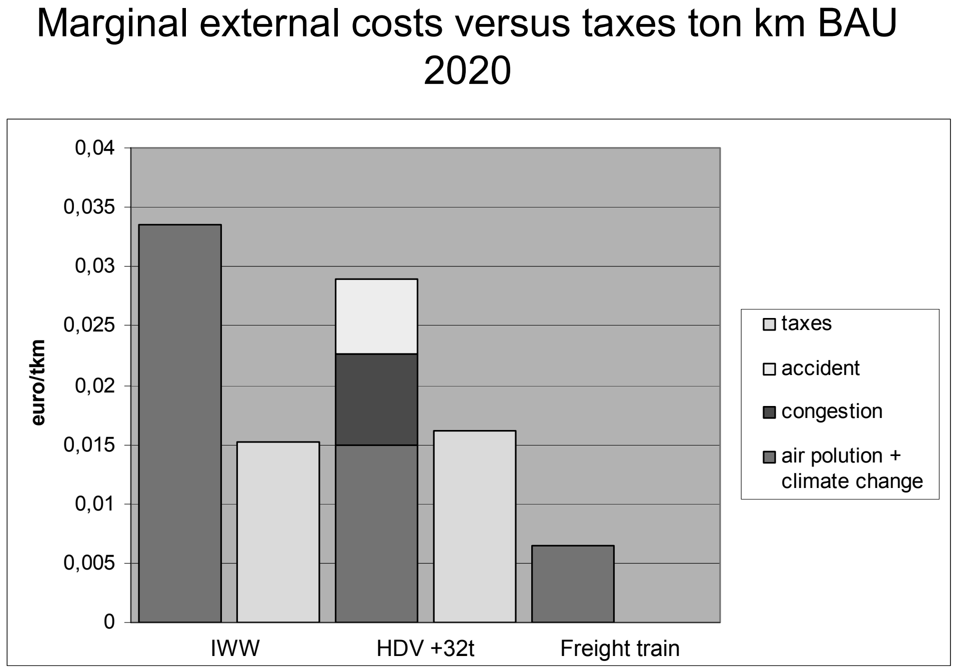


Figure 2**. Marginal external costs compared to taxes for 2020 – freight transportation in reference scenario**



In the alternative scenario (CO_2 tax + flat km charge), the effects of a combination of lower taxes on fuel (equal to the carbon tax) and km charges (differentiated by type of vehicle and country) are simulated such that all modes pay approximately their marginal social cost. This implies a tax on fuels that is only half of that in the reference scenario but a flat, high km charge that is differentiated by country and by type of vehicle[6].

The results are summarized in Table 3. A reform of the price system away from the current high fuel charges to more targeted taxes per mile with country and vehicle differentiation, generates important extra revenues and an important gain in welfare. Fuel taxes decrease but in most countries the km charges for car use are strongly increased to match the congestion, accident and air pollution costs. For public transport, subsidies on operation costs are abolished and this leads to an overall price increase that can be strong in some countries. The final result is a decrease in the volume of passenger transportation of 11.5% compared to the reference in 2020. The decrease in the volume of public transport is even higher, because public transport increases in price due to the abolishment of subsidies on operation costs, which are no longer justified now that car use is priced more correctly. The type of car also changes: away from large and medium diesel cars, which had an unjustified fuel cost advantage. For freight transport, similar decreases are expected.

Table 3. **Effects of pricing the transport modes more correctly**

2020 – difference with Reference	**Revenue**	**Overall welfare**	**Total environmental damage**	**GHG emission damage**
Difference expressed in % of GDP	+3.1%	+1.2%	-0.22%	-0.054%
	Passenger-km on road	**Total pass-km**	**Tonne-km on road**	**Total tonne-km**
% difference in quantities	-8.6%	-11.5%	-10.1%	-11.0%

Tax revenues (accounting for all changes in tax revenues and including all changes in subsidies to public transport) increase strongly (by 3.1% of GDP), and welfare increases by some 1.2% of GDP[7]. The major benefits come from a reduction of accident externalities and congestion. The total emissions of CO$_2$ decrease by 12.2% and this despite the strong reduction of the fuel excises. This is due to two effects. First, there is the overall reduction in volume of transportation. Second, there is the small effect of lower fuel taxes on the types of cars that are bought. In the model, there is a strong technological lock-in and although people would buy larger cars, the European car stock does not start to look like the US fleet. The model may underestimate this effect to less fuel-efficient cars.

In conclusion, pricing all externalities in the transport sector can be done more efficiently by using a combination of low fuel taxes based on carbon content and km charges where the latter charges are differentiated by vehicle type and country. This allows important welfare gains and does lead to a small "no regret" reduction of CO$_2$ emissions compared to the reference.

2. THE CONTRIBUTION OF THE TRANSPORT SECTOR IN REACHING THE NATIONAL EMISSION CAP: AN ENERGY TECHNOLOGY APPROACH

How far one should push the GHG reduction efforts in the transport sector can be analysed in two ways. One can take an exogenous national benchmark marginal cost level in Euro per ton of CO$_2$ and check what policies have a lower cost per ton of CO$_2$ reduction. This gives a potential of CO$_2$ emissions that can be reduced at a cost lower than the threshold value. In Section 1, this procedure was used to judge the effects of alternative pricing policies in the transport sector: all measures that generate CO$_2$ emissions at a cost below the threshold are, in principle, taken by consumers and producers and increase the welfare level.

The national benchmark cost level is ideally the result of a broader analysis, comparing the possibilities to reduce the emissions in all sectors including transportation. The outcome is then an efficient allocation of emissions over, for example, the transport, residential and electricity generation sectors, etc. In this section, we take this broader view, analysing all sources of CO$_2$ emissions in an economy and comparing them on the same basis.

We use the Belgian MARKAL-TIMES model[8] for this analysis. This model describes all energy transformation and use in an economy, from the import of fuel to the delivery of energy services (car-km, heated homes, etc.). The demand functions for energy services are given by expected sector activity growth rates (say, steel production or passenger car-km) and household incomes. The energy services (passenger car-km or process heat for steel-making) are then produced in the most cost-effective way, combining demand-side technologies (more energy-efficient light bulbs, more efficient car engines, etc.) and supply-side technologies (better power stations or refineries). In this way, one is able to simulate the potential role of new technologies in the energy supply and demand in a sector. This can be seen as a two-step procedure. In the first step, one minimizes the total system cost of satisfying a given demand for energy services. In the second step, one compares the marginal cost of satisfying this level of energy services with the willingness to pay of the user (household or firm) for the energy services. When the marginal cost of supplying a given level of energy services becomes very high, it is cheaper for the household or firm to reduce their demand for services by foregoing the trip or by substituting the energy services by other production factors. The model is dynamic and forward-looking in the sense that all choices (use of energy services as well as types of technologies) take into account the costs and benefits over the whole lifecycle. It is as if one central, benevolent planner could make all use and investment decisions to maximise the discounted welfare of the whole economy. The discounted welfare includes the benefits to all users (consumer surplus of energy using households and firms) as well as all variable and investment costs of delivering energy.

One useful feature of the model is that one can add a national emission cap[9]. The model then generates the most cost-efficient way of satisfying the national emission cap. This means specifying what combination of technologies and activity levels for energy use minimizes the overall system cost of satisfying this absolute cap.

Important inputs in any model exercise of this type are the expected growth rate of economic activities, their translation into energy service levels and the technological evolution. A GDP growth rate of some 2% is used and crude oil prices double between 2000 and 2020. In principle, the model allows for the progressive introduction of new technologies that become available in the period 2005 to 2050. For each technology, one specifies its earliest date of introduction, its efficiency and its variable and investment costs. If the technology is competitive in welfare terms, it will gradually replace the existing technology. Transport demand is assumed to increase at some 2% per year. Important assumptions for the transport sector are that the fuel efficiency of new traditional gasoline and diesel cars is assumed to improve by 15% in 2030 compared to 2005. Also all new technologies (hybrid, electric, hydrogen) can be chosen from 2010 onwards, except the hydrogen fuel cell which is only made available from 2030 onwards. This assumption on early introduction is chosen to test the competitiveness of these new technologies.

We consider national CO_2 reduction scenarios for Belgium that aim to reduce emissions drastically in the long term, as shown in Table 4. Compared to emissions in 1990[10], a reduction in emissions of 20% (in 2020) up to 52.5% (in 2050) is required. These reductions are even more impressive when they are compared with a reference case where, in the absence of climate policy, emissions would have grown by some 15% in 2020 compared to 1990 and by some 50% in 2050. Moreover, we assume that the nuclear power stations (which still produced more than 50% of the electricity production in Belgium in 2005) are all phased out in 2030 and that no international permit trade is possible. This is the most stringent scenario in terms of CO_2 reductions and it is chosen precisely to examine the role of the transport sector in overall emission reductions in the most demanding case.

Table 4. **Cap on national CO_2 emissions**

	2010	2020	2030	2050
% reduction required compared to 1990 emissions	-7.5%	-20%	-30%	-52.5%
% reduction compared to reference scenario without climate policy	-18%	-30%	-59 %	-76%

The point of this modelling exercise is to know what is the cost-effective use of different technologies and activity reductions that achieves the CO_2 emission objective at the lowest cost for the national economy. More specifically, what is the role of the transport sector in this cost-effective strategy?

Table 5 reports on the role of the transport sector in the reduction of CO_2 emissions, given the climate objectives of Table 4. The first line of Table 5 reports the marginal cost of CO_2 reductions in this ambitious emission reduction scenario. The marginal cost is the shadow price of the maximum national emission cap and tells us the marginal welfare cost[11] for the Belgian energy system of having to reduce emissions by one more tonne. This marginal cost can be the basis for considering international trading of emission rights. The marginal costs obtained are reasonable up to the period 2020–2030 but are clearly very high in 2050, and this despite all new energy saving and renewable technologies foreseen beyond 2030. The main reason why this scenario is very demanding for Belgium is the simultaneous strong reduction of total CO_2 emissions and the nuclear phase-out[12], combined with the absence of carbon trading.

Table 5. **Role of the transport sector in reduction of CO_2 emissions in Belgium**

Years	2010	2020	2050
Marginal cost of CO_2 reduction (Euro/tonne CO_2)	31	68	531
% reduction of emissions in transport sector compared to reference scenario	-1%	-17%	-48%
% reduction in national emissions country	-18%	-59%	-76%
% reduction of activity for car transport	0%	0%	0%
% reduction of activity for truck transport	-2%	-5%	-5%

The second line reports the ideal reduction of CO_2 emissions in the transport sector that is expected when all sectors are treated on the same least-cost basis. The expected reduction from the transport sector is very moderate (-1% in 2010 to -17% in 2020), and much smaller than the overall reduction needed for the country (-18% in 2010 to -59% in 2020). This shows that the same proportional reduction of emissions over all sectors is not at all cost-minimizing. In addition, this scenario shows that a strong reduction of emissions is technologically and economically feasible without requiring large efforts from the transport sector. In 2050, one attains a limiting case where the reduction of emissions is pushed to its extreme. In this case, emissions by the transport sector have to be reduced by 48% compared to an overall effort of 76%. In the latter case, one has to resort to very innovative technologies.

Emission reductions usually require a combination of a reduction of specific emissions per vehicle-km by using better technologies and a reduction of the level of activity (v-km, t-km in the transport sector). The two last lines of Table 5 show that the major reduction effort comes via adaptation of fuels and technologies rather than via a reduction in activity. The volumes of car and truck traffic are hardly affected.

It is interesting to see what technologies are used in the transport sector to respond to very strong CO_2 emission reductions. We find that, starting in 2020, the major change is the use of alternative fuels in conventional engines: CNG (compressed natural gas) in conventional combustion engines, ethanol and biodiesel. Many fancy technologies are not cost effective when they are placed in a fair comparison with traditional technologies. The gasoline and diesel parallel hybrid cars are more fuel efficient but this fuel efficiency comes at a very high cost. The same holds for the electric technologies: they never penetrate because the electricity needs to be produced using conventional gas power stations, as the nuclear power option is excluded and renewables quickly reach their potential. Table 6 reports the percentage decrease in investment cost that is needed for the penetration of some of the new car technologies in the strong emission-reduction scenario that is simulated here. As an example, take the hydrogen combustion car: its investment cost needs to decrease by 56% (2020) to 45% (2040) to make this technology interesting as a carbon emission saving technology.

Table 6. **Reduction in investment costs needed to make a particular technology cost effective in the CO_2 reduction scenario defined in Table 4**

	2020	2030	2040
Biodiesel	21%	13%	0%
Hydrogen.Combustion	56%	59%	45%
Diesel.EURO4	1%	1%	7%
Electric.Battery	41%	146%	163%
Hydrogen.FuelCell	58%	29%	20%
Hydrogen.Hybrid.FuelCell	59%	34%	25%
Gasoline.CNG	3%	0%	0%
Gasoline.EURO4	0%	0%	7%
Diesel .EURO4.parallelhybrid	18%	17%	20%
Gasoline.CNG.parallelhybrid	13%	8%	4%
Gasoline.EURO4.parallelhybrid	6%	3%	1%
Hydrogen.Hybrid.Combustion	57%	63%	49%

In conclusion, we find that, in the case of Belgium[13], the share of the transport sector in reducing its CO_2 emissions is small in a cost-effective reduction scenario. It is technologically feasible and cost effective to reach strong emission reductions (-30 to -50%) by reducing emissions strongly in sectors other than transport. When one really focuses on CO_2 emissions, technologies like CNG may be more promising than fuel-efficiency standards, hybrid cars or electric cars.

3. ROLE OF CO_2 EMISSION REGULATION IN THE TRANSPORT SECTOR: A WORLD VIEW

As climate change is a world issue, the costs and benefits for any region depend in the end on whether one's effort is part of an international agreement or not. The CO_2 emissions of one country generate climate damage (or benefits) for the whole world. Whenever one considers the benefits of emission reductions, the benefits for the EU or the USA are only a fraction (20 or 30%) of the world benefits of an emission reduction.

In any country, the reduction of emissions in the transport sector is motivated by the position that country takes in the international climate negotiations. If the country only takes into account the damage avoided in its own country (a non-cooperative approach), it will make a much smaller effort than when its efforts are part of a larger international agreement, where worldwide damage is taken into account (the cooperative approach). Most natural scientists assume that governments should base their policies on the cooperative approach. Economists take a different assumption: the governments can play non-cooperatively or cooperatively and the outcome of the game is uncertain.

We know from economics that reaching a large, stable coalition to reduce emissions is very difficult. Barrett (1994) showed with a simple model that the equilibrium number of signatories of an international agreement for a problem in the climate change category is small. In some of his stylised examples, only three out of one hundred equal countries would sign. The main problem is that international agreements have to be self-enforcing: a country signing a climate treaty should be at least as well off as when it does not, because no international law can force a country to observe a signed international agreement. More favourable outcomes are possible when one takes into account the fact that countries play this game repeatedly, and when countries are of unequal size.

Given our interest in the CO_2 emissions from the transport sector, there are two international cooperation issues that need our attention. The first is the possibility of an international agreement to reduce emissions and the associated worldwide trading of emissions which limits the costs of emission reductions. What are the likely impacts on carbon prices and what implications does this have on carbon policies in the transport sector? The second issue is the option for international cooperation to focus on the development and adoption of breakthrough technologies in the car sector that limit drastically emissions and fuel use.

3.1 International climate negotiations and their impact on transport emission reduction strategy

The EU has decided to reduce emissions of GHG by 20% in 2020, and even by 30% in 2020 (compared to 1990) if the other big emitters of GHG join them. The EU starts with a cooperative attitude in the hope that the other important players realise that this is also in their interest. It is difficult to assess the chances of this strategy. It is also important to assess the fallback strategy of the EU. If other big players do not follow, the EU wants to opt, unilaterally, for smaller emission reductions.

The effects of both strategies on total emissions, economic costs, trade in emissions and the price of carbon have been assessed using the GEM-E3 model (Capros *et al.,* 1997[14]). GEM-E3 is a world-based general equilibrium model, representing the world's economic activity by using a disaggregation into 18 groups of countries and 18 sectors. It includes trade in products but also trade in emission rights.

The "cooperative" scenario (with efforts by all important players) and the unilateral EU scenario (only efforts by the EU) are compared with the reference scenario, where the world economy grows by some 2.5 to 3% per year and where there are no specific CO_2 emission reduction efforts.

Table 7. **Costs and emission reductions of two EU climate change negotiation strategies**

% change compared to baseline with no reduction efforts	**Cooperative scenario**				**Unilateral EU scenario**	
	2020		**2030**		**2020**	
	Economic cost	**Emission GHG**	**Economic cost**	**Emission GHG**	**Economic cost**	**Emission GHG**
USA	-1.4%	-39.5%	-3.4%	-52.4%	0.0%	0.0%
EU-27	-2.3%	-28.1%	-5.7%	-41.6%	-0.2%	-5.8%
Brazil	-0.3%	-4,8%	-1.5%	-15.0%	0.0%	0.1%
India	-0.9%	-0.6%	-1.6%	-23.3%	0.0%	0.0%
China	+0.3%	-25.9%	-0.8%	-32.8%	0.1%	-15.2%
World total	-1.2%	-25.9%	-3.4%	-37.2%	0.0%	-3.6%
Price of carbon (US$/ton CO_2eq)		45		93		6

In the cooperative scenario, it is assumed that the EU and the US each promise a reduction of 30% in 2020 with respect to 1990; in 2030, the reduction effort would even reach -55% compared to 1990. The emission reduction can also be achieved by buying emission reductions in other countries that participate in the agreement. These other countries are China, India and Latin America. In this scenario, these countries commit themselves to limiting emissions per unit of output. Irrespective of the volume of trade in emissions allowances, China promises to limit its emissions by 12.5% compared to the reference emission levels. Because China can reduce emissions more cheaply than the EU and the US, this is an important component of a cooperative agreement. It is mainly China and India that sell emission rights to the US and EU. The EU-27 reduces its emissions by only 41.6% in 2030 but buys the remaining emission reductions in China and India (13.6% = 55% total effort for EU, -41.6% internal effort for the EU). With efficient trading worldwide, this scenario will, in 2020, only cost 1.2% of economic welfare for the world (before counting the benefits of reduced climate change). Welfare costs for the EU (-2.3%) are larger because they start from a lower level of emissions than the US and the rest of the world (except Japan).

The climate change benefits of this scenario are more uncertain than the costs but the objective is to limit global warming to 2° C (CEC, 2007; IPCC; Stern Report). This can be achieved with a worldwide emissions reduction of 37.2% in 2030 (see penultimate line of Table 7).

Important for the emission reduction strategy in the transport sector, is not so much the precise modelling of the transport sector in this world model but the marginal cost of CO_2 reduction at world level. This carbon price would grow from 45 USD/ton of carbon in 2020 to 93 USD/ton in 2030 (last line of Table 7). These are the orders of magnitude used in Section 1 and Section 2 (Table 6) to assess the cost efficiency of emission reduction efforts in the transport sector. This means that, taking a world point of view and including the possibilities of trading emission reductions worldwide, there is no need now to push the saving of CO_2 emissions in the transport sector, as there are cheaper options around.

Whenever the rest of the world does not follow the initiative of the EU to join them in an agreement that strongly reduces emissions, we end up in the unilateral EU scenario[15]. In this scenario, the EU is the only one to make strong reduction commitments. It promises a reduction of 20% in 2020. Because the other big players do not commit to any effort, it is in the interest of the EU to make an agreement with China to buy cheap emission reductions. The result is that the 20% reduction of emissions is mainly achieved by efforts in China. Table 7 (last column) shows how the -20% reduction in the EU means a reduction of emissions at home of 5.8% compared to the baseline, and a reduction in China of 15.2%. The overall emission reduction in the world is limited to 3.6% only – a tiny result compared to the 25.9% reduction achieved in 2020 in the cooperative scenario. In this case, the carbon price drops to USD 6 per ton of CO_2, because the required emission reduction is low and there is a cheap supply of CO_2 emission reductions outside the EU.

The implication for the transport emission reductions of this unilateral scenario is that, despite the cut in emissions proposed by the EU, the extra efforts expected from the transport sector in the EU are almost nil.

Only the future can tell whether the world will ever cooperate seriously to reduce CO_2 emissions. Even if it goes for very ambitious reductions, the role of the transport sector in emissions reductions will be very limited in the next 20 to 30 years, and certainly if international trading of emissions allowances is in place.

Theoretically, the EU is faced with an emission reduction target that is uncertain: the value of an emission reduction varies between USD 6 and USD 45 (2020) to USD 93 (2030) per ton of CO_2. Only when the EU learns more about the attitude of the other players can it definitely determine its policy. Furthermore, general information about the climate change puzzle will be updated regularly. According to Weitzman's theorem (1974), this type of uncertainty, together with the rather flat shape of the damage function for CO_2 emissions, pleads for the use of a more flexible price instrument rather than for a quantity instrument: CO_2 taxes in the form of fuel taxes would be preferred to fuel efficiency standards.

3.2 International agreements on fuel efficiency standards

One alternative approach to an international agreement that puts caps on the emissions of different countries is an agreement where a number of countries promise to cooperate in the development of a new, very carbon-efficient sectoral technology and promise to use it once it is established. This could be a car technology (e.g. hydrogen, breakthrough in traditional engine technology).

Can this type of agreement work, and what are the implications for current policy? Barrett (2006) used a small theoretical model with identical countries to provide some intuitive insight into this problem. Because the benefit of R&D funding depends on the number of adopters, one needs first to solve the question of the adopters before the R&D funding problem.

Countries would only adopt a breakthrough technology if a country's own extra benefit from adopting the new technology outweighs the extra operation and investment cost of the new technology. The development costs are considered as sunk costs once the technology is there. The net benefit is mainly the reduction in climate change damage for the country itself, and this depends on the number of adopters. The result is that the equilibrium number of adopters will be limited when the gains of cooperation are largest. There is one exception, however. If there are increasing returns from adoption (learning by doing), the equilibrium number of signatories may be much higher.

Let us turn to the R&D funding part of the international agreement. The benefit for a country of investing in R&D equals the expected avoided climate change damage. This avoided climate change damage increases according to the number of adopters. As long as the number of adopters is small, the country gains from an R&D funding agreement will be small. Only when there are important economies of scale in adoption can these technological treaties be successful.

Returning to the transport sector, is international R&D cooperation on the development of super fuel-efficient vehicles a priority? Two reasons mitigating our enthusiasm are, first, present car companies are already integrated worldwide and make use of possible returns to scale and, second, carbon is already highly taxed in the case of car fuel. A reason in favour of this cooperation is the existence of important economies of scale in adoption.

3.3 Spillovers of national fuel efficiency standards

Harrington *et al. (*1998) explored the economics of emission standards in a federal setting where California would set stricter standards for conventional pollutants than the rest of the US. They find that extending the stricter standard to the rest of the US would clearly benefit California via economies of scale in car production. The benefits in terms of pollution reduction outside California would probably be too small to make this generalisation cost efficient. In the case of CO_2, it is in the interest of a single country or region to lobby even more for a national adoption, because every region benefits from the reduced climate damage.

More limited spillovers of national fuel efficiency standards are possible in the absence of international agreements. Barla & Proost (2007) show that fuel efficiency standards can have a role in parallel with fuel taxes when the car-producing country (or dominant consuming country) is concerned with the damage from fuel use and when there is only one type of car on the market. The car-producing country can control emissions at home via a fuel tax but can only control emissions abroad via the car design. This type of indirect policy to limit emissions abroad will only give rise to an important reduction of emissions abroad if the production country is relatively large, because then it will reap a large share of the benefits.

4. CONCLUSIONS AND CAVEATS

This paper has analysed the role of emission reductions in the transport sector using a wider framework. First, it was shown how a global reform of transport pricing, geared to internalising all external costs of transport, leads to lower fuel taxes but higher km charges. The result is a reduction in transport volumes and emissions of CO_2 in the transport sector as an important by-product.

Second, it was demonstrated that an industrialised economy that wants to reduce its emissions of GHG at lowest cost, has more cost-efficient options to reduce CO_2 emissions in other sectors than the transport sector. This holds even for very ambitious national targets (30 to 50%): reduction of emissions in the transport sector is almost never a cost-effective option.

Thirdly, the main advantage of reducing GHG emissions is the reduced damage worldwide. If countries are not able to make a self-enforcing climate change agreement, the benefit for each country to reduce emissions in the transport sector (or in any other sector) becomes very small.

International cooperation to adopt and develop a super fuel-efficient car technology has some appeal because there are economies of scale in adoption. On the other hand, transport currently is carbon-intensive, this carbon is already very highly taxed in the transport sector and car production already benefits from strong economies of scale.

This analysis is far in the future on a very global scale and requires many assumptions. One underdeveloped aspect in our analysis is the uncertainty of the oil market. This raises two issues: first, the level of the oil price, second, the gains from cooperation for oil-importing countries. The oil price scenario that has been used is one of moderate increase. A much higher oil price (beyond USD 100/bbl) would at first sight reduce the need for specific GHG reduction policies. When one takes into account the potential replacement of current fuels by more CO_2-intensive substitutes, such as synfuels based on coal, high oil prices do not necessarily solve the climate change issues. When we discussed the gains from a reduction of fuel use in the transport sector, we did not consider the monopsony gains of the oil importers. They exist, but are less important than the GHG reduction benefits. Their magnitude will depend on the precise fuel reduction policy adopted, as this is a frequent game with the oil exporters (Liski and Tahvonen, 2004).

NOTES

1. We use CO_2 and GHG (Greenhouse gases) as synonyms in this text. In the transport sector, CO_2 is by far the most important greenhouse gas.

2. More information on the GRACE consortium work can be found on www.grace-eu.org The work reported here is part of Deliverable.

3. Earlier exercises of this nature can be found in Proost, Van Dender *et al.* (2001) and ECMT/OECD (2004).

4. Full documentation on the TREMOVE II model can be found on www.tremove.org. The results reported here can be found in Proost *et al.* (2008).

5. The value of extra tax revenue is parameterised and depends on who pays taxes and how it is used.

6. We present here results for a flat km charge. A better policy would be to differentiate the km charge in some countries by region, time of day and type of road. This gives higher welfare results but average tax levels that are similar and CO_2 emissions that are of the same order.

7. Welfare is here a simple sum of gains and losses for all groups in society. If one wants to pay attention to the distribution of income aspects, it is best to do this via the use of tax revenues and not by interfering in the efficient pricing. See Proost & Van Regemorter (1995) and Mayeres & Proost (2001) for illustrations on climate policies and transport pricing.

8. MARKAL-TIMES is a model initially developed within an IEA implementing agreement in 1981. The Belgian version has been developed by CES-KULeuven and VITO with funding of the Belgian Science Policy Office. We use here the results of Nijs and Van Regemorter (2007).

9. The cap can be combined with an international trading mechanism but this is not done in this exercise.

10. 1990 is used as the reference year in most Climate Change negotiations.

11. The avoided climate change damage is not counted in the welfare cost.

12. In Belgium, nuclear power plants will represent in 2010 some 60% of total power generation.

13. This is an analysis for Belgium where the transport sector represents 25% of CO_2 emissions. Results for other countries may be different if the transport sector represents already more than 50% of total CO_2 emissions, as options to reduce emissions outside the transport sector

are then much smaller. In this case, the use of the international trading of CO_2 emission reductions becomes important.

14. Model results of D. Van Regemorter, obtained in May 2007 and reported in Proost and Van Regemorter (2007). The methodology used for the computation is detailed in Russ, Wiesenthal, Van Regemorter and Ciscar (2007).

15. In fact, in a non-cooperative scenario, every country will make small efforts until its marginal costs equal the marginal damage in their own country. This gives rise to emission reductions that are anyway small (less than 20% of the cooperative level). See Eyckmans *et al.* (1993).

BIBLIOGRAPHY

Barla, P. and S. Proost (2008), Automobile fuel efficiency policies with international knowledge spillovers, Mimeo CES-KULeuven.

Barrett, S. (1994), "Self-enforcing Environmental Agreements", *Oxford Economic Papers*, 46: pp. 878-894.

Barrett, S. (2006), "Climate Treaties and Breaktrough Technologies, *AER Papers and Proceedings*, pp. 22-25.

Capros, P., P. Georgakopoulos, D. Van Regemorter, S. Proost and C. Schmidt (1997), The GEM-E3 General Equilibrium Model for the European Union, *Economic and Financial Modelling*, pp. 51-160.

CEC (2006), "Limiting Global Climate Change to 2° Celsius, The Way Ahead to 2020 and Beyond", Communication from the Commission to the Council, SEC (2007) 8.

ECMT (2003), Efficient Transport Taxes and Charges, CEMT/CS(2003)4.

Eyckmans, J., S. Proost and E. Schokkaert (1993), Efficiency and Distribution in Greenhouse Negotiations, *Kyklos,* 46 (3), pp. 363-397.

IPCC, www.ipcc.ch

Harrington, W. (2008), The Design of Effective Regulations in Transport, in: *The Cost and Effectiveness of Policies to Reduce Vehicle Emissions*, Round Table 142, ITF/OECD Transport Research Centre, OECD, Paris.

Harrington, W., V. McConnell and M. Walls (1998), Who is in the driver's seat? Mobile source pollution in the US Federal System, in: S. Proost, J. Braden (eds.), *Climate Change, Transport and Environmental Policy – Empirical Applications in a Federal System*, Edward Elgar Publishing, Chapter 6.

Liski, M. and O. Tahvonen (2004), Can carbon tax eat OPEC's oil rent? *Journal of Environmental Economics and Management*, 47:1-12.

Nijs, W. and D. Van Regemorter (2007), Possible Post-Kyoto Strategies for Belgium.

Mayeres, I. and S. Proost (2001), Marginal Tax Reform, Externalities and Income Distribution, *Journal of Public Economics*, 79 (2), pp. 343-363.

Plotkin, S. (2008), Examining Fuel Economy and Carbon Standards for Light Vehicles, in: *The Cost and Effectiveness of Policies to Reduce Vehicle Emissions*, Round Table 142, ITF/OECD Transport Research Centre, OECD, Paris.

Proost, S. and D. Van Regemorter (1995), The Double Dividend and the Role of Inequality Aversion and Macroeconomic Regimes, *International Tax and Public Finance*, 2, pp. 207-219.

Proost, S., K. Van Dender, C. Courcelle, B. De Borger, R. Peirson, R. Vickerman, E. Gibbons, M. O'Mahony, Q. Heaney, J. Van Den Bergh, and E. Verhoef (2002), How Large is the Gap Between Present and Efficient Transport Prices in Europe? *Transport Policy*, 9 (1), pp. 41-57.

Proost, S. and D. Van Regemorter (2007), Economie voor een Klimaatminister, Leuvens *Economische Standpunt,* No. 120.

Proost, S., S. Van Der Loo, E. Delhaye, B. Van Herbruggen, O. Ivanova, L. Cretegny, S. Suter, J. Bröcker, A. Korzhenevych, N. Schneeckloth, A. de Palma, N. Picard (2007), The Socio-Economic Impacts of Transport Pricing Reforms, Deliverable 9 of GRACE (Generalisation of Research on Accounts and Cost Estimation), funded by Sixth Framework Programme. ITS, University of Leeds, Leeds, UK.

Raux, C. (2008), How Should Emissions be Reduced? Potential for Emission Trading Systems, in: *The Cost and Effectiveness of Policies to Reduce Vehicle Emissions*, Round Table 142, ITF/OECD Transport Research Centre, OECD, Paris.

Stern Review: The Economics of Climate Change (2006), HM Treasury, London.

Weitzman, M.L. (1974), "Prices Versus Quantities", *Review of Economic Studies*, Oct. 41 (4), pp. 477-91.

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THE COST AND EFFECTIVENESS OF POLICIES TO REDUCE VEHICLE EMISSIONS

Transport sector policies already contribute to moderating greenhouse gas emissions from road vehicles. They are increasingly designed to contribute to overall societal targets to mitigate climate change. While abatement costs in transport are relatively high, there are plausible arguments in favour of further abatement in this sector.

Fuel taxes are a good instrument. Fuel economy standards are potentially justified because of the limited performance of markets in terms of improving fuel economy. The empirical basis to decide upon combinations of fuel economy standards and fuel taxes, however, remains weak.

This Round Table investigates the effectiveness and costs of various mitigation options in road transport, and discusses the distribution of abatement efforts across sectors of the economy.

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