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STIMULATING LOW-CARBON VEHICLE TECHNOLOGIES

ROUND TABLE

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SUMMARY OF DISCUSSIONS

SUMMARY CONTENTS

Paris, May 2010

1. INTRODUCTION

If the transport sector is to make deep cuts to its carbon emissions, it is necessary to reduce the carbon-intensity of travel. Reducing travel itself, at some times and places, is sometimes justified but it is extremely unlikely that under expected global economic development patterns overall demand will decline. This holds true even if there is saturation in some markets and demand management policies are widely adopted. Technological change is therefore crucial. The emerging view is that the focus for decarbonising transport should be first to improve the fuel efficiency of conventional engines and then gradually introduce alternative technologies.

Designing good (effective and least costly) policies to ensure the deployment of lower carbon technologies in accordance with policy aspirations requires an understanding of how markets for fuel economy work. The Round Table investigated this issue, with a focus on passenger car markets, aiming to answer the following questions as well as possible:

– What do consumers take into account when deciding what vehicle to buy?
– What drives manufacturer decisions on what range of vehicles to offer?
– Does the interaction of supply and demand lead to unsatisfactory fuel economy in relation to climate change objectives? Is the outcome unsatisfactory even if climate change is ignored, in the sense that there is "underinvestment" in fuel efficiency? In the latter case, what precisely is meant by an unsatisfactory outcome?

Answers to these questions help guide policy, for example on what instruments to use (fuel taxes and/or standards and/or purchase taxes, subsidies to producers, measures to mitigate information and coordination problems, etc.) to attain greenhouse gas emission abatement targets.

The questions raised are not new, and first principles of economic reasoning immediately suggest answers: consumers make optimal decisions from their own point of view, and all that is needed to align their point of view with the social perspective is a fuel tax that reflects the external cost of carbon implied by that social perspective. Does this basic recommendation need modification when the specificities of the market for fuel economy are taken into account[1]? The answer to this question is twofold.

First, a more in-depth look at this market should not lead anyone to conclude that appropriate carbon prices are a bad idea. Indeed, there is very wide agreement that carbon prices, implemented through fuel taxes or cap-and-trade systems, are a cornerstone of well-designed low-carbon policy in transport. They are critical to creating the demand for low-carbon technology in the market. However, it is unlikely that adequate price increases are politically feasible in all countries. Where appropriate carbon prices are not feasible, through the use of fuel taxes or tradable permits, other instruments or combinations of instruments, including consumer information programs, standards and emission-dependent ownership or purchase charges, can mimic them with varying degrees of accuracy. It is also widely acknowledged that land use and transport planning policies, although not discussed as such in the Round Table, have an impact on transport volumes and emissions and could play a role in broad greenhouse gas management policy packages.

Second, even where the scope for pricing carbon is not tightly constrained politically, it is not clear whether pricing carbon provides sufficient incentives to reduce carbon dioxide emissions in line with aspirations. Additional policy measures may be required that address uncertainty in fuel prices rather than the absolute level of fuel and carbon prices. In particular, fuel economy standards provide a degree of certainty for automobile manufacturers that carbon prices cannot. Such certainty is important for decisions to make capital intensive investments, for example in new internal combustion engine plant, and is required to trigger the investments that are needed for a transformation of the energy-base of transport from petroleum to new, less carbon-dependent propulsion systems. In this view, prices and standards are complementary measures.

Proponents of strong intervention in the transport sector emphasize the need for changing the primary energy sources for transport, assuming carbon free energy sources can provide sufficient energy at acceptable cost (linking vehicle standards to the way alternative energy for transport is produced is not easy). Sceptics of the value of standards in promoting decarbonisation of transport point out that they are potentially very costly as they impose a degree of uniformity in responses across a very diverse set of agents. Sceptics also tend to be more optimistic regarding the potential of reduced driving to cut emissions.

The rest of the paper develops these arguments in detail. Section 2 discusses how consumers' willingness to pay for fuel economy is best modelled. An accurate view on how decisions are made obviously helps design effective and least-cost policy. Section 3 considers the interaction between demand and supply in the market for fuel economy. With this background, Section 4 focuses on policy design. This paper does not discuss carbon reduction targets as such. It is assumed that the goal is to reduce carbon emissions from transport very strongly in the long run, so that reliance on fossil fuels is phased out. Whether such a target is appropriate is not obvious, but that is not the subject of this paper (see ITF, 2008 for views on that issue).

2. (WHY) IS THE WILLINGNESS-TO-PAY FOR PASSENGER CAR FUEL ECONOMY LOW?

Investing in vehicle fuel economy means incurring higher costs at the time of purchasing a car (or partly sacrificing attributes such as size or performance) in return for lower future costs of use. Basic economics suggests that current and future costs should be traded off at roughly the market rate of interest, i.e. the discount rate applied to car purchase should be similar to the market interest rate[2]. There is, however, considerable evidence that consumers use implicit discount rates considerably higher than market interest rates. Car manufacturers at the Round Table reported they see average "payback periods" in consumer decisions on fuel economy of about three years. This means that consumers strive to recover any extra expenditure on fuel economy through lower fuel expenditures within three years, much shorter than the expected lifetime (or usage time plus resale value[3]) of the car. Translating short payback periods into high discount rates produces values well above market rates (e.g. around 20%)[4]. Car manufacturers' views are supported by survey evidence on payback periods as well as by some econometric evidence (see the review in Greene, 2010), although the latter produces a wide range of results (from 4 to 40%). The econometric research evidence on implicit discount rates hence is inconclusive, and the reasons for the variation in results are not clear.

If one accepts the possibility of high implicit discount rates, as many but not all experts do, the question is why they could occur. The term "myopic" is often used to describe the use of high discount rates. This label is not entirely neutral, reflecting an implicitly held view that consumers somehow make a mistake and would be better off if they used lower discount rates. The case for policy intervention then depends on a judgment as to whether consumer sovereignty should prevail or whether consumers should be helped to make better decisions. A different, emerging view is that consumers do not make mistakes but act in their own interest under reference-dependent preferences, so that high implicit discount rates reflect the complexity of decisions in an uncertain environment rather than a shortcoming of decisionmaking.

The theory of reference-dependent preferences is an alternative to the standard neoclassical theory of behaviour in making choices. The latter posits that choices are driven by outcomes as such. Recent empirical and theoretical advances suggest that assuming reference-dependent preferences allows a better description of behaviour in many circumstances. In this framework, outcomes are evaluated by comparing them to a reference point. An important feature of behaviour that is regularly observed empirically is that choices reveal loss aversion, i.e. losses relative to a reference point reduce utility more than equal-sized gains would increase it. Loss-averse consumers appear to magnify the possible size and the probability of losses, and this is the key to understanding high implicit discount rates, e.g. in markets for fuel economy, where choices are made under uncertainty.

Uncertainty is pervasive in economic decisionmaking. In the case of deciding what car to buy, uncertainty over future fuel prices is compounded by uncertainty over how intensively the car will be used, and what level of fuel economy the vehicle will achieve in real world use. Poor information on fuel economy in use is particularly problematic, not necessarily because estimates of averages are bad (the EPA information in the US is accurate on average) but because averages are a poor indicator for individual experiences. Greene (2010) shows how this uncertainty can easily lead to high implicit discount rates and more generally to low willingness to pay for fuel economy.

The standard neoclassical theory on preferences has difficulties capturing this low willingness to pay, as extreme assumptions would need to be made on risk aversion and/or declining marginal utility of income. Reference-dependence and loss aversion provide a plausible description of consumer choices of fuel economy and are consistent with evidence pointing to high discount rates. Of course, this theory is not inconsistent with low discount rates either, as discount rates can differ according to circumstances including consumer type, consumer experience, information constraints, etc. In general, it is plausible that consumers differ in what discount rates they use, according to their preferences and to the circumstances under which they make decisions.

Does this perspective on consumer choices modify policy prescriptions compared to more standard theory? One view is that it does not. If consumers don't want to pay a lot for fuel economy, then aligning socially optimal and private choices of fuel economy just requires higher fuel taxes. (Second-best arguments on what to do when optimal fuel taxes are not politically feasible apply *mutatis mutandis.*) In addition, instruments that alleviate uncertainty, e.g. by providing better information, gain appeal in a loss aversion framework[5]. A different view is that fuel taxes are not sufficient to attain ambitious carbon-cutting targets because of choice behaviour, and that this issue weighs heavier when implicit discount rates are high. In other words, emphasizing loss aversion and the need for deep cuts in carbon emissions from transport leads to a different view on policy design. This argument is developed in detail in Section 4.

3. THE MARKET FOR PASSENGER VEHICLE FUEL ECONOMY

Fuel economy is one attribute of a passenger vehicle. The levels of fuel economy purchased in the market, and the average fuel economy of new vehicles, are the result of the interaction between demand and supply in new vehicle markets. The previous section discussed one feature of demand in the market: for at least some consumers, the willingness-to-pay for better fuel economy is low given the many uncertainties under which fuel economy is chosen and prospective buyers' aversion to loss. Other features of the market include the substantial degree of heterogeneity in preferences and budgets for new vehicles, the importance of strategic interaction among firms in the industry, and the strong dependence of business opportunities on policy choices. We discuss these issues briefly in the following paragraphs.

3.1. Willingness-to-pay for fuel economy is context dependent

When there is a perception[6] that many or even most consumers are willing to spend only limited amounts to get better fuel economy, it is no surprise that manufacturers focus mostly on other attributes for which the willingness to pay is higher (power, performance, design, etc.). The previous section discussed how such low willingness to pay can result from the combination of loss aversion and uncertainty. In addition, consumers appear to evaluate the fuel economy of their future new vehicle by comparing it to the fuel economy of the vehicle they currently own, not by trading off fuel economy against other attributes in the set of available new vehicles. Taking older technology as a reference point can also lead to lower willingness to pay for fuel economy[7].

Despite the intuitive appeal of the reference-dependence framework, many experts doubt whether current evidence on low willingness to pay for fuel economy, and generally low price elasticities of the demand for fuel should be taken as evidence that this willingness to pay is low in all circumstances. Consumer choices are the result of the interaction between their preferences, their budgets and prevailing prices and regulations. Estimates of elasticities based on these choices hence are conditional on these same factors, and if one of them changes then elasticities may change as well. For example, there is evidence that price elasticities of the demand for fuel do indeed increase as the price of fuel increases, i.e. consumers become proportionally more responsive to price changes as the initial price level increases[8]. Van Biesebroek (2010) shows preliminary results suggesting very strong heterogeneity of responses to fuel price changes, with quite elastic responses for some consumers, and with higher elasticities as fuel prices are higher. The latter result, that fuel price elasticities of fuel demand are higher as fuel prices are higher is consistent with aggregate evidence, which also points out that the same elasticity declines as incomes rise (Hymel *et al*., 2010). In addition, casual observation of higher and increasing sensitivity of European consumers to fuel-economy supports the view that the level of the fuel price matters. Evidence on the context-dependence of elasticities of fuel demand suggests that energy- and mobility-intensive lifestyles may be less engrained than is commonly believed, so that strong price changes could trigger strong demand responses. That such strong responses have not been observed, e.g. in the US, is simply because fuel price levels have generally been low, even if price changes sometimes were large. Casual observation on short-term responses to price spikes support this view. While this is an argument in favour of fuel price oriented policies over more intrusive regulation, in the sense that pricing policies may be more effective than evidence on past elasticities suggests, there is no guarantee that such policies are sufficient to attain drastic abatement targets. High price levels in the EU have lead to different behaviour than in the US, but have not triggered major shifts in the energy base of private passenger transport. Such a shift is needed if decarbonisation of transport is the objective (which, to repeat, is assumed here, although the assumption clearly is open to debate).

If evidence based on observed choices is not a reliable guide to behaviour under different circumstances, and if survey evidence on hypothetical choices under these alternative circumstances lacks credibility because of its hypothetical nature, evidence-based policy design is a tall order. It is therefore important that research strive to identify fundamentals that are as little context-dependent as possible. In the meantime, policy needs to be made on the basis of inconclusive evidence, i.e. decisions need to be made under uncertainty. Remarkably, consensus on what to do is broader than might be expected (although it is by no means complete) given the available evidence and differing interpretations of it. This will become clear in Section 4.

3.2. Consumers differ and this matters for policy design

Consumers differ strongly in what vehicles, i.e. collections of attributes, they like. Manufacturers respond to such heterogeneity in different ways. Some offer a full range of vehicles, attempting to cover the main market segments, but with differences in emphasis among them. For example, several French and German producers offer a wide range of cars, but the first focus more on small cars and the latter more on bigger and more luxurious models[9]. Other manufactures focus on particular segments. For example, BMW offers higher-end vehicles only. The observation that there is substantial heterogeneity is straightforward, but its consequences for policy design are sometimes ignored. If all consumers and all manufacturers were strongly similar, then they would all respond similarly to policies. In that case, prescriptive policy is reasonably cost-effective as long as the prescription is in line with the common response. But with strong heterogeneity, it becomes expensive to require all agents to respond in the same manner[10]. For example, it is costly to require someone that drives only 3 000 miles per year to invest in a highly fuel efficient car (Fullerton, 2010). Requiring manufacturers to attain a sales-weighted average fuel economy is particularly onerous for a manufacturer that focuses on relatively fuel-intensive market segments. This can be seen from the fact that luxury brands such as BMW have historically responded to the US CAFE standard by paying the fine for non-compliance instead of complying.

3.3. Supply characteristics depend on industry structure, demand, and policy

What vehicles are supplied depends on demand but also on how manufacturers interact among themselves. Heterogeneity in demand matters here, in that it leads producers to offer diversified products in an attempt to match preferences and to weaken competition. For example, the emergence of a taste for SUV’s in the US helped US manufacturers maintain profitability (and indeed was engineered by them for that purpose to some extent). This is not to say that competition in the industry is weak, just that there are strategies to try to dampen it. If product differentiation were emphasized, the car industry could be modelled as a monopolistically competitive industry. While plausible, it is more common to model it as an oligopoly. The reason is that oligopoly models emphasize strategic interactions among manufacturers: in deciding what to offer or what prices to set, manufacturers take account of demand conditions and of how they think their competitors will respond to their actions.

If a manufacturer expects aggressive responses by its competitors, it will keep prices fairly close to costs; its rivals will act similarly. The resulting prices benefit consumers directly but reduce manufacturers' ability to cover fixed costs, such as R&D expenses. This is the classical argument that market power may benefit innovation, as it helps generate the funds for it. However, market power also reduces the profitability of innovation, an effect going in the opposite direction. Recent work tends to view the second effect as dominant, so that more competition induces more innovation. To the extent competition in the car industry is strong, this then would mean considerable innovative effort. However, absent credible and strong policies to push innovation in the direction of carbon abatement, such innovation will focus on features for which consumers are willing to pay. Strong competitive responses can induce producers to be "conservative" in supply decisions: experimenting with innovative design choices becomes risky as any mistake (i.e. a more tepid consumer response than expected) translates into reduced market share and lower profits. Manufacturers innovate but at the same time do not wish to deviate from their rivals' choices too much. Such conservatism will be particularly pronounced with respect to features like fuel economy, for which consumer willingness to pay is low at present. The upshot is that strategic interaction in the car industry does not favour strong fuel-economy-oriented supply choices. Policy to steer innovation in the direction of better fuel economy then may be needed, and instruments that affect supply decisions rather directly, such as fuel economy standards, can be more effective than raising the cost of fuel for consumers and should be used in combination with pricing policies. This is the case in particular when transformative innovation (needed for decarbonisation) is the ultimate goal (see Barla and Proost, 2010, and ITF 2010 and references therein).

Supply choices depend on demand and on company strategies, but also on policies (either directly or through demand). As pointed out by Bastard (2010), policies affecting fuel economy choices are widespread (i.e. they have been developed in many countries), they are diverse (with strong differences among countries), and they are prone to frequent change. Relevant policies include fuel economy standards, emission or engine power based ownership taxes, fuel taxes, etc. The diversity of policies among countries is a source of costs for manufacturers. Ownership-based taxes tend to define vehicle classes. Furthermore, the definition of the threshold is critical for manufacturers, as tax liabilities for nearly identical cars may differ strongly if their small differences attribute them to different classes. A continuously graduated system of differentiation avoids this problem. Fragmentation of policies and the arbitrary nature of thresholds cause problems but are not the main headache for manufacturers.[11] The bigger problem is that policies change often. Tax rates in particular are subject to annual revision with little or no notice of the size of the change. Adaptations to policy changes increase costs directly for manufactures, and more so when changes are made at short notice. At least as importantly, there is an indirect cost increase through the uncertainty that is created. With a history of frequent revision of relevant policies it becomes difficult for government to make a credible commitment to fuel economy policies that are in line with long term greenhouse gas abatement targets. Such a lack of credible commitment is a disincentive to investment by carmakers.[12]

4. WHAT POLICY FOR LOW-CARBON VEHICLES?

The previous sections picture the markets for new vehicles and for fuel economy as consisting of heterogeneous consumers, many of whom are perceived to be reticent towards choosing strong improvements in fuel economy given inconclusive empirical evidence on the matter and given doubts whether simple estimates based on past behaviour can capture responses in different circumstances (e.g. higher prices). If ambitious goals for fuel economy improvement are set, then policy intervention will be required to attain them. There is considerable agreement that, if possible, carbon prices should be introduced that are consistent with policy targets. There is less agreement on what to do when such prices are not possible and on what to do *in addition* when such prices are feasible. One source of disagreement lies in what aspects of policy are emphasized: those proposing reliance on taxes alone emphasize the extra costs associated with using other instruments; those proposing a wider array of instruments point to the potential lack of effectiveness of taxes, especially where the goal is to change the primary energy used for transport. Ultimately, the disagreement is not so much about what policies might work and what they might cost, but about how important it is to reach decarbonisation targets with a reasonable degree of certainty. Views on the latter depend on how one weighs the risks of not reducing global carbon emissions overall and on how big one thinks the contribution of the transport sector ought to be in overall abatement targets. Those who agree that the transport sector needs to abate strongly tend to agree on the broad policy principles to be pursued. Section 4.1 explores the basic arguments and Section 4.2 discusses resulting attitudes towards policy instruments.

4.1. Reducing fossil fuel use does not equal changing transport's energy base

Fuel taxes are a good approximation to carbon taxes and could thus in principle be used to get the price of carbon right. If equilibrium levels of fuel economy are "low", i.e. the gap between that level and the one aspired to by policy is large, high fuel taxes are needed to close it. However, introducing the appropriate fuel taxes may not be politically feasible. In that case, the best that can be done is to use combinations of other (feasible) policy instruments to mimic the fuel tax (Fullerton, 2010). What combinations of instruments to use is a matter of empirical research, and it is clear that the economic costs of reaching the policy target through second-best policy will be at least as high as under the fuel tax. As emphasized in the previous section, heterogeneity among consumers and producers drives up the costs of command-and-control policies compared to the first-best fuel tax.

Viewing the use of policy instruments other than the fuel tax as a second-best approach may make sense for countries with relatively low fuel taxes, e.g. the US. Applying the same principle to European countries, however, should lead to the conclusion that other – widely used – policies are superfluous at best and create high extra costs at worst. Some experts subscribe to this view, others do not. One argument sometimes used in favour of additional instruments is that "they work", i.e. they have clearly visible effects. Ownership taxes dependent on emission levels or engine power are an example, as they have clear impacts on vehicle choice. Of course, "effective" does not equal "cost-effective". Ownership charges might be a costly means of attaining abatement targets, e.g. by discouraging the purchase of fuel-inefficient but otherwise appealing vehicles to people that do not drive much. Much less is known about the economic costs of ownership charges than about their direct effects. While ownership charges can be useful, e.g. when owners use discount rates that are thought too high from a social point of view, it is far from obvious that existing charges (which vary very strongly across countries) are anywhere near optimal.

A different argument for additional instruments is that fuel taxes do not discourage fuel use enough. According to the standard framework the best response then is to increase fuel taxes further if that is politically feasible. The argument about the insufficiency of the effects of fuel taxes is sometimes made with reference to Europe, where fuel taxes are high already. It is worth pointing out that it is the whole set of applicable policies, which together imply an unknown but certainly high price of carbon, that generates the insufficient response. Current European policies certainly lead to better fuel economy compared to the situation with less stringent policies or compared to the United States, but they are not capable of triggering a shift in the energy base of transport away from petroleum. Emphasizing the need for such a shift induces some experts to favour additional policy instruments (e.g. Greene, 2010), essentially on the grounds that this is uncharted policy terrain for which the traditional economic prescriptions ("internalize external costs") fall short. The first and foremost challenge is in this case not to price carbon correctly but to move to different primary energy sources. Pricing carbon is instrumental in attaining that objective but it is not sufficient. More generally, current demand-oriented policies cannot deliver in terms of switching energy sources. In the long run, reliance on a combination of improved conventional technology and reduced demand is taken to be insufficient or at least too risky a strategy. Instead, policy should get actively involved in pushing innovation in a particular direction. Arms-length policies (providing good framework conditions for markets to work and correcting price signals where required) may not be sufficient for such steering (see ITF, 2010, for more discussion), and more intrusive policies like standards may be needed.

As explained, one reason for potentially shifting the emphasis to supply of energy is that estimated elasticities of demand for transport are low, indicating high welfare costs and limited effectiveness of demand-oriented policies. However, as discussed in the previous Section, current evidence on transport elasticities may be a poor guide to what demand responses might look like when fuel prices are much higher – more specifically, responses might well be larger when prices are higher. The bottom line here is that the relevant demand elasticities are highly uncertain. This implies that policies working through prices have uncertain effects, and if decarbonisation is the priority such uncertainty needs to be avoided through the use of complementary policies.

A different reason for emphasising technology switching is that this route may be preferred over demand-oriented strategy by policy-makers. Policy-makers might judge that focusing on technology provides more certainty that the desired result will be reached. Alternatively, this preference may be based on perceived voter or pressure group interests. Whatever the reason, it is clear that when policy-makers have preferences on how to reach a policy goal, i.e. they do not just care about getting there as cheaply as possible, then instrument choice may differ from what standard economics would prescribe. The arguments of the previous section then carry more limited weight in policy design than might be expected. The message of the previous section is that care should be taken to avoid the risk that putting a very strong emphasis on attaining a policy goal ends up being a mandate to attain a goal at any cost, no matter how high.

4.2. Opinions on instruments

Carbon prices, land use and transport planning

There is, to repeat, wide agreement on the need for appropriate carbon prices. Fuel taxes or cap-and-trade mechanisms can fulfil that role. To take their full effect, carbon prices need to be embedded in a framework guided by land use and transport planning. It was also argued at the Roundtable that carbon prices in transport could usefully be relatively high compared to other sectors, to the extent that mobility is a less elastic and therefore less distortionary tax base than is found in other carbon-intensive sectors of the economy.

Fuel economy standards

Experts at the Round Table expressed quite broad support for fuel economy standards. Some stakeholders oppose standards on principle, arguing that manufacturers should not be made responsible for energy use in transport. At its most extreme this means no coercive policies (possibly including taxes) should be used. Alternatively it means that policies should work through demand rather than directly on supply. While few would take this line to argue against standards as such, the argument does have some bearing on what kind of standard to use. Defining standards in terms of sales-weighted averages requires manufactures to steer sales in a particular direction, rather than just attaining some performance level conditional on the type of vehicle. Standards can be made less intrusive and more technology-neutral by differentiating sales-weighted average targets by the average weight or size (footprint) of vehicles by manufacturer (fuel taxes, of course, are even more neutral with respect to choices, and therefore to be preferred on these grounds). It was also noted that, if the goal is to push innovation, it may be better not to structure standards to allow shifts in the sales-mix as a compliance mechanism[13].

An intermediate view is that fuel economy standards are useful when appropriate carbon prices cannot be implemented, but not otherwise. The predominant view during the meeting was that, as it is imperative to abate strongly and quickly, standards should be used to make sure targets are reached. In this view, standards and taxes should be combined and made to be mutually reinforcing. Taxes are mostly a demand-pull measure (Fullerton, 2010) and standards mostly a supply-push measure (Anderson *et al*., 2010). Given the structure of the market for fuel economy and perceived inertia in the demand for driving, both elements are needed (although some argue that driving *should not* be discouraged rather than that it is difficult to discourage it). Consistency between demand and supply-side incentives is required to keep emission concerns squarely among manufacturers' strategic priorities.

The auto industry needs a regulatory environment that provides as much certainty as possible if it is to make the large capital investments necessary to maximise the fuel economy of new cars, and even more so for shifting to new primary energy sources. Standards can provide this certainty, and the longer the planning horizon the better. Binding standards for the short term can be complemented by indicative targets for the longer term. For example the European Union's standard of 130 g CO_2/km by 2012 for the new car fleet average is accompanied by a 95 g CO_2/km target for 2020. Standards may outperform taxes in stimulating innovation because they are more closely tied to supply, where innovative effort is concentrated[14].

It may also be noted that harmonisation of tax structures is frequently more difficult than harmonisation of standards. This is particularly noticeable in the European Union, where fiscal policy is strictly subject to national sovereignty whereas a single fuel economy standard for the whole region was developed by the European Commission. Moreover, vehicle registration and circulation taxes have an element of local government control in many countries. In relation to the remark that taxes and standards should be mutually reinforcing, Bastard (2010) highlights the lack of coordination between the structure of taxes and vehicle efficiency labels in Europe and the Union's CO_2 standards for cars. Poor coordination raises compliance costs for manufacturers and weakens the incentive to design cars to maximise fuel efficiency because of the extreme fragmentation of the European market that results from the different break points employed in differentiation of taxes and labels.

Subsidizing low carbon vehicles

Temporary subsidies for low carbon vehicles are sometimes defended on the grounds that such technologies are at a cost disadvantage as long as the scale of production is small compared to that of conventional vehicles and because experience and competition keeps the cost of innovation for internal combustion drive trains relatively low. The subsidy then is designed to ramp up production. This is a separate function to subsidies to R&D intended to stimulate innovation and justified on the basis of knowledge spillovers.

When used, subsidies should be targeted to affect supply rather than increase profits, which is a risk in imperfectly competitive industries. For efficiency, subsidies should be designed to be as neutral as possible with respect to particular technologies. Research prizes combined with performance standards may be fairly neutral but complete neutrality is not possible. Even a subsidy based on graduated performance standards will need to check compliance at some point in time and will rely on imperfect information on (future) costs and performance. If innovation is to be steered in a particular direction, there is a price to pay in terms of abandoning pure neutrality. And while it makes sense to see the subsidies as temporary, deciding when the phase out begins is less than straightforward. Removing subsidies that industries have become dependent on is always difficult, even when the original reason for the subsidy no longer applies. This is a strong argument in political economy for avoiding subsidies in the first place. On the other hand, manufacturers risk seeing subsidies for the purchase of electric or fuel cell vehicles cut back before they can recoup the costs of developing the vehicles. The risks of relying on political commitments are exacerbated by the time it takes to develop new cars of this sort. Governments may be able to guarantee the availability of subsides for three or four years, but just getting new products to market may take much of this time. Electric vehicle subsidies in France, Germany and especially the UK have been structured to provide some security in this respect.

In sum, the risks associated with subsidies induce rather negative attitudes towards them among economists and sometimes manufacturers. Reluctant support is based on the premise that breakthrough technologies are needed if the energy base of transport is to be transformed. Innovation in the car industry is not of the "lone creative entrepreneur" type, as scale and structure prevent this "intuitive" approach to innovation from thriving. The transformative efforts required for very low carbon transport should not necessarily be expected to emerge from industry by itself. Policy intervention then is needed, even given tangible risks that measures will turn out more costly than hoped for, as long as the risks of not attaining policy targets are deemed larger than the risks of intervention.

Providing information

Section 2 emphasized that decisions on what level of fuel economy to invest in take place under considerable uncertainty. One important source of uncertainty is the effective fuel economy that a prospective purchase would deliver. Better information in that respect would lead to better decisions, and loss aversion would become less prominent in affecting outcomes. Better information can come in several forms. Simple labels, analogous to those used to indicate household appliances' energy efficiency in the EU, provide easy guidance for comparison among models[15]. But customised fuel economy information can be helpful as well. Giving prospective buyers access to tools (e.g. online) to investigate how a vehicle's average (labelled) fuel economy would change according to particular driving patterns reduces uncertainty and also invites buyers to think carefully about their usage patterns.

5. CONCLUSIONS

Current fuel consumption patterns in passenger car transport markets around the world need to change drastically if transport is to reduce its carbon emissions substantially. This paper has summarized views on how major cuts in carbon emissions from passenger cars are to be accomplished. Although there is debate over whether this should be done, it is taken as an objective here.

The diagnosis that a substantial portion of consumers in major markets are fairly unresponsive when fuel prices rise is widely accepted, despite a lack of conclusive evidence on the matter. However, the relevance of this observation to policy design is disputed, with some experts believing that elasticities will stay low if more stringent emission charging policies are introduced and others seeing potential for increased responsiveness. If consumers do become more responsive as fuel prices rise, then pricing approaches to carbon abatement become more attractive, especially given the large diversity in potential responses, which renders command-and-control policies more expensive.

Regulations, e.g. fuel economy standards, are more costly than charges for CO_2 emissions when they reduce flexibility in responses. However, standards are seen as a necessary component of policies that don't just aim to reduce fuel consumption in transport, but rather aim to change its principal source of energy. A preference for standards could be seen as a preference for attaining greenhouse gas abatement through technology rather than through reducing demand. Standards are a complement to prices; higher carbon prices reduce the demand for carbon-intensive energy and stricter standards reduce the supply of carbon-intensive vehicles. Together they send a strong signal. Standards provide certainty to producers on what fuel economy to reach. This helps create a favourable investment climate, especially when long-term goals are announced with sufficient credibility.

NOTES

1. The principle of marginal social cost pricing is also modified in an economy with multiple inefficiencies. This paper largely abstracts from this complication; see ITF 2008, for some discussion.

2. The reason is that, if a higher discount rate were used, the financial return on the saved investment costs would be lower than the increase in fuel expenditures. And if a lower discount rate were used, fuel expenditure savings will be below the market return from the extra money now spent on fuel economy. Of course, there are differences between financial and fuel economy markets that lead to some disparity between discount rates in both, but not enough to explain observed difference.

3. The role of used-car markets in explaining low willingness-to-pay for fuel economy is not very well understood. It is possible, but not certain, that information imperfections in those markets lead to a low propensity to pay for fuel economy, and this would have knock-on effects in new car markets.

4. There are several explanations for why the discount rate used for car purchases could be above market rates. However, standard theory has difficulties explaining by how much discount rates exceed market rates.

5. Energy efficiency standards and labels have been developed for many markets but they can be seen mainly as attempts to reduce the negative consequences of inadequate consumer information. Whilst loss aversion is prevalent in many markets, the justification for intervening in only a subset of these markets lies in the relative size of the negative social consequences of uncorrected market outcomes.

6. To repeat, this perception does exist among auto-makers, according to the discussion at the Round Table, while the empirical evidence is partially supportive but inconclusive overall.

7. This point is compatible with reference-dependence, but it is not included in the model as discussed in Section 2.

8. Note also that loss aversion has a relatively smaller impact on choices as fuel prices rise, because the expected gains from investing in fuel economy rise while the investment costs do not change.

9. Buyers of lower-end small cars tend to be particularly sensitive to the purchase price, more than to expected future fuel expenditures.

10. In principle, this problem could be avoided by adapting regulatory requirements to individual circumstances. But even if regulated parties would have incentives to reveal their characteristics truthfully, collecting the required information would still be very expensive.

11. Tax differentiation causes costs for manufacturers, but also complicates their pricing strategies, an issue for producers that is of little wider social concern.

12. It follows that improving the credibility of long-run policy targets is desirable from the manufacturers' point of view, as it reduces uncertainty. However, this will not stop them from complaining about the costs of reaching targets, as they prefer less stringent over more stringent policy constraints.

13. However, innovation is commonly seen as an intermediate goal, and if attaining abatement targets is more cheaply done (in a social sense) through modifying the sales mix, that is better. Nevertheless, the industry sees a bigger potential for abatement with bigger cars, because of lower price elasticities and an increased scope for deploying technological solutions.

14. Standards then should become more stringent over time, to mimic the lasting incentive to innovate provided by taxes (as taxes are paid on all units, not just the ones exceeding some regulated level).

15. Tax policies and labels should be consistent , i.e. labels and tax incentives should be structured similarly. Given the fragmentation of political competencies, such consistency is not easily attained (as in the case of taxes and standards).

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COMBINATIONS OF INSTRUMENTS TO ACHIEVE LOW-CARBON VEHICLE-MILES

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SUMMARY

Champaign, February 2010

ABSTRACT

In cases where the first-best carbon tax and a reasonable second-best gasoline tax are unavailable, this paper demonstrates how alternative combinations of instruments can form economically-sound, environmentally-motivated policies for substantial reductions in vehicle carbon emissions. In order to implement alternative approaches successfully, our point is that policymakers may need to take a holistic approach when designing policy. This holistic approach would recognise that policies to reduce carbon emissions must be politically feasible, and that all sectors of the economy generate carbon emissions. A holistic approach would not focus just on one method of abatement, like encouraging low-carbon vehicle technologies, but instead on the efficient balance between all different abatement methods.

1. INTRODUCTION

Policymakers and economists have considered a number of different policies to reduce carbon emissions, including a carbon tax, a cap-and-trade permit system, a subsidy for the purchase or use of low-carbon vehicle technology, a renewable fuel standard, and mandates on manufacturers to increase the average fuel efficiency of the cars they sell. In this paper, we address issues in the use of these instruments separately or together. We consider the conditions under which policymakers should consider each such policy, and we show how the stringency of one such policy must depend upon the extent to which other such policies are already employed.

According to the theory of Pigou (1932), a simple tax or permit price per unit of emissions can minimize the total social cost of a given amount of emission abatement, because it would induce all individuals and firms to cut emissions in the cheapest ways, using any abatement method that costs less per unit of abatement than the tax that would have to be paid on the emissions. In general, this ideal Pigouvian tax would have both substitution effects and output effects. For example, a tax on smokestack emissions would raise the price of pollution and encourage the firm to substitute into cleaner use of capital or other inputs instead. It would also raise the price that the firm would have to charge in order to break even, and so customers would buy less of their output. In other words, less pollution per unit of output *and* less output.

For vehicle emissions, the driver is the polluter. A Pigouvian tax on carbon emissions would raise the cost of driving large cars with low fuel efficiency, and so it would encourage drivers to substitute into low-carbon vehicles such as hybrids to reduce the emissions per unit distance (per mile or per kilometre). The carbon tax would still have to be paid on the fuel that does get used, however, so it would also encourage all drivers (even those with hybrids) to reduce distances driven. That is, the substitution effect reduces emissions per mile, and the "output effect" in this case is to reduce the number of miles driven.

In other words, if a tax or price of carbon is already in place, at the optimal rate, then that one policy by itself will encourage drivers to switch to low-carbon vehicles, to the optimal degree, with no need whatsoever for any additional policy to subsidize low-carbon vehicle technology. Indeed, an additional policy to encourage low-carbon vehicles would be not only "counterproductive" but would lead to excess social costs from too many such vehicles.

Unfortunately, however, a Pigouvian tax is not always available. For some greenhouse gas emissions, it might be too expensive to measure the number of units from each source in order to apply the tax per unit. Also, political realities in some countries make the implementation of a new tax unlikely or impossible. In the US, many think the income tax is too high and they fear that an additional tax would just make government larger. Politically, any new "tax" is a dirty word. Even the enactment of a cap-and-trade permit system is called "cap-and-tax". In addition, a carbon tax or permit price would raise the cost of electricity and gasoline and have regressive effects, with disproportionate burdens on low-income families that spend a high proportion of their income on these goods. If all of these reasons prevent the enactment of a carbon tax or price, then policymakers cannot achieve the "first-best", cost-minimizing policy and can instead consider which policies might be "second best". Without a carbon tax or price, the second best might be achieved by a combination of policies that could include a subsidy to low-carbon vehicle technology, as well as other taxes, subsidies or mandates that help reduce carbon emissions in relatively cheap ways.

According to the United States Environmental Protection Agency (US EPA), approximately 95% of direct greenhouse-gas emissions from vehicles are in the form of carbon dioxide and are proportional to the amount of gasoline or diesel fuel consumed. The remaining 5% of direct vehicle greenhouse-gases come from methane and nitrogen dioxide, which form in proportion to the number of miles driven. In addition, hydrofluorocarbons (HFCs) leak from vehicles' air-conditioning units[1]. Due to the high correlation between fuel usage and direct carbon emissions, and in the absence of an ideal Pigouvian tax, a gasoline tax appears to be a reasonable second-best policy for reducing carbon emissions from vehicles. Yet political constraints also limit the effectiveness and feasibility of using a gasoline tax to combat climate change. First, politicians may find it expedient to provide tax exemptions for special interest groups. Second, even if a gasoline tax equally applies to all industries and sectors, the tax rate would likely be set below the marginal environmental damage from carbon. Third, many politicians, especially in the United States, will not vote for any policy that raises any tax rate.

In cases where the first-best carbon tax and a reasonable second-best gasoline tax are unavailable, this paper demonstrates how alternative combinations of instruments can form economically sound, environmentally motivated policies for substantial reductions in vehicle carbon emissions. In order to implement alternative approaches successfully, our point is that policymakers may need to take a holistic approach when designing policy. This holistic approach would recognise that policies to reduce carbon emissions must be politically feasible, and that all sectors of the economy generate carbon emissions. A holistic approach would not focus just on one method of abatement, like encouraging low-carbon vehicle technologies, but instead on the efficient balance between all different abatement methods.

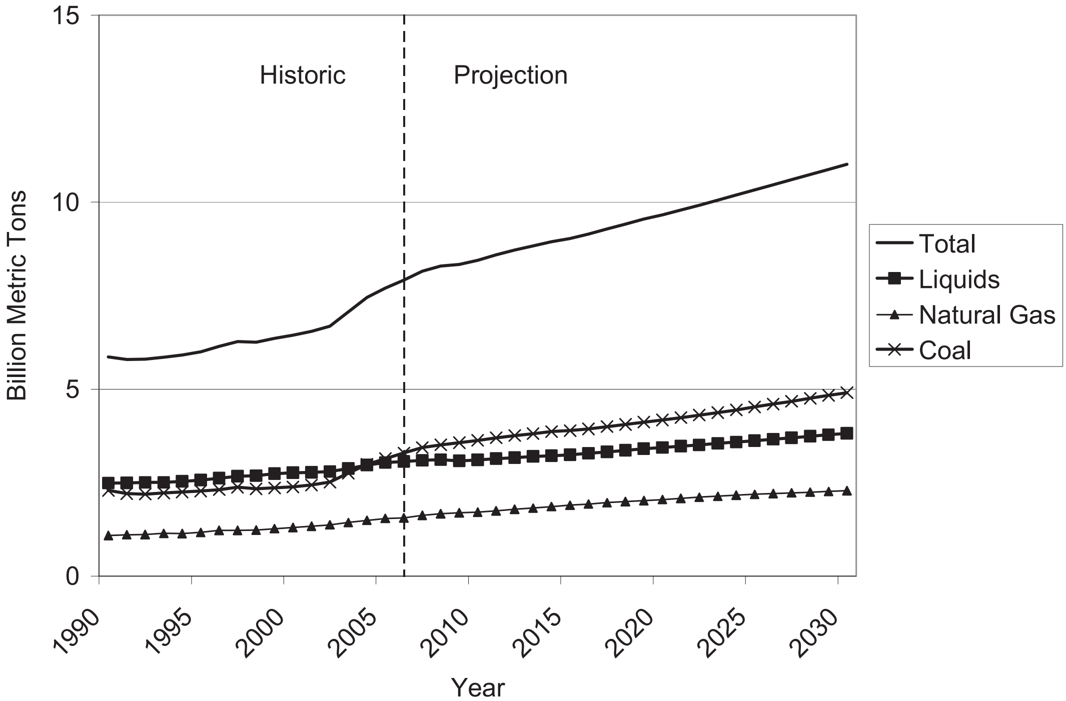
Combinations of carefully calibrated policy instruments can mimic the efficient outcomes of the first-best pollution tax (as discussed in Fullerton and West, 2002; 2010). The fundamental idea is to consider how everyone – consumers and producers alike – would act in the event of a carbon tax, including their diverse uses of different abatement methods. Facing a carbon tax, some would buy a hybrid car, while others would telecommute to work. Some would buy insulation for their homes, while others would move to a different house (perhaps with more insulation, or maybe close enough to walk to their place of employment). Then, without a carbon tax, policymakers could provide separate incentives or mandates for each of those same actions to be undertaken by each of those same individuals and corporations. That is, the instrument combination could be designed to induce the equivalent substitution effects and output effects of the ideal Pigouvian tax. An incomplete list of alternative instruments includes: fuel efficiency standards, fleet hybrid quotas, subsidies for new vehicle purchases, subsidies to scrap old vehicles and low-carbon fuel standards.

The first section below provides relevant descriptive statistics that inform our case for policies that mimic a carbon tax to achieve all of the same substitution effects and output effects. Next, we summarize some of the current policies in the United States and Europe that directly or indirectly limit carbon emissions from vehicles. In the subsequent sections, we briefly discuss externalities from vehicles, and the ideal cost-efficient tax on emissions; we expand on the idea of taking an holistic approach to reducing carbon emissions; and we lay out the additional policy objectives related to enforceability, political feasibility, leakage, heterogeneity, equity and fiscal sustainability. Continuing, we provide three examples of how alternative instruments can mimic the effects of a carbon tax. Finally, we address four complicating issues (vehicle portfolio choice, uncertainty and learning, fleet dynamics and infrastructure). These considerations would all enter into a holistic approach to the implementation of multiple alternative policy instruments.

2. TOO MUCH POLLUTION, TOO MANY CARS, TOO MANY MILES

Carbon emissions from vehicles significantly contribute to global greenhouse-gas pollution, which threatens the planet's ecology and economy. The most recent International Energy Outlook (IEO) calculates that the burning of liquid fuels in 2006 contributed 38.7% of the 8 billion metric tons of world energy-related carbon emissions. (The gasoline and diesel fuels used in ground-level vehicles constitute a major component of the liquid fuel category.) Figure 1 charts global historic and projected energy-related carbon emissions by fuel type from 1990-2030, as estimated by the IEO. Liquid fuel constituted the highest share of energy-related carbon emissions until 2004, when coal became the largest single emitter by fuel type. While stationary sources (e.g. power plants) burn much of the world's coal, the consumption of liquid fuels mainly occurs in mobile sources (e.g. vehicles), creating a different set of regulatory challenges for policymakers. Therefore, the importance of considering policies to promote low-carbon vehicles is not diminished by the fact that coal now forms the largest share of worldwide, energy-related carbon emissions.

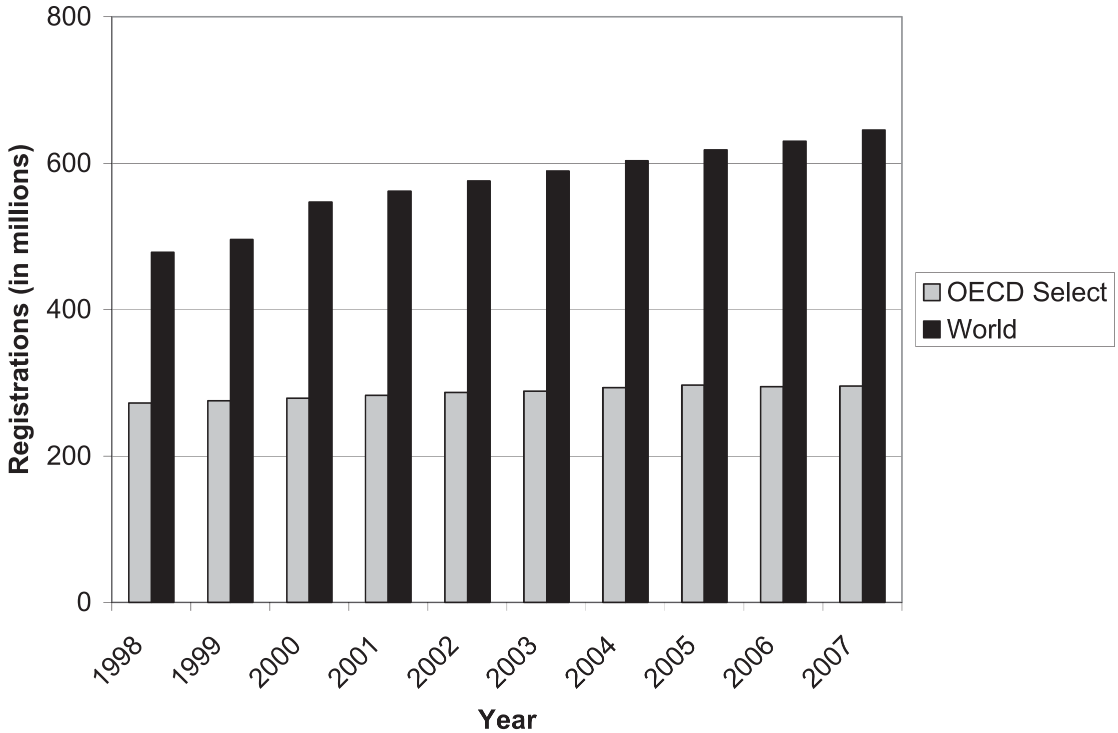
Figure 1. **Annual world energy-related carbon emissions by fuel type, 1990-2030**



Source: International Energy Outlook 2009, Figure 81 (converted to carbon); DOE/EIA-0494(2009).

The projected increase in liquid fuel consumption is not unexpected, as the number of worldwide vehicles continues to grow. Using data from the latest *Transportation Energy Data Book* (TEDB), Figure 2 graphs worldwide car registrations from 1998-2007, showing that the 600 million car level was surpassed in 2004. By 2007, global car registrations increased by 34.8% compared to the 1998 level, while the United Nations estimates that the world's population only increased by 5.7% over that same time period. Yet the staggering number of car registrations reported by the TEDB significantly underestimates the total number of vehicles, for two reasons. First, these data do not count trucks or two-wheeled vehicles. Second, official statistics cannot account for illegally operated vehicles. In short, the total number of vehicles on Earth is likely increasing faster than population growth. In addition, Figure 2 graphs car registrations from 1998-2007 for a subset of OECD countries (France, Germany, Japan, the United Kingdom and the United States). In 1998, these five countries had 56.9% of the world's cars, but exhibited just 8.6% growth over the period. By 2007, they accounted for just 45.8% of global car registrations, a drop of more than 10 percentage points in a decade.

Figure 2. **Car registrations for some OECD countries and the World, 1998-2007**

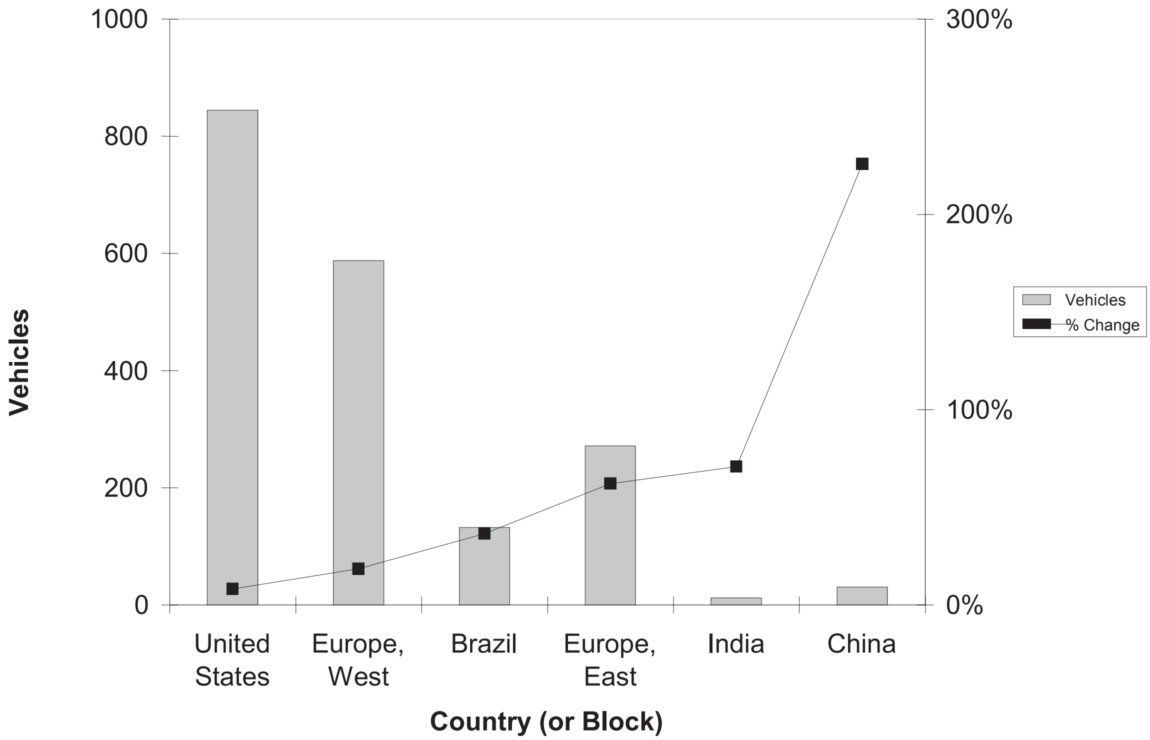


Source: *Transportation Energy Data Book* (TEDB), Edition 28-2009, Table 3.1.

Disclaimer: Our "OECD subset" includes all OECD countries for which we have TEDB data, though this definition in no way reflects the opinion or structure of the OECD. Our OECD subset includes France, Germany, Japan, the United Kingdom and the United States.

On a per capita basis, vehicle registrations and growth rates vary widely across countries. As calculated by the TEDB, the bars in Figure 3 show, for selected countries, the *number* of vehicle registrations per thousand people (measured relative to the left-side vertical axis). Then the line in the figure shows the *change* in the number of vehicle registrations per thousand people (measured relative to the right-side vertical axis). The United States has a relatively high vehicle saturation rate, with 844.4 vehicles per thousand people in 2007, an 8.2% increase from the 1996 level. Countries in western Europe have similarly high vehicle saturation rates and low growth rates. In contrast, China had only 30.3 vehicles per thousand people in 2007, due to its large population, but even that low level constitutes a 225% increase over the 1996 level. India reports a similar profile to China. Interestingly, eastern Europe and Brazil have medium vehicle saturation rates and medium growth rates. It is not surprising that the growth in the per capita vehicle rate slows as the number of vehicles approaches parity with the population; given the large populations of China and India; however, the potential remains for a very large number of vehicles to begin operating in those countries.

Figure 3. **Vehicle registrations per 1 000 people for selected countries (or blocks) in 2007, and % change from 1996 level**



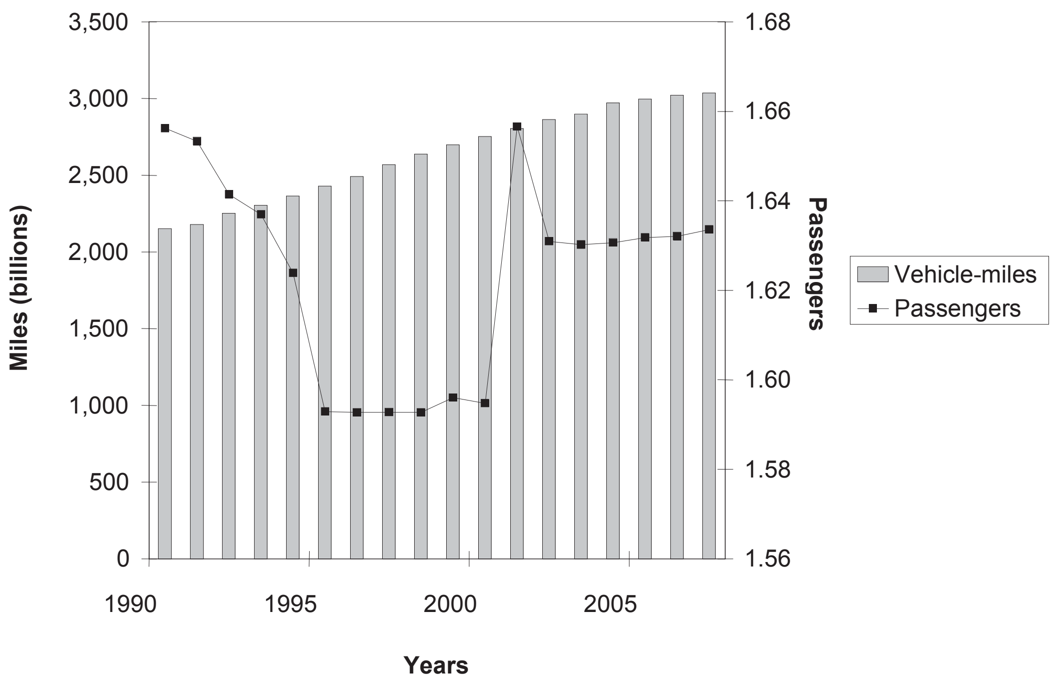
Source: Transportation Energy Data Book (TEDB), Edition 28-2009, Tables 3.4 & 3.5.

Disclaimer: The block definitions used by the TEDB in no way reflect the opinion or structure of the OECD.

Block definitions: Europe, West: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Latvia, Luxembourg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom; and, Europe, East: Belarus, Bulgaria, Croatia, Czech Republic, Hungary, Montenegro, Poland, Romania, Russia, Serbia, Slovakia, Slovenia and Ukraine.

The latest statistics from the US Department of Transportation provide evidence that the ever-growing fleet of vehicles are being driven greater distances. For instance, in 2006, residents of the United States travelled 16 418 highway passenger-miles per capita, a 15.3% increase over the 1990 level; that is, during this single year, the average American travelled in vehicles for a distance equivalent to two-thirds of the Earth's circumference. However, multiple passengers often occupy the same vehicle, and so the total vehicle-miles driven are fewer than the total passenger-miles travelled. While adding passengers marginally increases the fuel consumption of a vehicle, a large share of vehicle emissions occurs regardless of the number of passengers. The bars in Figure 4 show the gradually increasing number of total US highway vehicle-miles (measured relative to the left-hand vertical axis). From 1990-2007, total highway vehicle-miles increased 41.2% to over 3 trillion miles per year; meanwhile, the population of the United States increased only 20.8% over the same period. The line in the figure shows the average passenger occupancy rate, APOR (relative to the right-hand vertical axis). The APOR falls and remains low through the 1990s, but appears to jump in 2001 and subsequently stays above 1.62 passengers per vehicle[2]. Multiplying vehicle-miles (the bars) times the APOR (line) yields the total passenger-miles in each year.

Figure 4. **United States highway vehicle-miles and average passenger occupancy rates, 1990-2007**

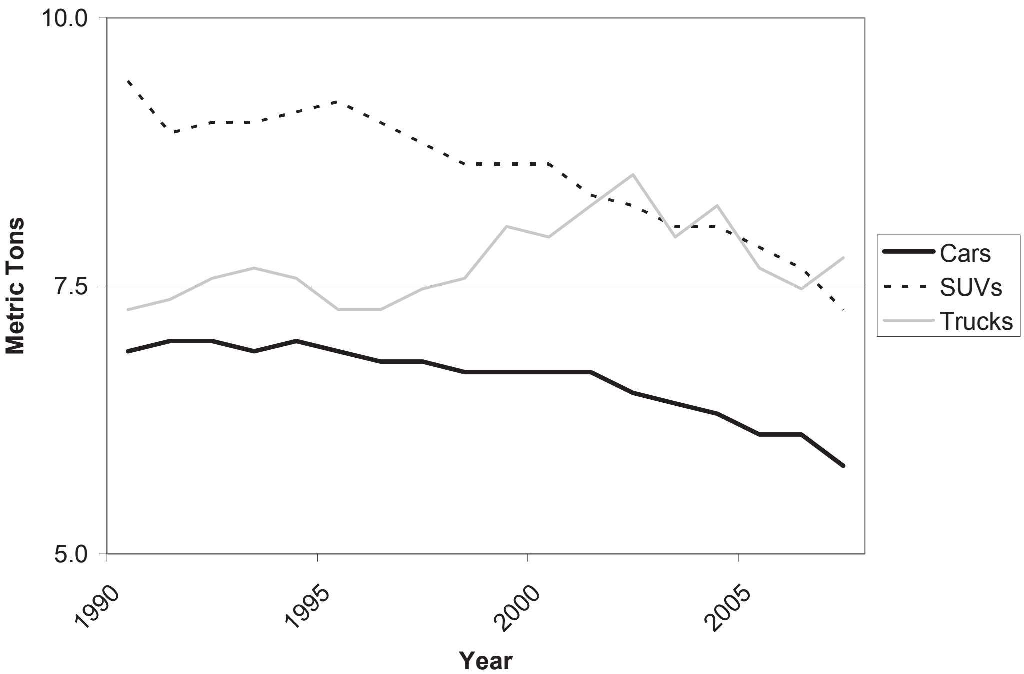


Source: US Bureau of Transportation Statistics, National Transportation Statistics (NTS), Table 1-32 & Table 1-37.

Methodology: To derive the Average Passenger Occupancy Rate, we divide total US highway passenger-miles by total US highway vehicle-miles. According to NTS Table 1-37, "Passenger-miles for passenger car, motorcycle, and other 2-axle, 4-tyre vehicles were derived by multiplying vehicle-miles for these vehicles by average vehicle occupancy rates, provided by the Nationwide Personal Transportation Survey (1977, 1983 and 1995) and the National Household Travel Survey (2001)."

Despite the 41.2% increase in vehicle-miles, total emissions from vehicles still might have fallen over that period, 1990-2007, if vehicles greatly reduced their emissions per mile. Figure 5 charts the sales-weighted annual carbon footprint of new, medium-sized US domestic and import cars, sport utility vehicles (SUVs) and pickup trucks, from 1990-2007. (The annual carbon footprint assumes 15 000 miles, with 55% city driving and 45% highway driving, and it includes greenhouse-gas emissions from carbon dioxide, methane and nitrogen dioxide.) Both cars and SUVs exhibited declines in their annual carbon footprint – by 15.5% and 22.7%, respectively – while trucks showed a slight increase of 6.7% over the period. In the end, the decreased carbon footprint of some new vehicles did not offset the large increase in vehicle-miles for the entire fleet. As a consequence, the US EPA's 2009 Greenhouse Gas Inventory reports that carbon emissions from cars, SUVs and trucks indeed increased 34.0% from 1990-2007.

Figure 5. **United States sales-weighted annual carbon footprint of medium-sized, new domestic and new import cars, SUVs and trucks, 1990-2007**



Source: Transportation Energy Data Book, Edition 28-2009, Tables 11.8 and 11.9

3. CURRENT POLICIES IN THE UNITED STATES AND EUROPE

Many countries have direct or indirect policies to address the problem of carbon emissions from vehicles. This section provides a brief overview of some of these policies in the United States and Europe.

The United States does not have federal greenhouse-gas (GHG) emission regulation for vehicles or stationary sources. Indeed, it was not until April 2009 that the US Government officially recognised greenhouse gases as a threat to public health through the effects of climate change. However, many other federal policies may indirectly limit carbon emissions from vehicles, and we highlight two examples: the Corporate Average Fuel Economy (CAFE) programme and the Renewable Fuel Standard (RFS).

In 1975, Congress enacted CAFE in response to the 1973-74 Arab oil embargoes. As the US National Highway Traffic Safety Administration explains, CAFE sets a 25 miles per gallon (mpg) minimum target for the "sales-weighted average fuel-economy…of a manufacturer's fleet of passenger cars or light trucks with a gross vehicle weight rating (GVWR) of 8 500 lbs or less, manufactured for sale in the United States, for any given model year." As a co-benefit to reducing oil usage, CAFE likely reduces direct emissions from vehicles under the GVWR limit. The additional environmental benefit is mitigated by two factors. First, popular large trucks and large sport utility vehicles have not all been subject to the CAFE programme[3]. Second, if CAFE increases vehicle mpg, then it reduces the cost per mile driven and may therefore encourage more driving. This "rebound" effect is discussed in much literature, as summarized in Parry *et al.* (2007).

One other point about the CAFE standards is relevant to the comparison of regulatory mandates and other incentive-based policies, like a tax or subsidy. Any given car manufacturer can use two basic methods to help satisfy this mandate regarding their corporate average fuel economy (the sales-weighted average of the vehicles sold that year). First, they can adjust the technology of their cars sold, to increase the fuel efficiency of any given car. Second, given the chosen technology, they can try to increase the number of small, fuel-efficient car sales relative to large car sales. Thus the car company has some incentive to cross-subsidize, charging a little more for large cars in order to cut the price of small cars. In doing so, each car company can still break even, in competitive equilibrium. In other words, this mandate probably leads to an equilibrium pricing *outcome* that looks a lot like a public policy incentive programme to tax large car purchases and use that tax revenue to subsidize small, fuel-efficient car sales.

Next, the Renewable Fuel Standard (RFS) programme, authorised by the Energy Policy Act of 2005, mandates renewable fuel blending into gasoline. The RFS mandate specifically requires 36 billion gallons of renewable fuels blended into gasoline per year by 2022, an increase of 350% over the 2008 level. These renewable fuels consist of corn ethanol, biomass-diesel and advanced cellulosic ethanol. Carbon dioxide may be emitted during combustion of these feedstocks, but it is recycled through absorption during the growth of the feedstocks. Still, concerns have been raised about the lifecycle carbon impact from increased land usage to grow feedstock, nitrogen-based fertilizer application and energy use in the conversion process (Holland, Hughes and Knittel, 2009).

In addition to federal policies, individual states and groups of states have substantial power to enact their own environmental policies. For example, individual states have gasoline taxes (which average to a rate similar to the federal rate of tax per gallon)[4]. Also, ten northeast and mid-Atlantic states form the Regional Greenhouse Gas Initiative (RGGI), which limits carbon emissions from the power sector using a cap-and-trade programme. With regard to vehicle emissions, California has been particularly aggressive in promulgating rules and regulations. Specifically, California's regulators fought for and recently obtained a waiver from the US EPA that allows an increase in that State's vehicle efficiency standard beyond the CAFE standard.

Unlike the United States, Europe has far-reaching and direct carbon policies. Phase II of the European Union Emissions Trading Scheme (EU-ETS) currently limits carbon emissions from a range of sources and industries, using a cap-and-trade programme. However, the EU-ETS does not currently apply to the transportation sector, as gasoline and diesel are already subject to high tax rates in most countries. A problem is that the existing fuel tax rates do not necessarily reflect the marginal environmental damage from carbon, because they were set to meet other objectives[5]. Still, high fuel taxes in Europe may already be inducing shifts toward fuel-efficient vehicles.

4. BENEFITS, COSTS AND EXTERNALITIES

The externality from vehicle pollution fundamentally occurs because individual drivers do not take into account the full social cost of their actions, where those social costs include not only the individual's private cost but also the monetary value of all negative impacts on others. This section discusses those private and external costs, focusing on climate change. The "bottom line" is that an individual who weighs the private costs and benefits of driving will generate more carbon emissions than is socially optimal.

Individuals privately benefit from driving in many ways. If these benefits can easily be met using low-carbon alternatives, then it will be easier to reduce carbon emissions. We identify three categories of driving benefits. First, driving is a substitute for other forms of transportation; individuals are more likely to drive private vehicles when they do not have viable low-carbon alternatives, like some public transit, walking and bicycling. Second, driving is a complement to particular goods and services. If an individual must be in a specific location to consume a good or use a particular service, then driving is a complement to that good or service. For instance, driving might be considered a complement to leisure. Finally, driving has intrinsic joys. One can imagine these intrinsic joys deriving from a desire to drive faster or travel farther than can be achieved by human locomotion.

Conversely, the private costs of operating a vehicle include the purchase or rental price, repairs and maintenance, fuel costs, insurance premiums and the time spent driving.

Beyond the private benefits and costs, drivers produce negative externalities that may include: local ambient air pollution, congestion and increased risk of accident, as well as the global externality of climate change from carbon emissions. While the scientific community has consensus about the human causes of climate change, the economic community does not have consensus about the monetary costs of these damages. Estimates of the marginal environmental damage vary widely from $20 to $300 per short ton of carbon, which translates into a range of 5 to 72 US cents per gallon of gasoline (or about 0.14 to 2.0 € per litre)[6]. Among other reasons, differences in social discount rates lead to the wide range of monetary damage estimates.

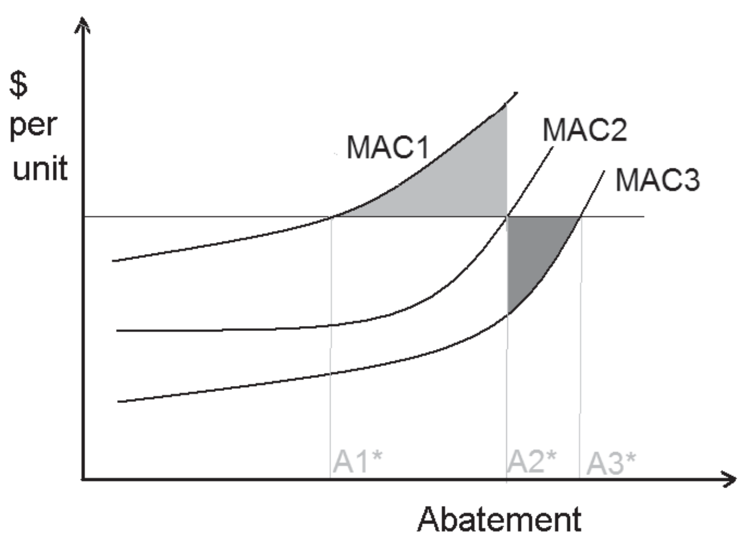
While this paper focuses on carbon emissions, vehicles and driving produce other negative externalities (as surveyed by Parry *et al.*, 2007). Traffic congestion on roads is perhaps the most salient negative externality from driving, and London has famously introduced a congestion fee for vehicles entering the city centre. The technology may now be available to use each car's global positioning system (GPS) to record exactly when and where that car is driven, in order to send a bill at the end of the month[7]. Then the fee for driving could be higher on particular roads when they are more crowded. In addition, each extra mile driven raises somebody else's chance of an accident. Driving also causes air and water pollution. Vehicles commonly leak fuel, fluids and lubricants that eventually flow into streams, lakes and oceans. On top of carbon emissions that cause global warming, vehicles also cause significant negative health consequences for children and adults from emissions of many criteria pollutants (particulate matter, ground-level ozone, carbon monoxide, sulfur oxides and lead).

5. THE "IDEAL" TAX ON EMISSIONS

According to the theory of Pigou (1932), damages from an externality such as pollution can best be mitigated by imposing a tax (or permit price) per tonne of emissions from any source. If the problem is global warming from carbon dioxide emissions, this theory suggests imposing a tax per tonne of carbon dioxide emissions. This price per tonne then can encourage any emitter to undertake the cheapest forms of abatement – using any technology that reduces a tonne of emissions in a way that costs less than the tax. Such a policy is economically efficient, because it minimizes the total cost of any given amount of abatement.

To abate carbon dioxide emissions from vehicles, one can: get a tune-up; fix broken pollution control equipment; retire and scrap an old vehicle with low fuel efficiency; buy a newer car with any number of features that increase fuel efficiency; change driving style to avoid aggressive driving; and avoid cold start-ups. These choices are all abatement options, because they reduce CO_2 emissions for a given number of miles driven. In addition, one can reduce miles driven: ride a bike, take mass transit, telecommute one day per week, move to a home closer to work, or change jobs to work closer to home. Each of these many abatement methods has a different, rising marginal abatement cost (MAC). Figure 6 shows just three MAC curves, where the horizontal axis measures abatement and the vertical axis measures the per-unit cost of abatement.

Figure 6. **Stylized marginal abatement cost (MAC) curves**



For example, suppose MAC1 represents the cost of achieving additional carbon dioxide abatement by getting people to use mass transit; this curve may rise because initial rail users can easily walk to the train station from houses nearby, while additional riders must get to the stations from further away. Suppose MAC2 is the cost (per tonne of carbon dioxide abatement) from additional telecommuting; one day per week is no problem, but the second day comes at higher cost. Equivalently, some workers can telecommute easily, while others do so at increasing marginal cost. And suppose MAC3 is the cost of achieving additional abatement by making cars lighter to get better fuel efficiency and cut gasoline use per mile. This curve rises because some components can easily be made from lighter materials, while other components are less suited to be made from lighter materials.

Next, suppose that a tax per unit of carbon emissions is imposed, with the rate equal to the height of the horizontal, grey line in the figure (ideally, this Pigouvian tax would equal the marginal environmental damage from carbon). Then commuters would face higher costs of driving and they would sort themselves efficiently. In this figure, A1* of abatement would be achieved when some commuters walk to the train station at low cost, while other commuters find that difficult and still drive. Also, A2* of abatement is achieved when some workers telecommute, while others need to be at the office and still drive. And A3* of abatement is achieved when people buy cars that are lighter and more fuel efficient - but expensive methods to achieve fuel efficiency are not undertaken.

The key is that this combination minimizes the cost of that total emission abatement. If the government were to mandate or subsidize enough mass transit so that method 1 was used to achieve as much abatement as method 2, then the extra cost to society would be the light grey area (the extent to which those abatement costs are higher than necessary). Conversely, if the government were to mandate or induce too little fuel efficiency, so that method 3 were to achieve only as much abatement as method 2, then the net loss to society would be the dark grey area (the foregone cost savings from not using that cheaper form of abatement).

The same theory applies more generally, with any number of abatement methods. If all sources in all sectors face the same price per tonne of emissions, then each has the incentive to use any method to abate carbon dioxide emissions that is cheaper than paying the tax per unit of carbon dioxide emissions.

Thus, a carbon tax by itself will induce all methods of abatement to the efficient, cost-minimizing degree. Yet, if a carbon tax is unavailable, then a carefully planned policy can use combinations of instruments to mimic the carbon tax, but only if each of the abatement behaviours is induced to the efficient level. In the example above, the government would need to encourage mass transit ridership to the right degree for those particular additional riders. It would need to encourage or require telecommuting to the right degree, but only for the right workers. And it would need to encourage or mandate lighter cars, but to the right degree for the right cars.

To achieve perfect efficiency using all these multiple policies is unlikely, but efficiency does not need to be "perfect". If policy induces almost the right number of rail commuters, then the light grey shaded area in Figure 6 may be small; if government requires almost the right increase in vehicle fuel efficiency, then the dark shaded area may be small. In other words, it may be possible to achieve a fairly efficient combination of abatement methods through the artful combination of policies such as a CAFE standard, a subsidy to hybrid vehicles, a low-carbon fuel standard, an attractive price on mass transit and a subsidy for the home use of internet for telecommuting[8].

Yet this alternative combination of policies has a major drawback. To achieve economic efficiency using just the carbon tax, authorities do not need to estimate the MAC curves. They just set the tax rate and let individuals decide for themselves whether and where to drive. To enact a set of policies that would mimic that carbon tax, however, the information requirements are enormous. The authorities would need to estimate each MAC curve to be able to determine the optimal or nearly optimal amount of that abatement method. That information is costly to acquire and it is estimated with error, so the outcomes may well be inefficient. Studies show that incorrectly implemented mandates can incur costs many times greater to achieve the same level of abatement as the efficient tax (e.g. Newell and Stavins, 2003).

6. HOLISTIC APPROACH

The authors were asked to write a paper about policies to encourage the adoption of low-carbon vehicle technologies, and certainly a good research effort could focus on this narrow question. Yet we find it difficult to think about what policies could *optimally* encourage the adoption of low-carbon vehicle technologies, because the answer to that question depends on what policies are already in place to affect other driving choices. Indeed, if drivers already faced the ideal Pigouvian tax on carbon emissions, then that policy would already induce the optimal choices of vehicle, and any additional policy to encourage low-carbon vehicle technology would be counter-productive – and efficiency reducing. But if the carbon tax is zero and the gasoline tax is “too low”, then households may not be willing to pay extra to buy hybrids or at least cars of a lower weight with more miles per gallon. In this case, the second-best optimal policy might well include subsidies to low-carbon vehicles. Thus, the optimal second-best subsidy logically depends on the existing carbon tax or gasoline tax.

Moreover, that second-best optimization problem also depends on what policies can be implemented politically, what emissions can be cheaply monitored and what regulations can be adequately enforced. Therefore, we suggest a holistic approach towards reducing carbon from vehicles. This holistic approach would take into account multiple, fundamental aspects of the climate change crisis. In this section, we discuss a few of these other considerations.

6.1. Enforceability

An enforceable environmental incentive policy often requires piggy-backing on transactions with receipts, in order to eliminate tax evasion and subsidy scams. Even without taxes or subsidies, the accurate measurement of abatement actions is still required to enforce quotas or mandates. These considerations make it very difficult or impossible to use market-based incentives for most conventional pollutants from vehicles, because a price per unit of those emissions would require a device to measure the actual emissions from each tailpipe, for hundreds of millions of cars. Those emissions are not a “market transaction” with an invoice to help administer the tax.

It would also be difficult to measure the carbon dioxide emissions from each tailpipe, but this problem is mitigated by the very high correlation between fuel consumption and direct vehicle CO_2 emissions. A carbon tax can be imposed on the carbon content of the gasoline or other fossil fuel at the time of purchase, using an invoice to help administer the tax. Alternatively, global positioning technology can easily and cheaply track miles driven, but potentially flawed testing procedures or averages might then be used to assign emission rates for each vehicle.

Enforceability matters for the holistic approach: if the ideal Pigouvian emissions tax cannot be administered and enforced, then the second-best policy might be a combination of instruments to encourage nearly the right amount of each separate abatement activity.

6.2. Political feasibility

Another important aspect of the holistic approach is to consider political feasibility. A direct tax on carbon emissions may be economically efficient, but political realities and special-interest lobbying often prevent ideal policies from being enacted. In the United States, it appears unlikely that any Congress in the foreseeable future will pass a comprehensive carbon tax or cap-and-trade programme. Instead, the US Congress seems to prefer to set mandates and to provide subsidies.

Even in the European Union, with its "ideal" carbon pricing through the Emissions Trading System, political feasibility at the time of enactment allowed the EU Parliament to apply the EU-ETS only to about half of total carbon emissions (the "trading sector" includes electricity generation and certain major industries, but it excludes other industries, residences and all of transportation). Using Figure 6, we could say that MAC1 represents the marginal cost of abatement in the trading sector, MAC2 is abatement in the residential sector and MAC3 is abatement in the transportation sector. Even if abatement within the trading sector is efficient, inadequate abatement in the other sectors still means inefficiency, because cheap forms of abatement in other sectors are not being undertaken. In this case, the EU might need a "combination" of instruments to improve efficiency, such as permits in the trading sector and a carbon tax in the non-trading sector.

A goal of this paper is to show that a proper mix of alternative policy instruments can be used in combination to mimic direct and comprehensive carbon policy. Each nation may face different political constraints, to different degrees, across a variety of different policy instruments. We therefore mean to provide a menu of policy approaches, from which policymakers can choose the workable combination for their own circumstances, in a way that depends on what is available. Even if a carbon tax is available it may be too low and other policies might be needed to supplement it. If a carbon tax is not available, then a normal gasoline tax might be very useful, to encourage less driving, while other policies for low-carbon vehicle adoption can help reduce the emissions per mile (kilometre).

At the present time, the accumulation of carbon emissions continues relatively unabated, so waiting for the right political conditions to enact the perfect piece of legislation could lead to actual outcomes much worse than using other available policy options.

6.3. Leakage

Greenhouse-gas emissions from any source and from any sector contribute equally to climate change. Furthermore, carbon dioxide and the other greenhouse gases are stock pollutants that accumulate in the atmosphere, so emissions today have approximately the same climatic effects as emissions a decade from now. Two kinds of problem may arise from focusing too much attention on any one source of carbon emissions in a particular time period.

First, it can lead to emission leakage into other countries, or similarly into other sources, sectors and years. That is, any targeted attempt to reduce vehicle emissions can lead to offsetting effects if households do something else instead that creates carbon emissions. Instead of driving, they may stay at home and burn natural gas in their furnace and they may turn on the lights, the television, or other household appliances that run on electricity. And this electricity may be generated using fossil fuels such as coal or natural gas. Or, the policy may be designed to reduce vehicle emissions by encouraging households to buy zero-emission electric vehicles. For example, suppose a mandate requires 10% of each manufacturer's sales of new vehicles to be all-electric vehicles. The batteries used to power these motors will be recharged using electricity from the power grid, however, and this electricity may also be generated by the burning of fossil fuels. In order to mitigate the leakage from the all-electric vehicle mandate, a complementary policy instrument would need to limit carbon emissions in the electricity sector, such as a renewable portfolio standard that mandates the generation of renewable electricity. In general, leakage can be mitigated only by comprehensive policies that affect all burning of fossil fuels – not just petrol in vehicles.

Second, even without leakage, a targeted attempt to reduce vehicle emissions cannot be the most efficient way to reduce a given amount of carbon emissions. It may require proceeding up the rising marginal cost curve for that particular form of abatement, while ignoring some other cheaper way to abate the same quantity of emissions from some other source.

6.4. Heterogeneity

Firms differ from each other in terms of size, available technology and cost of abatement. Thus, they should not all be required to abate the same amount. Individuals differ from each other in terms of wealth, income, demographic characteristics and preferences. As a result, the economically efficient policy generally will not require the same amount of abatement from each, nor even the same types of abatement. Facing a uniform carbon tax on all carbon emissions, some individuals will take the train, others will bicycle, some will buy a smaller car and others will buy a hybrid. Some may not abate at all, choosing instead to pay the tax. The outcome is efficient, since each only abates by the methods and to the extent cheapest for them.

This idea is important for the design of a combination of multiple instruments intended to mimic the "ideal but unavailable Pigouvian tax on emissions". Such a combination might well involve getting some people to buy hybrids or other low-carbon vehicle technologies, but a mandate that everybody must buy a new low-carbon vehicle technology may be an extremely expensive way to achieve any given amount of abatement. The little old lady who drives only once a week to the grocery store only one kilometre away should not be made to spend an extra $20,000 to buy a hybrid. Efficiency requires that she should buy the old fuel-inefficient large car from someone else who drives more distance (while that other person buys the new hybrid).

These considerations suggest the use of incentive policies in general, rather than mandates. A simple subsidy can encourage some to purchase a hybrid vehicle, while others do not. Note that even a mandate on each manufacturer's sales of vehicles can work as incentives to customers, like the CAFE standard described above. Similarly, if each manufacturer is required to sell electric vehicles as 10% of all new vehicle sales, then that policy is officially a "mandate", but it still allows some individuals to buy electric vehicles while others do not.

If a mandate or other policy requires the same amount or types of abatement from everyone, the result is an inefficient allocation of abatement. For example, Fullerton and West (2010) study non-carbon emissions from cars (volatile organic compounds, nitrogen oxides and carbon monoxide). If all individuals were identical, then the first-best welfare gain of an ideal Pigouvian tax can be achieved in their model by a uniform tax on gasoline, a tax on engine size and a subsidy to "newness" of the vehicle[9]. But using the heterogeneous individuals in their data, they calculate that 71% of that maximum welfare gain can be obtained by imposing those uniform tax rates. The efficiency loss increases with the degree of individual heterogeneity.

6.5. Equity

These differences between individuals also potentially lead to unequal burdens. In general, policies designed to reduce carbon emissions can be regressive, for any of six major reasons, outlined in Fullerton (2009). For instance, low-income individuals, on average, spend a disproportionate amount of their income on carbon-intensive goods and services, such as electricity and gasoline, so a policy that raises prices on these carbon-intensive goods and services hurts low-income individuals to a greater degree. However, rebates to low-income individuals can significantly reduce the regressive nature of carbon policies (Bento *et al*., 2009). Regarding vehicles, environmental policy that raises the cost of driving may not be regressive across the lowest income groups, because those with the least income may not own vehicles at all, as a result of high fixed costs and credit constraints. Instead, individuals in the middle of the income distribution disproportionately bear the burden of policies that raise the cost of vehicle travel. These middle-income individuals are wealthy enough to own vehicles, but not wealthy enough to ignore an increase in the variable cost of operating those vehicles. On the margin, some middle-income individuals may forego vehicle ownership. However, a fundamental tension remains between the policy objectives of efficiency and equity, due to imperfect information about individual abilities and limitations on the ability of government to make lump-sum transfers.

In our holistic approach, we argue for a combination of multiple policies to improve economic efficiency. Here, we note that a combination of multiple policies can help with equity as well. In addition to a carbon tax, policymakers might also want to provide some aid to low-income families as part of the policy reform package. And if a carbon tax is not available, then alternative policies in the package might be designed not just for economic efficiency, but also for equity. The package might include subsidies to low-income families to buy low-carbon vehicles, even if it does not subsidize high-income families to buy low-carbon vehicles.

6.6. Fiscal sustainability

Economists recognise that the revenue generated by a carbon tax, or a cap-and-trade programme that auctions permits, can be used for other welfare-improving purposes, such as cutting income tax rates or paying down national debts (e.g. Fullerton and Karney, 2009). Unfortunately, political constraints limit the feasibility of environmental policies that raise revenue. Instead, if a policy plans to employ subsidies as a means of inducing carbon abatement, the large size of the transportation sector will require a non-trivial portion of fiscal expenditures to support the subsidy programmes. Due to concerns about large national debts in many countries, environmental policies that are not fiscally sustainable may be cut in the future under budgetary pressure. In the long run, government budgets must balance. Since carbon emissions have approximately the same negative effect on the climate regardless of when they are released, removing a subsidy later would offset the benefit of previous abatement.

Furthermore, if a government promises unrealistically large subsidies for future abatement activity, then economically rational agents might not undertake necessary investments to enable that abatement, fearing that the subsidy would be cut in the future. Wind power in the United States provides a case in point. Beginning in the year 1992, wind generation during the first ten years of a wind farm's operation became eligible for 2.1 cents per kilowatt-hour production tax credit (PTC). Some members of Congress viewed the PTC as a needless and expensive subsidy, however, so the PTC was allowed to lapse in 1999, 2001 and 2003. In each of the subsequent years – 2000, 2002 and 2004, respectively – the quantity of new wind capacity projects fell dramatically, reducing the growth of carbon abatement opportunities. Even without an explicit lapse in the PTC, the threat of a lapse discourages the marginal investor from undertaking the upfront investment. In general, fiscal constraints lead to inherent uncertainties about subsidies, which limit their practical effectiveness.

7. POTENTIAL ALTERNATIVE INSTRUMENT COMBINATIONS

In this section, we provide three examples of how alternative instrument combinations can mimic the outcomes of an ideal carbon tax. A Pigouvian tax creates both a set of substitution effects and a set of output effects, and the multiple instruments can replicate all such effects. The principle at work here is to imagine what would occur under a carbon tax and then induce those outcomes by other means. The three examples in this section are not meant to be a comprehensive list of all possible carbon tax outcomes or alternative instrument combinations to achieve those outcomes, but we provide them here for intuition about how such mechanisms can operate. Table 1 contains a summary of the three examples: replace old vehicles with new hybrids, increase biofuel use and reduce solo commuting. Below, we explain the examples in detail.

Before doing so, however, we note the extreme difficulty of setting each standard or subsidy in an efficient mix of multiple instruments. Cost-efficiency requires pursuing each abatement method until its marginal abatement cost (MAC) is the same as for each other method of abatement. See Figure 6. Too much or too little incentive for any one abatement activity means that the achieved total abatement is more expensive than if achieved from a Pigouvian tax on all sources of carbon dioxide. To set each separate incentive or standard, the policymaker would need much data on the marginal abatement cost of each activity.

Table 1. **Examples of alternative instrument combinations to mimic an unavailable carbon tax on vehicle emissions**

Example	Carbon tax outcome	Alternative instruments	
		Substitution Effect	**Output effect**
1	Replace old vehicles with new hybrids	Mandate hybrid sales	Subsidize scrapping
2	Increase biofuel use	Subsidize blending	Tax mileage
3	Reduce solo commuting	Subsidize mass transit	Tax solo drivers

7.1. First example: Scrap old vehicles plus mandate hybrids

One outcome of a carbon tax is that some individuals would scrap their old, high-carbon vehicles and *some* of them would buy a new hybrid or other fuel-efficient vehicle. A substitution effect is the switching of vehicles, but an output effect is that *some* individuals might do without a car at all. Without a carbon tax, one might think that policy could subsidize the purchase of hybrid and other fuel-efficient vehicles. That subsidy could achieve the substitution effect, but it would not encourage others to go without a car at all. Thus, the replication of effects of a carbon tax would require the *combination* of a subsidy or mandate to increase sales of hybrid vehicles and a cash subsidy to scrap existing vehicles. By itself, a hybrid mandate can encourage producers to cross-subsidize sales so that marginal consumers purchase new hybrids instead of other new vehicles (the substitution effect). However, the mandate provides no incentive for existing high-carbon vehicle drivers to scrap their vehicles, because the cost of driving does not change. The subsidy for scrapping high-carbon vehicles increases the opportunity cost of continuing to operate the old vehicles, and thus it creates the incentive to reduce the number of high-carbon vehicles on the roads (i.e. output effect).

7.2. Second example: Biofuel subsidy plus miles tax

Another result of an "ideal" carbon tax would be an increase in biofuel use by vehicles, displacing traditional gasoline and diesel. In lieu of a carbon tax, subsidizing biofuel blending and taxing vehicle-miles can mimic the same outcomes. The blending subsidy makes it profitable for refiners to substitute away from 100% petroleum-based gasoline. However, the subsidy might reduce the price of fuel. Cheaper fuel may induce individuals to drive more. Therefore, driving needs to be discouraged, and a miles tax can achieve that goal. Recently, global positioning system (GPS) technology has fallen dramatically in price, so requiring GPS on all new vehicles can help make a miles tax enforceable.

7.3. Third example: Mass transit plus tax on solo driving

Fewer solo commuters would also result from the implementation of a carbon tax, as the cost of gasoline increases. However, other means of transportation can substitute for driving to work, such as public transit. Thus, subsidizing public transit by lowering the cost per bus ride or subway trip encourages individuals to substitute away from driving. The subsidy would increase public transit ridership, but under a carbon tax, these new riders may have been telecommuting to work instead of physically commuting. Therefore, another instrument needs to reduce the number of solo commuters among those still driving. A tax on solo commuters entering a city centre creates the desired output effect.

8. ADDITIONAL COMPLEXITY

When considering combinations of alternative instruments to mimic an ideal but unavailable carbon tax on vehicle emissions, many factors complicate the calculations needed to calibrate the right amount of incentives to provide to each separate abatement activity. In this section, we identify additional sources of complexity: vehicle portfolio choice, uncertainty and learning, fleet dynamics and infrastructure. These additional sources do not comprehensively cover all of the dimensions of complexity, but they do provide an insight into the challenging issues confronting policymakers in their design process – if they are to achieve economically efficient combinations of abatement choices without using a tax on carbon.

8.1. Vehicle portfolio choice

Many households make a complicated joint decision about their portfolio of vehicles. In 2000, almost 60% of all households in the United States owned two or more vehicles. These vehicles provide different amenities, such as fuel efficiency, number of seats, cargo capacity and off-road capabilities. For example, a single household often owns both a small, fuel-efficient car for commuting to work and a large, gas-guzzling sport utility vehicle for weekend and group activities. The vehicle portfolio choice becomes important when implementing instruments to promote low-carbon vehicle adoption at the household level, such as a tax credit that can be applied to a joint tax return.

8.2. Uncertainty and learning

New technologies such as hybrid and all-electric vehicles lead to uncertainty and information constraints among potential consumers. In their own self-interest, producers have an incentive to advertise these new vehicles to encourage sales, but to the extent that helpful information does not reach everyone, supplemental information campaigns provide a public good. In addition, individuals can learn about new technology from their neighbours, family and friends. Therefore, temporary policies that subsidize new vehicle technology adoption by some families can also help other families to resolve uncertainty about how hybrids and all-electric vehicles perform.

8.3. Fleet dynamics

Vehicles are expensive, durable goods that individuals and corporations do not replace regularly. The stock nature of the vehicle fleet leads to lags in the full adoption of abatement opportunities, when policies provide incentives to switch away from high-carbon vehicles. In other words, policies that apply only to new vehicles will require time to take full effect. Credit constraints may exacerbate the lag. This lag is important because trying to retrofit all existing vehicles is unfeasible for many types of low-carbon technologies.

This problem affects not only the time it takes to achieve carbon dioxide reductions, but indeed whether reductions occur at all. If low-carbon technology mandates apply only to new cars and are expensive, then owners of older cars may decide to delay the purchase of a new low-carbon vehicle. If so, then the nationwide average vehicle age may increase, emissions per mile may increase and total emissions may increase (Gruenspecht, 1982). This logic suggests a subsidy to new low-carbon vehicles rather than a mandate, plus a subsidy to scrap old vehicles.

8.4. Infrastructure

Another complicating issue is the interaction between urban planning, highway engineering and the amount of traffic congestion. Sitting in slow or stopped traffic burns extra fuel and wastes time, and politicians often call for the building of additional lanes to ease the flow of vehicle traffic. However, in 1962, Anthony Downs observed that the number of vehicle-miles grows in proportion to the length of available highway lanes. This phenomenon became known as the Fundamental Law of

Highway Congestion (FLHC), and was recently confirmed by Duranton and Turner (2009) using updated statistical techniques. As a consequence, a policy to reduce carbon emissions by building more highway lanes is unlikely to succeed. Instead of building new lanes, California lets hybrid vehicles with specific registration stickers use the High Occupancy Vehicle (HOV) lanes, which had previously been reserved for buses and carpools. But the FLHC still applies, because new highway lanes became available despite no construction. Besides providing more lanes for vehicles, urban planners and highway engineers can invent creative solutions to allow free-flowing traffic, and economic policy can provide incentives for alternate commuting behaviour, such as non-peak driving and telecommuting.

9. CONCLUSION

This paper demonstrates how alternative policy combinations can mimic an ideal but unavailable carbon tax on vehicle emissions. When calibrated correctly, these instruments can replicate all of the substitution and output effects of the ideal Pigouvian tax. The economic principle governing the use of these alternative instruments is to consider the multiple and diverse effects of a carbon tax and then implement multiple policies to achieve that same set of outcomes. Moreover, using mandates and subsidies eliminates some political constraints, as part of a holistic approach to reducing carbon emissions. We also discuss key policy objectives, such as economic efficiency, equity, enforceability and fiscal sustainability. We discuss key complicating factors, such as individual heterogeneity, vehicle portfolio choice, uncertainty and learning, fleet dynamics and infrastructure. All of these objectives and complicating factors need to be considered when implementing multiple policies using alternative instruments.

NOTES

1. From here on, we use "carbon" as a synonym for all greenhouse gases, unless otherwise specified.

2. The jump may be more apparent than real, for two reasons. First, the scale on the right-hand vertical axis shows much finer gradation than the left-hand scale; the numbers are not very different from each other. Second, the vehicle occupancy rate survey changes calibration in 2001, so the jump might just be a data adjustment issue.

3. Light trucks exceeding 8 500 lbs are still exempt through 2011. The NHTSA website states that: "*The most recent light truck rulemaking for model years 2008-2011 brought in large SUVs, referred to as "medium duty passenger vehicles" (MDPVs) in model year 2011 and beyond*."

4. The federal tax is 18.4 cents per gallon. State taxes range from 8 cents for Alaska to 46.6 cents for California. They average to 28.5 cents, so the total federal and state rate is 46.9 cents per gallon.

5. Existing fuel taxes in Europe may be too high or too low relative to marginal damages from multiple externalities (carbon emissions, local pollutant emissions, congestion and increased risk of accidents). Even if overall fuel taxes roughly match marginal environmental damage, however, they are currently based on the energy content of the different fuels, and on other political factors, rather than based on carbon content. Thus the relative prices of the different fuels do not induce the reductions in the use of each fuel that would represent the most efficient forms of carbon emission abatement.

6. The range of $20-$300 per tonne is suggested by Parry *et al.* (2007), in their survey of automobile externalities. They draw from a range of other published sources that are referenced in their paper.

7. See http://www.washingtonpost.com/wp-dyn/content/article/2010/02/05/AR2010020504790.html for an article in *The Washington Post*, dated February 7, 2010 (entitled "Racking up miles? Maybe not").

8. The current or proposed CAFE standard in the US may be too high or too low, depending on several factors. One problem is to determine the correct shadow price of carbon (in the range of $20-$300 per tonne of carbon as mentioned above). Another problem is that the appropriate CAFE standard in the mix of multiple instruments depends inherently on the stringency of the other instruments in the mix.

9. The subsidy to newness in that model is effective because newer cars are cleaner than old cars, both because emission rates deteriorate with the age of the vehicle and because newer vintages face stricter standards. That study looks at local pollutants, and it assumes one vehicle per household. For carbon emissions, such a programme is only effective if newer cars have lower carbon emission rates. And if the total number of cars is not fixed, then a subsidy to buying a new car is not equivalent to a subsidy for scrapping an old car.

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WHY THE MARKET FOR NEW PASSENGER CARS GENERALLY UNDERVALUES FUEL ECONOMY

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SUMMARY

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ABSTRACT

Passenger vehicles are a major source of greenhouse gas emissions and prodigious consumers of petroleum, making their fuel economy an important focus of energy policy. Whether or not the market for fuel economy functions efficiently has important implications for both the type and intensity of energy and environmental policies for motor vehicles. There are undoubtedly imperfections in the market for fuel economy but their consequences are difficult to quantify. The evidence from econometric studies, mostly from the US, is reviewed and shown to vary widely, providing evidence for both significant under- and over-valuation and everything in between. Market research is scarce, but indicates that the rational economic model, in general, does not appear to be used by consumers when comparing the fuel economy of new vehicles. Some recent studies have stressed the role of uncertainty and risk or loss aversion in consumers' decision-making. Uncertainty plus loss aversion appears to be a reasonable theoretical model of consumers' evaluation of fuel economy, with profound implications for manufacturers' technology and design decisions. The theory implies that markets will substantially undervalue fuel economy relative to its expected present value. It also has potentially important implications for the welfare analysis of alternative policy instruments.

1. INTRODUCTION

How markets determine the energy efficiency of new vehicles not only has important consequences for the quantity of carbon dioxide (CO_2) emissions and petroleum consumption, but it is also the most important factor in the choice of mitigation policies. Globally, light-duty vehicles account for about 12% of energy-related CO_2 emissions and about one-third of petroleum use (IEA, 2009a). The importance of light-duty vehicles is growing rapidly in the world's emerging economies. The International Energy Agency (IEA) anticipates a tripling of light-duty vehicle sales and stocks by 2050 over 2005 levels under business as usual. As a consequence, passenger car fuel economy has been a major focus of national energy policies for decades. Governments, from China to Australia, Japan, the EU, Canada and the US, have adopted fuel economy or greenhouse gas (GHG) emissions standards, either in place of or in combination with motor fuel taxes, as a means of reducing vehicle fuel consumption and emissions below what would otherwise be achieved by market forces alone (Onoda, 2007).

Whether the market for automotive fuel economy is efficient and fully accounts for the expected, discounted present value of fuel savings of the lifetime of new vehicles, or whether it systematically undervalues fuel economy improvement is a central question for energy and environmental policy for motor vehicles. If markets systematically undervalue fuel economy, market-determined levels of fuel consumption (l/100km) and emissions (g/km) will be too high and will not respond efficiently to price signals. In addition, there would likely be a systematic underinvestment in research and development of energy-efficient technologies.

There will be important implications for both the choice of policy instrument and its intensity. For example, Fischer *et al*. (2007) showed that if US consumers count only the first three years of fuel savings, tightening fuel economy standards would increase social welfare based on private costs and benefits alone. On the other hand, if consumers fully valued the full lifetime expected value of fuel savings, the same level of fuel economy standards would decrease social welfare. The efficiency of the market for fuel economy is especially important in countries with relatively low fuel taxes and a large vehicle parc, such as China and the US.

When matters as serious as global climate change are at stake, it is not sufficient to rely on textbook models of efficient markets for policy assessment. Policy analysis must be based on how real world markets actually function. Costs and benefits may vary widely, depending on how markets really function. Given this, it is disappointing that so little is known about how real world markets for energy efficiency in durable consumer goods actually work. It is no exaggeration to say that hundreds of billions of dollars are at stake. To say that more research is warranted is an understatement.

2. FUEL ECONOMY AND THE RATIONAL ECONOMIC CONSUMER

"*There is no longer any doubt about the weight of the scientific evidence; the expected-utility model of economic and political decision making is not sustainable empirically. From the laboratory comes failure after failure of rational expected utility to account for human behavior*."

(Jones, 1999, p. 297)

Despite the evident failures of expected utility theory, it is the preferred premise of many policy analysts when it comes to automotive fuel economy. The utility-maximizing rational consumer has fixed preferences, possesses all complete and accurate information about all relevant alternatives, and has all the cognitive skills necessary to evaluate the alternatives. These are strict requirements indeed, and even advocates of the rational consumer model claim only that it is approximated in reality.

The rational economic consumer considers fuel savings over the full lifetime of a vehicle, discounting future fuel savings to present value. This requires the consumer to know how long the vehicle will remain in operation (L), the distances to be travelled in each future year [M(t)], the reduction (ε) in the rate of fuel consumption (G), and the future price of fuel. A formula for continuous discounting of future fuel savings is presented below as equation 1. If the price of fuel can be assumed to be constant over time ($P_t = P_o$), the discounting formula simplifies, as shown in the second half of equation 1. In general, the information consumers will have on fuel consumption will be a test cycle number. Thus, the consumer must also estimate the fuel economy that will be achieved in real world driving, based on the official estimate. Finally, the consumer must know how to make a discounted present value calculation, or must know how to obtain one. The importance of uncertainties in all the factual information required to calculate the present value of fuel savings will be taken up below, as will the ability or willingness of consumers to make such calculations.

Equation 1. **Lifetime discounted present value**

$$V_L = \int_{t=0}^{L} P(t) M_0 e^{-\delta t} \left(G_0 - G_0(1-\varepsilon)\right) e^{-rt} dt = \frac{1}{\delta + r}\left[1 - e^{-(\delta + r)L}\right] P_0 M_0 \left(G_0 - G_0(1-\varepsilon)\right)$$

P(t) = price of fuel, for simplicity of exposition only assumed to be P_0 for all t;
M_0 = annual kilometres travelled for a new vehicle;
e = base of naperian logarithms;
-δ = rate of decline in vehicle use per year (-0.04);
G = base year fuel consumption (l/100km);
ε = fractional decrease in fuel consumption;
r = consumer discount rate;
L = vehicle lifetime, in years.

2.1. Market "failures" or imperfections

The literature on consumer evaluation of energy efficiency improvements to energy using durable goods has, until recently, focused on market imperfections and discount rates. Energy economists have identified several forms of market failure[1] to explain the high discount rates consumers appear to apply to future energy savings (e.g. Howarth and Sanstad, 1995; ACEEE, 2007; Train, 1985):

1. Principal agent conflicts;
2. Information asymmetry;
3. Imperfect information;
4. Transaction costs;
5. Bounded rationality;
6. Lack of skills to perform necessary calculations;
7. External costs;
8. Consumer myopia.

2.1.1 Principal agent conflicts

In the market for light-duty vehicles, consumers themselves choose directly among existing makes and models. However, manufacturers act as consumers' agents in making the technology and design decisions that determine a vehicle's energy efficiency. They decide how much cost should be incurred in adding energy-efficient technologies. With exceptions (such as diesel and hybrid vehicles), consumers are not aware of the fuel economy and cost trade-offs available to manufacturers. One consequence of this is that consumers' perceptions of fuel economy are based on the trade-offs they observe in the range of choices available at any given time. The manufacturers, on the other hand, are aware of the "fuel economy supply curve" defined by technology, and decide, on behalf of consumers, how much technology to adopt and for what purpose (fuel economy, performance, size, mass or accessories). The question is whether there is any reason for manufacturers to supply less fuel economy than would be optimal based on its expected value to the consumer. We will return to this subject below, but simply note here that manufacturers have repeatedly stated that consumers will pay, in increased vehicle price, for only two to four years of fuel savings.

2.1.2 Information asymmetry

It follows from the principal agent discussion, that manufacturers know more about energy-efficient technology and its cost than do consumers. In theory, a market failure could result if some manufacturers under-supply fuel economy, yet claim that their vehicles are just as efficient as their higher-priced competitors' vehicles. In general, one would expect widespread fuel economy labelling to make such claims difficult. Still, this can be observed to a limited degree in the United States, when manufacturers report only their vehicles' "highway" fuel economy ratings in television advertising.

2.1.3 Imperfect information

With fuel economy ratings widely available, it might at first appear that imperfect information could not be a significant problem. However, differences between official ratings and the fuel economy motorists experience on the road can be very large (Greene *et al*., 2006). Figure 1 plots fuel economy estimates provided by individuals to the US Government's website www.fueleconomy.gov *versus* the corresponding official EPA estimates. The variance around the official ratings is in the order of +/- 33%. Factors such as driving style, traffic environment, temperature and terrain (as well as estimation errors) lead to substantial uncertainty about the fuel economy that any given consumer will actually achieve. However, the official estimates do not appear to be seriously biased. While information about fuel economy is abundant, in most cases there is little information about its price. Except where fuel economy is linked to a priced vehicle attribute, such as a larger engine, no explicit information about its cost is generally provided. In such cases, consumers must infer the cost of fuel economy by comparing the multiple attributes of different vehicles, an exceedingly complex task. The chief problem with available fuel economy information, therefore, appears to be uncertainty, which can lead loss-averse consumers to undervalue fuel economy improvements. This subject will be discussed in greater detail below.

2.1.4 Transaction costs

Transaction costs do not appear to be a significant problem for the market for fuel economy.

2.1.5 Bounded rationality

The concept of bounded rationality recognises that consumers face limitations in terms of the information available to them, their cognitive abilities, and the time available to make decisions. Of these three, cognitive limitations seem the most relevant to fuel economy and vehicle choice. Choosing among the thousand or so makes, models and engine/transmission combinations available is a complex task. Vehicles are bundles of multiple attributes, e.g. price, size, materials, workmanship, styling, accessory features, fuel economy, warranty, acceleration, comfort, safety, reliability, and more. Utility optimization requires that all these attributes be simultaneously compared and traded-off - a complex task. Consumers may instead optimize on the three or four attributes of greatest importance and sacrifice the rest. Especially in countries with low energy prices, this could lead to undervaluing fuel economy. In the United States, for example, fuel economy rarely ranks among consumers' top five concerns when purchasing an automobile. Where fuel prices are high enough to make fuel economy one of new car buyers' top few concerns, decision-making may be closer to the rational, utility-maximizing model. Unfortunately, little research has been done on this subject.

2.1.6 Lack of skills to perform necessary calculations

Calculation of the present value of fuel economy improvements requires mathematical skills many consumers do not possess. They could, however, have others make such calculations for them, for example, via an Internet site.

2.1.7 External costs

Use of petroleum by motor vehicles produces several important externalities: greenhouse gas emissions; local air pollution; oil dependence. Some also count externalities associated with motor vehicle use, such as traffic congestion and safety (e.g. Parry and Small, 2005). These externalities, however, are not directly linked to fuel use or fuel economy. In some countries, motor fuel taxes may exceed the external costs of motor fuel use, while in others they are probably less.

2.1.8 Consumer myopia

In the expected utility-maximizing framework, shortsightedness implies some form of market failure, unless it reflects risk aversion. Shortsightedness might arise from cognitive limitations, or simply from irrationality. An explanation offered more in the popular media than in scholarly studies is that consumers count fuel savings only for the period over which they intend to own a vehicle. This begs the question of why the used-car market would not be willing to pay for better fuel economy. Clearly, for the new-vehicle market to operate efficiently, the used-vehicle market must also. Since most vehicles change ownership during their lifetimes, new car buyers must believe that used car markets will fully value the remaining fuel savings. There is little empirical information to confirm or refute that used-car markets are efficient.

For comparison with full lifetime discounting (equation 1), the equation for a simple three-year payback is shown in equation 2. In its study of the US Corporate Average Fuel Economy standards, the US National Research Council (NRC, 2002) calculated "cost-efficient" fuel economy improvements using both methods.

Equation 2. **Simple three-year payback**

$$V_3 = 3P_0M_0\left(G_0 - G_0(1-\varepsilon)\right)$$

The ratio of equation (1) to equation (2) is the following:

$$\frac{\frac{1}{\delta + r}\left[1 - e^{-(\delta + r)L}\right]}{3}$$

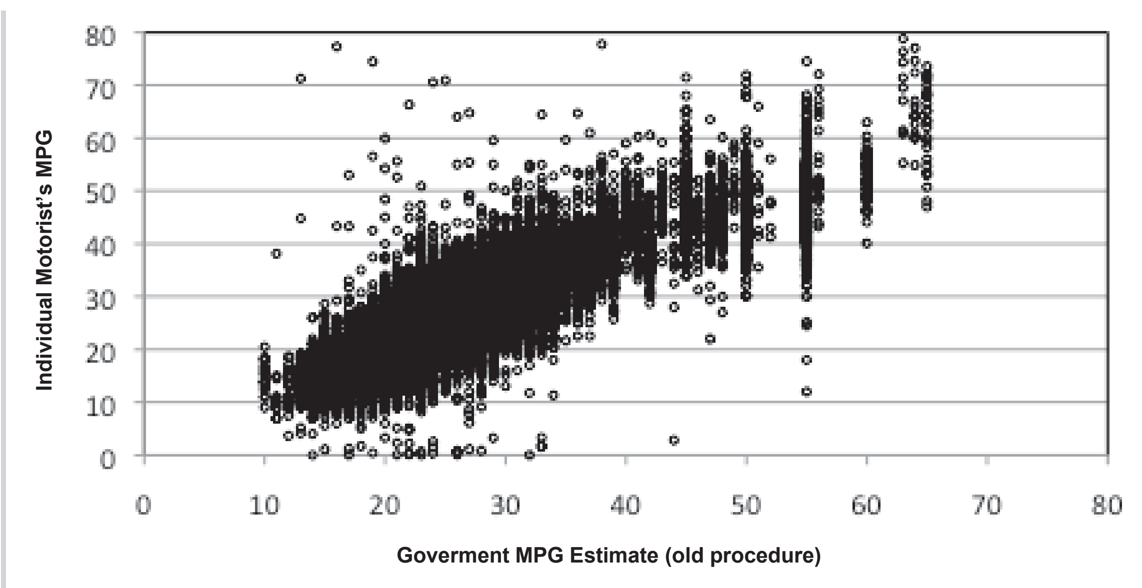
For parameter values, δ = 0.04, r = 0.07, and L=14, the ratio of full lifetime discounted fuel savings to a simple three-year accumulation is approximately 2.7. A consumer with these values for the rate of decrease in vehicle use with age, discount rate and vehicle lifetime, who used a simple three-year payback to value future fuel savings, would underestimate their lifetime discounted present value by a factor of 2.7. Although these equations are useful for analytical purposes, there are reasons to doubt that any significant number of consumers make such calculations, or have them done for them.

2.2. Uncertainty and risk aversion: Expected utility maximization

Of course, every variable in the lifetime discounted present value calculation is subject to some degree of uncertainty. Uncertainty and risk can be introduced into the utility maximizing framework by describing each variable as a probability distribution. This requires even more information about future states of the world but, in theory at least, it is possible. Consumers are then assumed to maximize expected utility. This allows risk aversion to be incorporated into the expected utility maximizing model, since risk aversion is a preference. As such, it is a matter of consumer sovereignty rather than irrational behaviour. Recent analyses have identified uncertainty and risk aversion as at least as logical an explanation for apparently high discount rates in the expected utility maximizing model.

Hassett and Metcalfe (1993) and (Diederen *et al*., 2003) demonstrated that uncertainty about future energy prices would lead to underinvestment in energy efficiency if consumers are risk averse. However, energy prices are not the only source of uncertainty about future energy savings. The performance of energy using durable goods, such as motor vehicles, may be even more important (Bjornstad and McKee, 2006). Fuel economy estimates provided by individual motorists to the US Department of Energy's website, www.fueleconomy.gov, show very substantial variability around the government's official fuel economy estimates (Figure 1). While some of this variance represents measurement error rather than genuine differences in realised fuel economy, a large fraction probably represents differences in driving style, traffic conditions, types of trips and their environment. In either case, if motorists perceive great uncertainty about the fuel economy they will actually achieve, this could have a profound effect on how they value fuel economy, as will be shown below.

Figure 1. **Motorists' fuel economy estimates *vs.* official estimates (www.fueleconomy.gov)**



Using expected utility maximization with risk aversion, Delucchi (2007) showed that risk-averse new car buyers would appear to have high discount rates for fuel economy, relative to a risk-neutral consumer. Rather than using explicit probability distributions for each parameter, Delucchi assumed that consumers would in all cases make "conservative" assumptions about the price of fuel, vehicle lifetime, miles driven and other key variables. He found that risk-averse consumers with a discount rate of 5.5% for investments without risk would appear to have a discount rate of 19% when taking risk into account and making "conservative" assumptions about likely outcomes. Delucchi concludes the following:

"*Thus, the high implicit discount rate that consumers appear to apply to fuel-economy purchase decisions is best understood not as an explicit expectation of a very high rate of return on investment foregone by spending money on fuel economy, but rather as the implicit equivalent of a series of conservative assumptions about fuel prices, fuel economy improvement, resale value, and so on, combined with an expectation of a normal rate of return on foregone investments* (Delucchi, 2007, pp. 16-17)."

3. EMPIRICAL EVIDENCE OF CONSUMERS' WILLINGNESS-TO-PAY FOR FUEL ECONOMY

Evidence from the econometric literature concerning consumers' willingness to pay for fuel economy, based on the expected utility-maximizing model, is contradictory and therefore inconclusive. Most available estimates are derived from random utility models of consumers' choice of vehicle. The estimates are highly variable, ranging from significant undervaluing to significant overvaluing of fuel economy. A handful of studies using hedonic price models and other methods are equally conflicting. In some cases, flaws in model formulation or estimation methods can be identified, but in most cases there is no obvious explanation for the extreme differences among studies.

3.1. Econometric estimates

Implicit consumer discount rates were estimated by Greene (1983), based on eight early multinomial logit choice models. In some models, discount rates were a function of consumer income; in others, discount rates were random variables. The estimates ranged from 0% to 73%, setting aside the one study with the most extreme results. Many estimates are below 10% but an equally large number are over 20% per year (Table 1). Most fall between 4% and 40%. Some of the variation may be explained by systematic variation in discount rates with income. For those models in which discount rates vary with income, higher income groups tend to show lower discount rates. To a large degree, this relationship is dictated by the modeller's decision to represent vehicle price by price divided by income. The sensitivity of discount rates to income varies widely across the models, however.

Table 1. **Estimated unadjusted discount rates**

1	**Lave and Train (1978)**					
				Auto Price (1977$)		
			2500	3500	5000	
	Income	10 000	0.23	0.21	0.19	
	(1977$)	20 000	0.12	0.12	0.11	
		25 000	0.10	0.10	0.09	
		30 000	0.08	0.08	0.08	
		50 000	0.05	0.05	0.05	
2	**Cardell and Dunbar (1980)**					
	Median = 0.43		Mean = 0.25			
3	**Beggs and Cardell (1980)**					
		Base model			**Financial and size variables only**	
	Household	10 000	0.59		0.73	
	Income	20 000	0.35		0.35	
		25 000	0.31		0.31	
		30 000	0.29		0.28	
		50 000	0.24		0.23	
4	**Boyd and Mellman (1980)**					
	Simple logit 0.06					
	Hedonic	Median = 0.09		Mean = 0.02		
5	**Manski and Sherman (1980)**					
	a) One-vehicle households					
		Urban			**Rural**	
		Low I	**High I**		**Low I**	**High I**
	College	0.10	0.06		0.18	0.19
	No College	0.17	0.18		0.54	-0.16
	b) Two-vehicle households					
		Urban			**Rural**	
		Low I	**High I**		**Low I**	**High I**
	College	0.64	0.09		-1.64	0.19
	No College	28.4	0.26		-0.61	2.26
6	**Beggs, Cardell and Hausman (1981)**					
		Common tastes			**Individual tastes 0.30**	
		10 000	0.36			
		20 000	0.30			
	Income	25 000	0.29			
		30 000	0.29			
		50 000	0.28			
7	**Sherman (1982)**					
	One-vehicle households		0.13	[dependent on ln (miles annually) here 10 000]		
	Two-vehicle households					
			Annual Miles (both cars)			
			10 000	20 000	25 000	
	Income	10 000	0.02			
	(1978$)	20 000	0.01	0.00		
		30 000	0.01	0.00	0.00	
8	**Train and Lohrer (1982)**					
	One-vehicle households					
	0.12 if I ≤ 12 000		0.09 if I > 12 000			
	Two-vehicle households					
	0.12 if I ≤ 12 000		0.09 if 12 000 < I ≤ 20 000			0.05 if I > 20 000

Source: Greene (1983), Table 3.

Empirical estimates of discount rates for all types of energy using consumer durable goods were analysed by Train (1985).

"*The average discount rates for automobile choice calculated from the estimated models in each of these studies is listed below (with real fuel prices assumed to be constant over time and the useful life of vehicles assumed to be infinite): (1) Lave and Train: 20%, for a $4 000 vehicle in 1977 dollars; (2) Manski and Sherman: 6-18%, for one-vehicle urban households depending on income and education; (3) Cardell and Dunbar: 25%; (4) Beggs and Cardell: 41%; (5) Boyd and Mellman: 2-6%, depending on the model; (6) Beggs, Cardell and Hausman: 30%; (7) Sherman: 13%, for one-vehicle households, and 0-2%, for two-vehicle households; and (8) Train: 9-12%, for one-vehicle households, depending on income, and 5-12%, for two-vehicle households, depending on income. These estimates vary widely, from a low of 0-2% for two-vehicle households in the Sherman study to 41% in the study by Beggs and Cardell* (Train, 1985, p. 1249)."

The pattern of wide variation in discount rates and very high apparent discount rates at the upper end of the range is common not only to automobiles but to many other consumer choices of energy-using equipment. Train summarized his findings on discount rates for all energy-related consumer purchases as follows.

"*The range of estimated average discount rates found in previous studies is listed below by the type of choice in which the discount rate is implicit. Measures to improve the thermal integrity of dwellings: 10-32%; space heating system and fuel type: 4.4-36%; air conditioning: 3.2-29%; refrigerators: 39-100%; other appliances (water heating, cooking, food freezing) 18-67%; automobiles: 2-41%; and unspecified actions: 3.7-22%* (Train, 1985, p. 1250)."

Train concluded: "*Clearly this is an area of research requiring considerably more attention* (Train, 1985, p. 1252)."

Studies of consumers' willingness to pay for improved fuel economy, conducted over the past 20 years, were reviewed by Greene (2010). The largest number of studies were based on discrete choice models, either nested multinomial logit or mixed logit models. Both models permit heterogeneity in consumers' preferences: nested models allow willingness to pay to vary by vehicle class, while mixed logit models also allow parameters to vary randomly across the population of consumers. Some models were estimated using aggregate sales data while others were based on surveys. Studies estimating hedonic price models and other methods were also included. Greene summarized the results in terms of consumers' willingness to pay for fuel economy improvement as a percentage of the full-lifetime discounted present value of fuel economy, using either each study's reported vehicle usage and expected lifetime or standard assumptions published by the US Department of Transportation.

The more recent studies exhibit at least as wide a range of estimates as the earlier surveys by Greene (1983) and Train (1985): from <1% to 400% of the expected present value. In the vast majority of studies, there was no evident explanation for the wide differences among the estimates. The evidence from the empirical literature, 25 years after the early summaries by Greene and Train, remains contradictory and inconclusive.

Table 2. **Summary of consumers' evaluation of fuel economy improvements, based on 22 recent studies (Greene, 2010)**

Authors	Model Type	Data / Time	W-T-P as % of Discounted PV	Implied Annual Discount Rate
Alcott & Wozny (2009)	Mixed NMNL	Aggregate US, 1999-2008	25%	> 60%
Gramlich (2009)	NMNL	Aggregate US, 1971-2007	287% to 823%	
Berry, Levinsohn & Pakes (1995)	NMNL	Aggregate US, 1971-1990	<1% Non-significant	
Sawhill (2008)	Mixed NMNL	Aggregate US, 1971-1990	140%, range of -360% to 1 410%	
Train & Winston (2007)	Mixed NMNL	Survey, US, 2000	1.3% Non-significant	
Dagupta, Siddarth and Silva-Risso (2007)	NMNL	Survey, CA, 1999-2000		15.2%
Bento, Goulder, Henry, Jacobsen & von Haefen (2005)	NMNL	Survey, US, 2001	No direct estimate but MPG insensitive to price of gasoline	
Feng, Fullerton & Gan (2005)	NMNL	CES, US, 1996-2000	0.03% to 1.3%	
Brownstone, Bunch & Train (2000)	Mixed NMNL Stated & Revealed Preference	CA Survey, 1993	132% to 147%	
Brownstone, Bunch, Golob & Ren (1996)	NMNL Stated & Revealed Preference	CA Survey, 1993	-420% to 402%	
Goldberg (1998)	NMNL	US CES, 1984-90	Consumers "not myopic".	
Goldberg (1995, 1996)	NMNL	US CES, 1983-87	Consumers "not myopic" but based on 7-year vehicle "holding period".	5% over 7 years
Cambridge Econometrics (2008)	Mixed logit	UK survey, 2004-2009	196% but uncertain of estimate. Authors contacted for clarifications.	
Eftec (2008)	NMNL	UK 2001 to 2006	TBD – authors contacted for clarifications.	
Fan & Rubin (2009)	Hedonic Price	State of Maine, 2007	Cars: 25% Lt. Trucks: 16%	Cars: 37% Lt. Trucks: 77%
McManus (2007)	Hedonic Price	US, 2002	90%	
Espey & Nair (2005)	Hedonic Price	US, 2001	109%	

Arguea, Hsiao & Taylor (1994)	Hedonic Price	US, 1969 to 1986	3% to 46%
Bhat & Sen (2006)	Choice model	San Francisco Bay Area, 2000	Elasticities of vehicle choice with respect to fuel costs 2% to 3% of purchase price elasticities.
Langer & Miller (2008)	Price Regression	US, 2003 to 2006	Approx. 15% of PV of fuel cost changes reflected in vehicle price changes.
Busse, Knittel & Zettelmeyer (2009)	Price Regression	US, 1999 to 2008	Transaction prices adjust by 1.2 years worth of fuel savings for new cars.
Li, Timmins & von Haefen (2009)	Vehicle sales by fuel economy quantile	US Metro Areas 1997 to 2005	Short-run price elasticity of MPG with respect to sales mix +0.02,long-run +0.2.

Source: Greene, 2010.

Econometric estimation of vehicle choice remains a technically challenging problem. The sophistication of the models has advanced significantly, but hard statistical problems remain. Vehicle choice is a complex, multidimensional problem, further complicated by the fact that consumers' preferences are heterogeneous. In general, it is not possible to define, let alone accurately measure all the relevant variables. For example, safety may include measures of frontal impact for driver and passenger, side impacts, and rollover propensity, at least. Performance may include 0-50 km, 50-100 km, and even > 100 km/hr acceleration times, as well as a variety of handling measures. Reliability, comfort and luxury are also not easily measured, not to mention prestige and style. Even fuel economy will vary significantly according to where, how and when vehicles are driven. This results in a combination of omitted and errors-in-variables problems that are compounded by correlations among many relevant variables (e.g., fuel economy, mass, size, horsepower, price, accessories, etc.). All of this is a recipe for unstable or biased parameter estimates. For estimates based on historical data, there is also the problem of disentangling the effects of fuel economy standards from consumers' preferences. Finally, the expected utility-maximizing, continuous trade-off model is at best an approximation of the decision processes used by real consumers. While this is no reason to give up on attempts to estimate consumers' willingness to pay for fuel economy, at present the available literature does not appear to provide a reasonable consensus, nor does it help to resolve the question of whether consumers under- or over-value fuel economy improvements. If anything, it casts doubt on the validity of the model of the expected utility-maximizing consumer.

3.2. Evidence from surveys and focus groups

Evidence from surveys, focus groups and anthropologic research in the US indicates that the rational economic model of trading off cost or other vehicle attributes for the discounted present value of expected fuel savings is rarely used by car buyers in their real-world decisionmaking. The most useful insights come from in-depth, semi-structured interviews of 57 households in California, conducted by researchers at the University of California, Davis (Turrentine and Kurani, 2007). Without prompting respondents about their views on fuel economy, the researchers asked for a description of each household's entire vehicle ownership history, and their reasons for acquiring and disposing of each vehicle. Few respondents mentioned fuel economy as a factor.

In the final stage of the interviews, the researchers revealed their interest in fuel economy, ultimately asking respondents about their willingness to pay for a vehicle with a 50% increase in fuel economy. The answers reveal an absence of quantitative assessment.

"*In eight interviews in which we did ask the question, the household could not or would not offer a value. Ten other households offered a range, e.g. '$2000 to $4000' or '$5000 to $7000.' Sometimes this range conveyed obvious uncertainty; sometimes these ranges represented disagreement between household members who were unable to agree on an amount in the course of the interview. Among households who offered specific dollar amounts (or answers in a range less than $1 000), values ranged between zero and $10 000. Even excluding the eight households from whom we did not solicit a value, half the households are unable or unwilling to offer a numeric answer* (Turrentine and Kurani, 2007, p. 1219)."

These results bear a striking similarity to the econometric estimates described above. Both results are consistent with the hypothesis that there may be no single underlying model used by consumers to evaluate fuel economy.

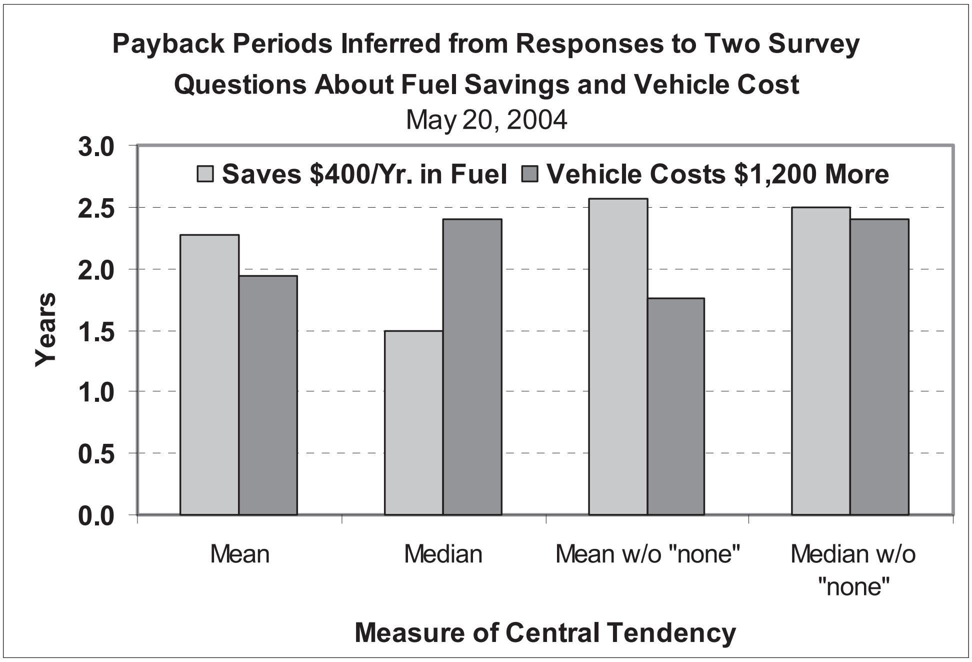
"*We found no household that analyzed their fuel costs in a systematic way in their automobile or gasoline purchases… . One effect of this lack of knowledge and information is that when consumers buy a vehicle, they do not have the basic building blocks of knowledge assumed by the model of economically rational decision-making, and they make large errors estimating gasoline costs and savings over time* (Turrentine and Kurani, 2007, p. 1213)."

However, the lack of a rigorous model for evaluating fuel economy implies that consumers will neither undervalue nor overvalue fuel economy.

The evidence from automobile manufacturers is anecdotal but revealing. The US National Research Council report on the US Corporate Average Fuel Economy Standards (NRC, 2002) made estimates of cost-effective fuel economy levels based on two alternative assumptions: 1) present value of discounted, expected future fuel savings; and 2) a simple three-year payback rule of thumb. As a member of that Committee, the author can report that the latter assumption was based on statements made to the Committee by several manufacturers. Manufacturers' rules of thumb ranged from two to four-year simple paybacks to three-year paybacks, to 80 000 km paybacks (the average usage of a new car in the US is approximately 24 000 km per year). When asked for the source of this information, manufacturers' representatives invariably cited proprietary market research.

A nationwide random sample survey of 1 000 households for the US Department of Energy asked half of the respondents how much more they would be willing to pay for a vehicle that saved them $400 per year in fuel costs (Opinion Research Corp., 2004). The other half of the respondents were asked how much annual fuel savings they would require in order to be willing to pay an additional $1 200 for a new vehicle. In both cases the vehicles were described as identical in every way except for their fuel economy.

Figure 2. **Fuel economy payback periods inferred from a DOE consumer survey**



The striking similarity of the implied payback periods from the two subsamples would seem to suggest that consumers understand the questions and are giving consistent and reliable responses: they require payback in 1.5 to 2.5 years. However, Turrentine and Kurani's in-depth interviews indicate something else. They found almost no evidence of consumers thinking about fuel economy in terms of payback periods. When asked such questions, some consumers became confused while others offered time periods that were meaningful to them for other reasons, such as the length of their car loan or lease.

Evidence from focus groups conducted for the US DOE and EPA Fuel Economy Information Program indicated that consumers may not think in terms of trading off fuel economy for higher initial cost at all (Nye, 2002). Indeed, some consumers were confused when asked such a question. They expected to pay less for higher fuel economy, not more. They associated fuel economy with inexpensive, small, low-power vehicles. Trading off higher vehicle price for fuel economy was not a concept with which they were familiar.

4. UNCERTAINTY AND LOSS AVERSION: CONTEXT-DEPENDENT PREFERENCES

Probably the most well-established principle of behavioural economics is that, when faced with uncertainty, consumers 1) weigh potential losses far more than potential gains and, 2) exaggerate the probability of loss (Della Vigna, 2009). In contrast to the concept of risk aversion, the theory of loss aversion (or prospect theory) is premised on context-dependent utility (Tversky and Simonson, 1993). Which theory is more correct has important implications for the welfare analysis of policies such as fuel economy standards. Risk aversion assumes that consumers' preferences are fixed and that one of their preferences is to avoid situations in which losses are likely. Thus, if consumers are forced to accept risky bets, there is a real and measurable loss of utility that does not change if the context of the bet is changed, nor does it change once the bet has been resolved. This led Arrow and Lind (1970) to conclude that governments should impose risky investments on the public only when the government also insured individuals against the consequences of losses. Prospect theory asserts that utility is context dependent, meaning that a consumer's evaluation of the utility of a risky bet could be different *ex post* and *ex ante*.

Under risk aversion, if consumers would reject a 50/50 bet of win \$150/lose \$100, then even if after the bet half of the consumers won \$150 and half lost \$100, for an average net gain per consumer of \$25, there would be a net loss of utility, considering the entire process. Prospect theory does not answer this question definitively but allows the possibility that, on average, consumers might consider themselves better off after the bet.

With respect to new cars, a further complication is that decisions about the technological content and design of vehicles are not made by consumers but by manufacturers acting as consumers' agents. It has already been asserted above that manufacturers state that consumers think in terms of short payback periods. However, the detailed interviews of households in California indicate that consumers typically do not think in terms of payback periods or any quantitative assessment of fuel savings and costs, but rather rely on a variety of different decision rules. As will be shown below, the behaviour of a loss-averse consumer approximates that of a consumer with a very short payback period.

Greene *et al*. (2009a) considered the implications of loss aversion and uncertainty for manufacturers' decisions about the use of technology to increase fuel economy. The authors quantified consumers' uncertainty about the future value of fuel savings by constructing probability distributions of vehicle use, lifetime, gasoline prices, real-world versus official test fuel economy estimates, and the cost of improved fuel economy. Key parameters of their probability distributions are shown in Table 3.

Table 3. **Key parameters of the consumers' fuel economy choice problem**

Variable	Value Assumed
Miles travelled (first year)	5%=14 000, mean=15 600, 95%=17 200
Rate of decline in usage	4.5%/year
Rate of return required by consumer	12%/year
Vehicle lifetime (extreme value)	5% = 3.6, mean = 14 years, 95% = 25.3
Gasoline price distribution (lognormal)	5% = $1.78, mean = $2.05, 95% = $2.63
Incremental price distribution	5% = $665, mean = $974, 95% = $1 385
Fuel economy lower	5% = 21 mpg, mean = 28, 95% = 35
Fuel economy upper	5% = 28 mpg, mean = 35, 95% = 42
In-use fuel economy factor	0.85

Source: Greene *et al*., 2009a.

In the absence of uncertainty, the problem of choosing the optimal level of fuel economy is a matter of finding the level that yields the maximum difference between the net present value of future fuel savings and initial cost. Figure 3 illustrates this, using data from a recent fuel economy study by the US National Research Council (2002). The solid black line shows the net present value of fuel savings, calculated using the assumptions shown in the graph. The dot and dash line shows the committee's "average" estimates of the cost (in retail price equivalent) of increasing fuel economy (in miles per gallon). The committee also provided high and low cost estimates. The rational utility maximizing consumer is interested in the difference between the two, the net present value of increased fuel economy, illustrated by the "Xed" line. Note that this function is relatively flat near its optimum, varying by only about $100 over a range of 6-7 miles per gallon. The optimum value is approximately 36 miles per gallon (6.5 l/100km), a 25% increase over the base level of 28 miles per gallon (8.4 l/100km).

If the parameters in Table 3 are used to describe uncertainty about the value of future fuel savings, the value of increasing fuel economy to, say 35 MPG (6.7 l/100km) becomes not a certain value but a probability distribution. This is illustrated in Figure 4, in which the expected value of $405 is close to the certain value of just over $500, but it is also possible to lose up to $3 000 or gain up to $4 500. Incorporating uncertainty transforms the sure thing into a risky bet. Does this change the way consumers would evaluate the option to improve fuel economy? According to the theory of loss aversion, widely regarded as the most firmly established principle of behavioural economics, the answer is yes, it changes things profoundly.

Figure 3. **Incremental price, present value of fuel savings and net value of increasing fuel economy to the consumer**

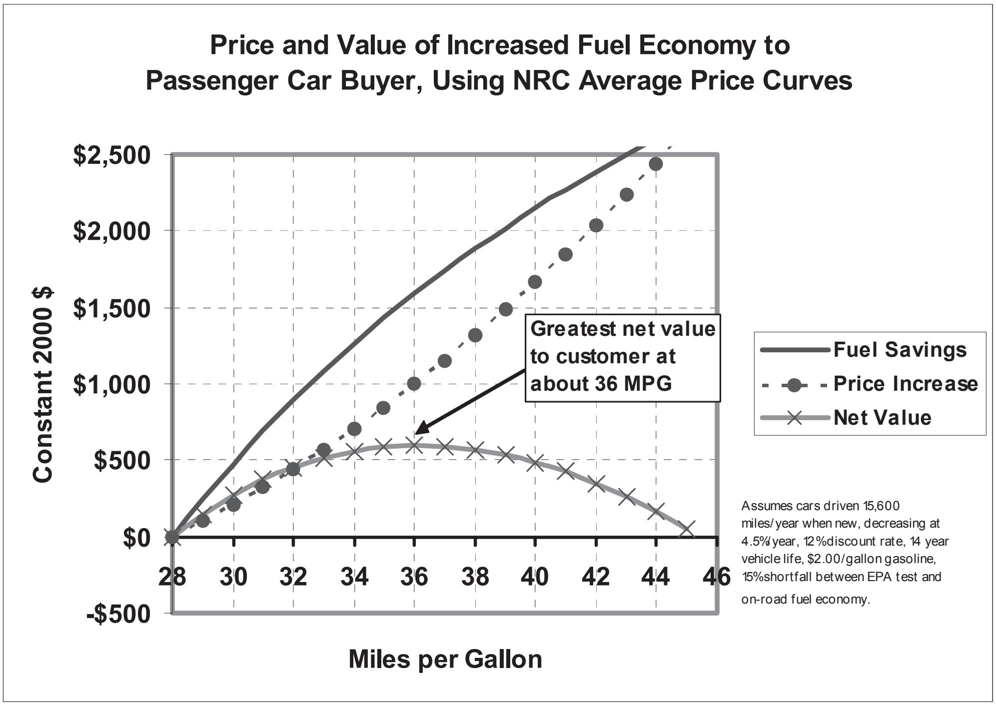
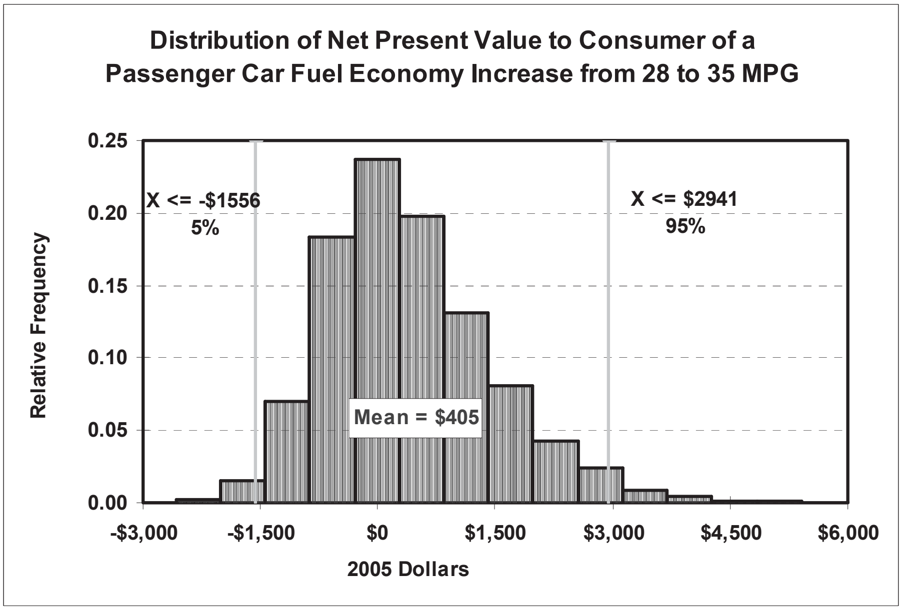


Figure 4. **Distribution of net present value to consumer of a passenger car fuel economy increase from 28 to 35 MPG**



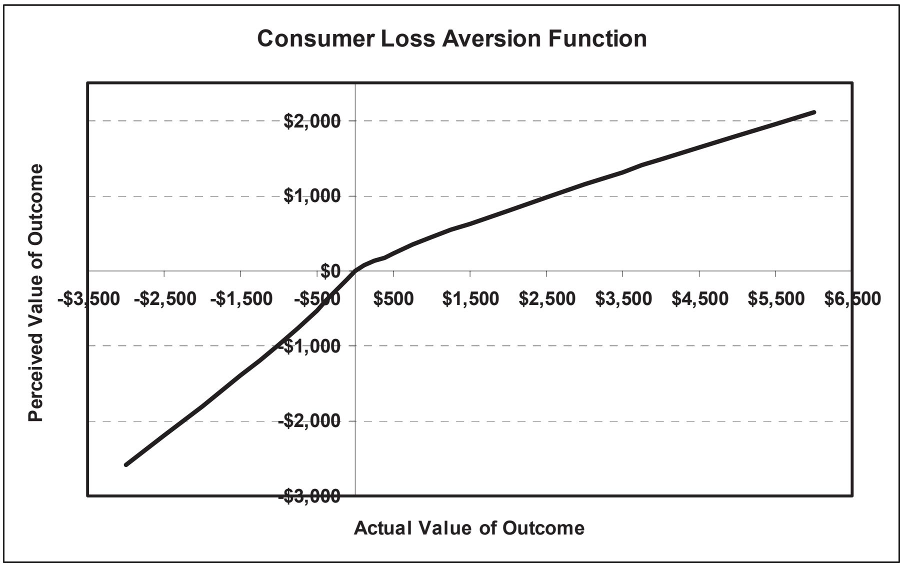
Behavioural economics has discovered several types of situations in which consumers' choices are not consistent with utility maximization. One of these is loss aversion, in which consumers define gains and losses relative to their status quo, weight losses approximately twice as much as gains, and exaggerate the probability of loss (DellaVigna, 2009; Gal, 2006; Tversky, Knetsch and Thaler, 1991). A typical loss aversion function estimated by Tversky and Khaneman (1992) is the following equation, illustrated in Figure 5:

Equation 3:

$$V(x) = \begin{matrix} x^{\alpha} & if \quad x \geq 0 \\ -\lambda(-x)^{\beta} & if \quad x < 0 \end{matrix}$$

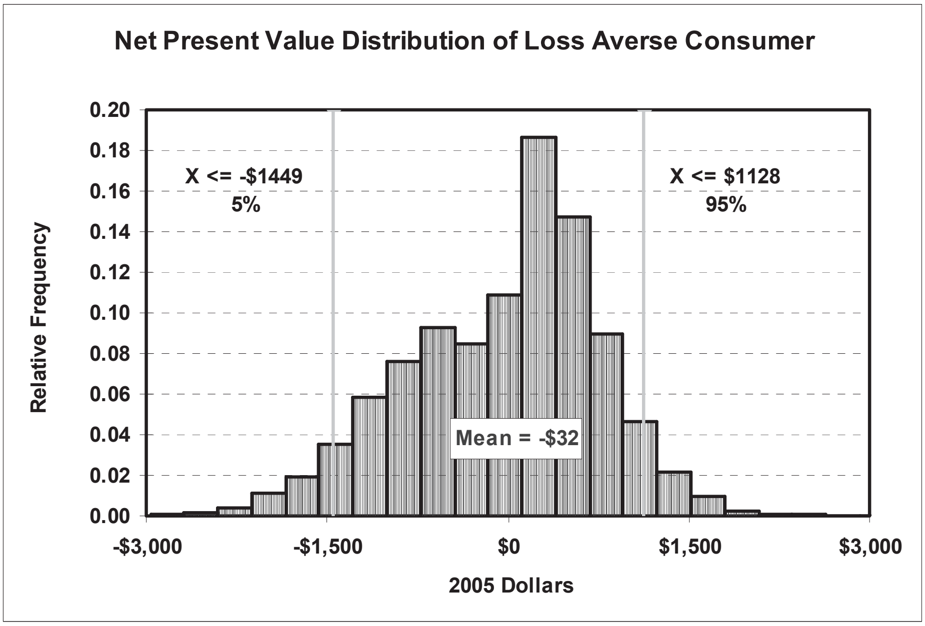
The variable x is the payoff of a risky choice and V is its utility or perceived value to the consumer. Note that this implies that V is not necessarily denominated in dollars, even when x is. Typical values for the loss aversion function coefficients are $\lambda = 2.25$, $\alpha = \beta = 0.88$ (Bernatzi and Thaler, 1995). The above loss aversion function is illustrated in Figure 4.

Figure 5. **Kahneman and Tversky's loss aversion function**



If the loss aversion function is applied to the probability distribution of future fuel savings shown in Figure 4, the result is a new probability distribution of the perceived utility of the bet. The mean of this distribution is not +$405 but -32 (again, although the axis of Figure 6 is labelled in $, the units are not the same as in Figure 4). In this example, it is not assumed that consumers have exaggerated the probability of loss, although that is generally the case. Clearly, that would further bias the perceived value of the risky bet toward loss.

Figure 6. **Perceived distribution of utility to loss averse consumer**

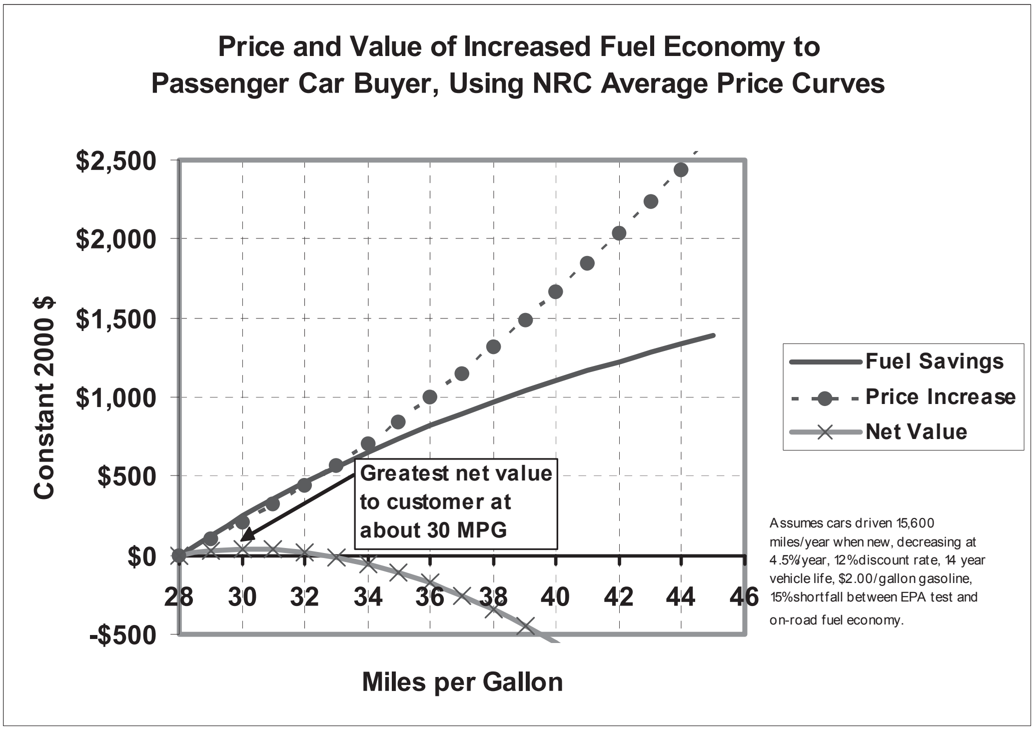


Improving passenger car fuel economy from 28 to 35 miles per gallon (8.4 l/100km to 6.7 l/100km) would appear, to an expected utility maximizing consumer, as a gain of $405. However, to a typical loss averse consumer, the improved fuel economy appears not as a gain but as a loss. If manufacturers correctly understand consumers' willingness to pay for fuel economy improvements, they would decline to adopt the technologies necessary to raise fuel economy to 35 MPG (6.7 l/100km). In fact, in the above example, there is no increase in fuel economy that gives a positive return to the loss averse consumer. This result is almost identical to the simple rule of thumb that consumers will pay for only three years of fuel savings. As illustrated in Figure 7, the three-year payback rule, applied to the same cost and present value calculations as in Figure 3, results in a nearly zero net value for even small fuel economy improvements.

Returning to the fact that it is manufacturers who act as consumers' agents in deciding which fuel economy technologies to adopt and how to design vehicles for fuel economy, the theory of uncertainty and loss aversion appears to be entirely consistent with their observations that consumers are willing to pay for only 2-4 years' worth of a potential fuel economy improvement. Even if the characterization of consumers' decision rule as a simple payback calculation is incorrect, as Turrentine and Kurani's (2007) research certainly suggests it is, it is nevertheless a useful rule of thumb in that it leads to the same conclusion.

Even if fuel prices are increased, uncertainty and loss aversion result in an undervaluing of fuel economy (Greene, 2010). If fuel prices were doubled, some fuel economy improvement would appear cost effective, even to the loss averse consumer. Manufacturers would presumably then increase fuel economy up to the level for which the loss averse consumer was willing to pay. But due to the increasing slope of the fuel economy cost curve, as fuel economy is increased further increases become more costly. Once fuel economy has been increased to the level for which the consumer is willing to pay, there is once again a significant potential for loss, which the consumer will overweight relative to the potential for gain. Thus, even in countries with relatively high fuel prices, loss aversion will still create a tendency to undervalue fuel savings. In countries with low fuel prices, such as the US and China, the undervaluing of fuel economy improvements can be very substantial, a factor of two or more (Greene, 2009b).

Figure 7. **Private cost and expected benefit of increasing passenger car fuel economy using a simple three-year payback rule**



Source: Greene, German and Delucchi (2009).

An important unresolved issue for the theory of loss aversion is how to carry out a welfare analysis of public policies when loss averse behaviour is prevalent. Unlike risk aversion, context dependent preferences are a central premise of the theory of loss aversion. Consumers evaluate gains and losses relative to their current reference point, i.e. their status quo. Once a bet is over, the consumer has a new status quo. If the consumer lost $100, the loss is $100, no more and no less. Likewise, if the consumer gained $100, it is a gain of $100. Although in the context of the risky bet the consumer behaves as though these amounts were different, once the bet is finished there is no reason for that context-dependent evaluation to persist. There is not yet a consensus in the literature on this point, however (Bateman *et al.*, 1997). If one accepts this line of reasoning, it implies that consumers forced to accept a risky bet on improved fuel economy would not suffer a welfare loss, on average, assuming that the expected value were a gain and that uncertainties were accurately characterized.

5. CONCLUDING OBSERVATIONS

The value that car buyers assign to increased fuel economy has important implications for policies to reduce greenhouse gas emissions and petroleum consumption. If consumers undervalue fuel economy improvements relative to their expected present value over the full life of a vehicle, the market will provide too little fuel economy and will under-invest in research and development of energy efficient technologies. In addition, policies that influence the market via purchase price, such as feebates, or regulatory policies such as fuel economy standards, will have greater leverage on fuel economy than fuel prices. Finally, if consumers undervalue fuel economy, such policies can increase private welfare as well as providing societal benefits. If consumers fully value fuel economy improvements, then the above assertions would be incorrect.

As important as it is to understand how the market for fuel economy really works, evidence from econometric studies is unfortunately contradictory and inconclusive. Peer-reviewed and grey literature studies provide support for sizeable undervaluation, significant overvaluation and everything in between. There is no definitive answer as to why this is so, but the complexity of the choice decision, difficulty in identifying and measuring all relevant variables, and consequent statistical problems caused by omitted variables, errors in variables and correlations among variables appear to be a part of the explanation. There is also reason to believe that the model of expected utility maximization via continuously trading off multiple vehicle attributes may be an inaccurate description of consumers' actual decision-making. This result is not unique to energy efficiency in the automotive market but seems to be a general characteristic of markets for energy-using consumer durable goods.

What little market research is publicly available is decisively against the rational economic model when it comes to fuel economy decision-making. Survey evidence indicates that consumers require short payback periods of 1.5 to 2.5 years. This is also consistent with anecdotal evidence from vehicle manufacturers, who cite payback periods of 2-4 years. The most detailed evidence on consumers' decision-making comes from a single study of 57 households in California. The researchers found no evidence of the rational economic model in households' decisions about fuel economy. Most of this evidence comes from the United States and it is not clear to what extent it applies to countries with much higher fuel prices. The theory of bounded rationality implies that if fuel prices are high enough to make fuel economy one of consumers' 3-5 top considerations, it may be considered in a manner closer to the rational economic model.

The more recent theories of behavioural economics may provide a more appropriate quantitative model. Behavioural economics has established that when faced with a risky bet, consumers exaggerate the probability of loss and weigh potential losses approximately twice as much as potential gains. Energy efficiency is a risky bet for consumers because of uncertainty about future fuel prices, the true in-use energy efficiencies of vehicles as opposed to their official ratings, future vehicle use, vehicle lifetime, and other factors. Uncertainty and loss aversion could explain consumers' lack of interest in quantifying potential future fuel savings and apparently short payback requirements. It may also explain manufacturers' reluctance to invest in increasing vehicle fuel economy. How to do welfare analysis of public policies under such conditions has not yet been resolved. Unlike the model of risk aversion, the theory of loss aversion allows the possibility that a risky bet that consumers would decline could actually increase wellbeing if it were imposed by regulations such as fuel economy standards.

Given the importance of the market for fuel economy, we know surprisingly little about how it functions in the real world. More fundamental research of the type reported by Turrentine and Kurani (2007) is needed. Alternative decision models need to be developed and tested. On balance, however, the available evidence suggests that the market for fuel economy does not operate efficiently according to the rational economic consumer model. At present, the theory of uncertainty and loss aversion may be the most consistent with the available evidence.

NOTE

1. The term "market failure" is unfortunate because the usual meaning of the word "failure" conveys a complete inability to perform a function. Market deficiency or imperfection are perhaps better terms.

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THE IMPACT OF ECONOMIC INSTRUMENTS ON THE AUTO INDUSTRY AND THE CONSEQUENCES OF FRAGMENTING MARKETS – FOCUS ON THE EU CASE

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SUMMARY

Paris, February 2010

1. ABSTRACT

For several years now, numerous states and regions have developed policies to reduce CO_2 emissions from the transport sector. More precisely, CO_2 emissions reductions from cars were in most cases the first target of these policies. Over the last two years, policymakers have tightened the rules currently in force and developed new regulations, in line with public concern about climate change and the growing importance of energy policies.

Policymakers can use a variety of instruments in implementing policies. We can identify in particular: regulations, taxation and incentive schemes, consumer information, or a combination of these.

This paper will focus on taxation issues addressing CO_2 emissions in the European Union. When observing the different systems in place, a very broad diversity appears, even with a cursory first glance. Actually, the diversity of taxation schemes among the Member States is such that it jeopardizes the concept of a Single Market in the European Union. Furthermore, this tax environment is not predictable. Even if the question of the efficiency of using such taxes to reduce CO_2 emissions is put to one side, cost-effectiveness is an important issue, including in terms of the consequences for vehicle and component manufacturers.

This paper is divided into three sections. First, the diversity of the schemes will be analysed in terms of intensity and predictability in order to identify the key consequences for manufacturers. This will be illustrated with different examples. The second section comprises a short description of how the OEM can deal with the diversity and unpredictability of taxation. In the third section, a specific analysis of policies addressing “electric vehicles (EVs) and very low CO_2 emitting vehicles” will be presented.

This paper is developed from a manufacturer’s rather than a policymaker’s perspective. It intends to give a practical understanding of the diversity of economic instruments from a manufacturer’s point of view and to examine how an OEM (Original Equipment Manufacturer) can try to manage this diversity. The paper does not attempt a complete political and economic evaluation of the various policy options, which would be a very complex exercise, considering the different and cumulative instruments applied simultaneously on car markets and the dynamics of the wider economic environment, including the impact of both the current economic crisis and the evolution of oil prices.

For manufacturers, the key issues regarding taxation are twofold:

– Mid- and long term, when defining the product plan and designing new vehicles and new powertrains: how to anticipate the fiscal environment of the vehicles in a time frame of up to 10 years, as CO_2 taxation will impact the competitiveness of the product, and even possibly accelerate its obsolescence; how fiscal measures and regulations will interact together; and how to arbitrate between costs and CO_2 performance of a car in a highly competitive market.

– Short term: how to prepare or adapt the marketing of vehicles in each country to CO_2 taxation, which weighs on the market and competition more than ever, with effects that differ with customers.

Key conclusions are:

– The current economic instruments applied in the EU do produce a strong environmental incentive, driving a decrease in CO_2 emissions of the new car fleet.

– The current fragmentation of regulations and taxes seriously complicates manufacturing decisions and represents a significant cost.

– Incentives should be designed to correlate as closely as possible to CO_2 and other aspects of the environmental performance of vehicles.

– In this very mature industry, new, innovative technologies will require extensive support from national governments, with legitimate potential benefits for climate change policies.

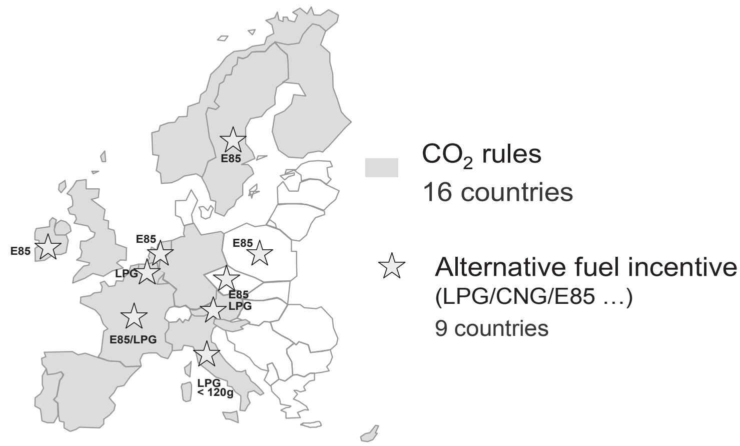
2. OVERVIEW OF FISCAL MEASURES IN THE EUROPEAN UNION FOR REDUCING CO_2 EMISSIONS FROM CONVENTIONAL CARS

2.1. Some elements of context

As from the beginning of 2010, 16 EU Member States have put in place one or several economic measures intended to reduce CO_2 emissions from cars. Most of them were introduced in the last three years.

A large number of these policy developments were simultaneous with, or close to the period where the EU regulation on car CO_2 emissions reductions was discussed and adopted, and close to the end of the Voluntary Commitments made by three car manufacturer associations in 1998-99. The Voluntary Commitments set a target of 140 g/km for the average CO_2 emissions of the new car fleet, by 2008 for ACEA, 2009 for JAMA and 2009 for KAMA. After agreeing the industry’s commitments, the Commission suggested in its recommendations that the Member States establish taxation schemes based on CO_2 emissions to provide a demand-side incentive for meeting the target; this was not effective at the beginning of the period of the commitments, as governments were slow to either differentiate existing taxes according to CO_2 emissions or introduce fee bates. Only much later did momentum build for tax differentiation, by which time it already appeared that a regulatory EU standard for CO_2 emissions was inevitable, in response to a period of slower than hoped for progress in reducing average CO_2 emissions from the new car fleet.

Figure 1. **European fiscal context on CO_2, beginning 2010**



It is also important to note that, in 2005, the Commission adopted (Community reference: COM(2005)0261/Final of 5 July 2005) a draft for a Directive on car taxation addressing CO_2 emissions, but finally this draft was never adopted by the European Council. *Vis-à-vis* CO_2, the draft contained two main elements: all or a major part of the taxation of cars should be based on the CO_2 emissions of the vehicle, and the taxes on vehicles should be based on ownership and annual taxes, rather than on purchase.

When analysing taxation and its effects, one should admit that 2008 and 2009 were not "normal years" with respect to the car market. The setting and the impacts of tax differentiation schemes cannot be analysed independently of two key elements – with deep impacts on the economy as a whole, on purchasing power, on key patterns of consumption, on mobility and on the car industry itself:

1. *The evolution of the oil price, with its impacts on fuel costs in 2008*. This element itself impacted purchasing patterns of both private and professional buyers, as it made clear that the part of fuel cost in mobility was highly variable and likely to increase. This certainly induced changes in the market, as consumers now bear in mind that the fuel price is an uncertain and major part of their transport costs. (Transport costs represent, on average, 12% to 15% of household consumption in the EU.)

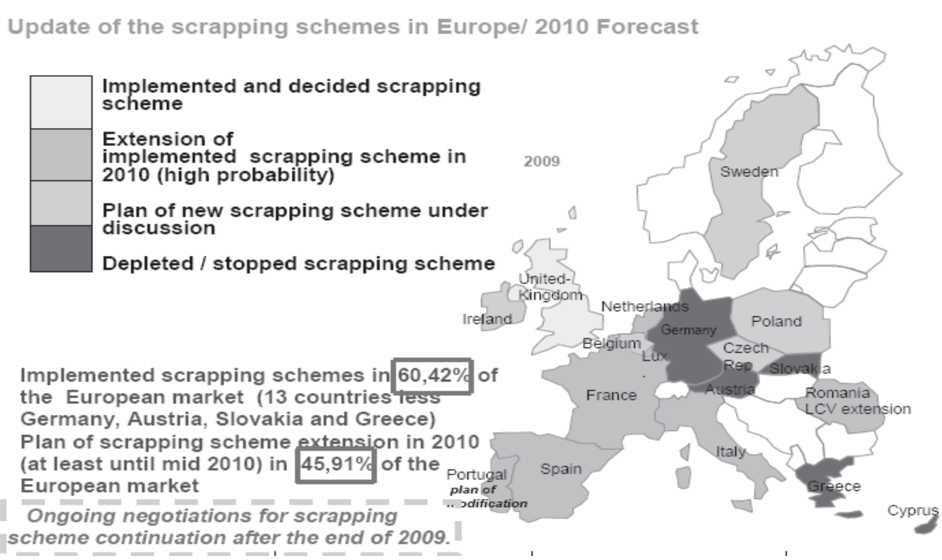
2. *The crisis in 2008-2009*, *with its direct impact on markets, distribution networks, industry and the economy as a whole, on purchasing power and on consumer confidence*. The crisis deeply affected the market and the automotive industry as a whole (see Table 1). Due to the importance of this sector for the economy, it forced governments to adopt specific measures to support distribution networks and the automotive industry – manufacturers and suppliers – in numerous countries in the EU. By mid-2009, 17 EU countries, representing more than 85% of the new car market, had specific schemes in place, some of them having decided on, and others still considering, extension of their measures in 2010. Many of these schemes took the form of incentives for purchasing a car and scrapping an old one; others took the form of loans for car purchase. They presented a large diversity in monetary value, criteria and duration.

Table 1. **Production of cars worldwide**
Comparison 3 quarters 2008-2009

CARS only	2008 Q 1+2+3	2009 Q 1+2+3	VARIATION 09/08		PdM 2009	Change PdM 09 / 08
EUROPE	**14 853 930**	**10 970 307**	**-26,1%**		**33,7%**	**-3,0%**
FRANCE	1 773 633	1 288 878	-27,3%		4,0%	-0,4%
GERMANY(1)	4 350 927	3 610 993	-17,0%		11,1%	+0,3%
ITALY	556 660	498 603	-10,4%		1,5%	+0,2%
ROMANIA	185 027	201 545	+8,9%		0,6%	+0,2%
TURKEY	**524 329**	**374 927**	**-28,5%**		**1,2%**	**-0,1%**
AMERICA	**7 224 017**	**4 901 673**	**-32,1%**		**15,1%**	**-2,8%**
- NAFTA	**4 789 546**	**2 730 427**	**-43,0%**		**8,4%**	**-3,5%**
USA	2 956 456	1 520 946	-48,6%		4,7%	-2,6%
SOUTH AMERICA	**2 434 471**	**2 171 246**	**-10,8%**		**6,7%**	**+0,6%**
ARGENTINA	315 445	257 276	-18,4%		0,8%	+0,0%
BRAZIL	2 096 618	1 898 486	-9,5%		5,8%	+0,6%
ASIA-OCEANIA	**18 083 252**	**16 525 265**	**-8,6%**		**50,8%**	**+6,0%**
CHINA	5 187 998	7 155 866	+37,9%		22,0%	+9,1%
INDIA	1 451 391	1 565 985	+7,9%		4,8%	+1,2%
JAPAN	7 699 319	4 709 218	-38,8%		14,5%	-4,6%
SOUTH KOREA	2 566 899	2 195 137	-14,5%		6,7%	+0,4%
AFRICA	**266 131**	**157 667**	**-40,8%**		**0,5%**	**-0,2%**
SOUTH AFRICA	243 462	155 402	-36,2%		0,5%	-0,1%
TOTAL	**40 427 330**	**32 554 912**	**-19,5%**		**100,0%**	**+0,0%**

Source: OICA.

Figure 2. **Scrappage schemes in EU, December 2009**



Source: Renault.

In summary, average CO_2 emissions from the new car fleet in the EU decreased in 2009 by 7 g/km, following a decrease of 5 g/km in 2008 compared to 2007 (*source*: AAA, preliminary data for 2009 that might be refined in the coming months). Compared to the trend over recent years, this represents a rapid acceleration. All the elements above – taxation, scrappage schemes, oil prices – have influenced this significant decrease in new car emissions.

When considering the different EU countries, we can observe in the 2006-2009 period very different evolutions in the emissions of new cars: from -24 to -7 g in absolute values, from 15% to 4% relative to 2006. Also we can still observe a very large range of CO_2 fleet average values, from 165 to 134 g/km in 2009 (this range narrowed from 45 g to 30 g in recent years). The ranking below is based on the percentage decrease in emissions between 2006 and 2009.

Table 2. **EU15 – Average fleet CO_2 value 2006-2009 and evolution (absolute and %)**

Country	A 06	A 07	A 08	A 09	Decrease 2009 - 2006	Decrease % 09/06
GRECE	169	167	163	162	7	4,3%
BELGIQUE	153	153	149	145	8	5,1%
ITALIE	149	147	146	141	8	5,3%
PORTUGAL	144	143	138	136	8	5,4%
LUXEMBOURG	165	164	160	155	10	6,1%
AUTRICHE	162	162	159	151	11	6,9%
ESPAGNE	156	157	152	145	11	7,2%
Europe 15	**161**	**159**	**154**	**147**	**14**	**8,7%**
ALLEMAGNE	172	170	165	154	18	10,4%
ROYAUME-UNI	167	164	159	150	17	10,4%
PAYS BAS	165	164	157	148	17	10,5%
FRANCE	150	149	140	134	16	10,5%
SUEDE	188	182	175	165	23	12,5%
FINLANDE	179	178	162	157	22	12,5%
IRLANDE	166	165	159	145	21	12,5%
DANEMARK	163	157	146	139	24	14,9%

Figure 3. **New car fleet, CO_2 average, 2006-2009; EU 15 average**

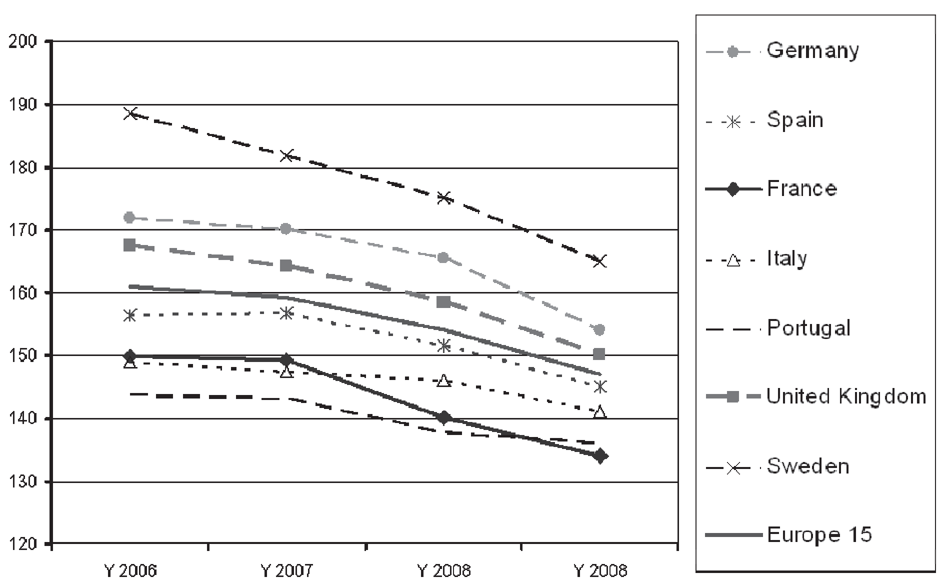
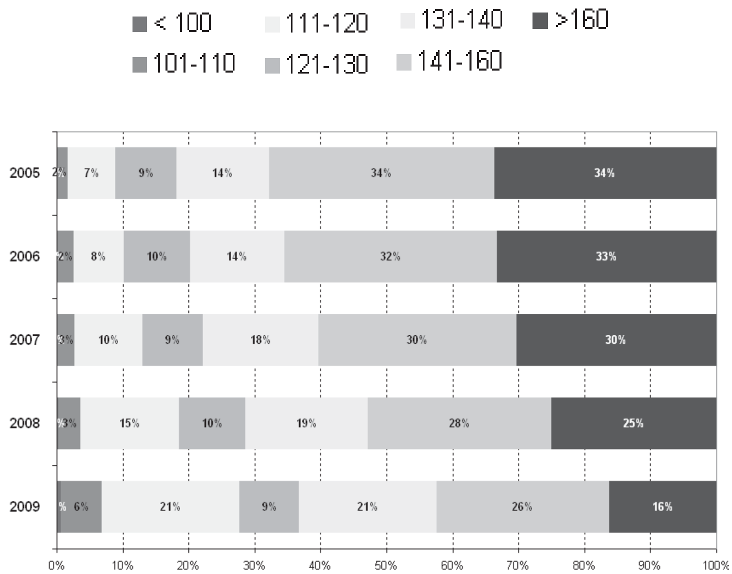


Figure 4. **New car fleet, CO_2 per class of CO_2, 2005-2009; 5 main EU countries, average**



2.2. Diversity of economic instruments addressing cars' CO_2 emissions

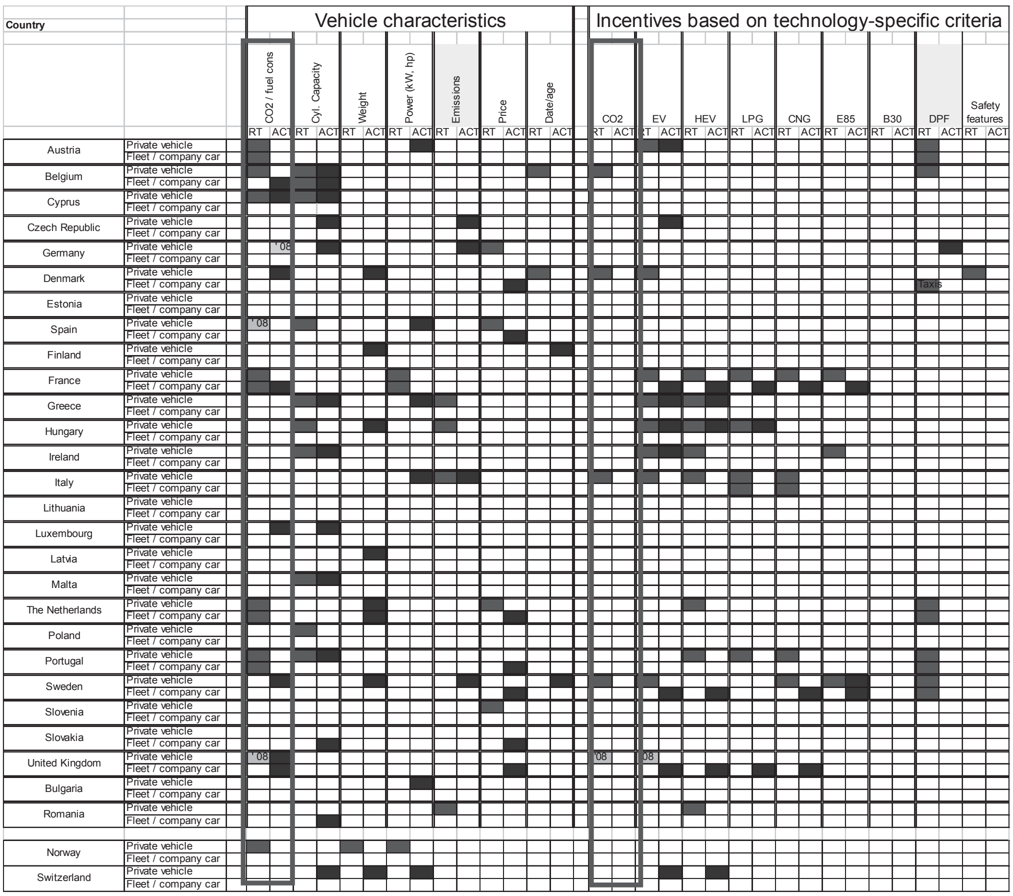
2.2.1 Overall development in recent years

Car taxation in the EU is very diverse and complex. As an illustration of this point, the table below indicates some of the criteria already used in 2007 for determining taxation for EU countries; this has since become even more complex.

The taxation specifically related to CO_2 emissions is in itself very complex: it associates numerous parameters that are managed independently by the EU Member States and which will be described below. It is also very unpredictable: Member States may change these parameters on a time-frame that is very short in comparison to product planning and industrial planning cycles for the car industry, or even compared to yearly sales and marketing planning.

This diversity, along with the high level of unpredictability, creates a real difficulty for manufacturers. Sixteen EU Member States have currently put in place one or several fiscal dispositions intending to reduce the CO_2 emissions of the car fleet. These elements were mainly adopted in the last three years. Their setting was quite simultaneous with, or close to, the period where the EU Regulation on car CO_2 emissions reductions was negotiated and adopted. When it agreed to the industry CO_2 commitments, the European Commission suggested that the Member States develop taxation schemes based on CO_2 emissions. Further to that, the Commission adopted in 2005 a draft for a directive relative to car taxation, addressing their CO_2 emissions, but no text was finally adopted by the Council due to objections from some of the States. *Vis-à-vis* CO_2, the draft contained two main elements: all or a major part of the taxation of cars should be based on the CO_2 emissions of the vehicle; and the taxes on vehicles should be based on ownership and annual taxes, rather than purchase.

Table 3



RT: Registration Tax
AT: Annual Circulation Tax

Comparing when EU Member States introduced their economic instruments addressing CO_2 emissions, some of them acted rather early (Portugal, France, the UK, the Netherlands), others have only just adopted or started implementing new schemes (Germany, Slovenia,…) and some are still only at the stage of contemplating or studying introduction. Those with a scheme in place implemented them progressively.

2.2.2 Criteria for CO_2 taxes and incentives

Independently of measures adopted to address the crisis, the diversity of forms of CO_2-based taxes and incentives is obvious. The criteria on which incentives are based can be categorised as follows:

- Form of taxes on conventional cars: on new cars at purchase (Registration Tax, RT), on the fleet (Annual Circulation Taxes, ACT) or on usage (Fuel taxes, Carbon Tax; in the future, "pay as you drive" or even possibly "congestion charges"). (We do not deal with taxes related to registration of second-hand cars here, with specific issues for imported vehicles.)

- The move from RT to ACT, which was a target of the draft directive of the Commission related to car taxation, is not generally seen as a result of the changes in taxation.

- Instead, countries tend to retain their existing systems of taxation and replace parameters like engine capacity or price with taxes based on CO_2, totally or partially (Portugal, The Netherlands, Germany, for instance).

– Who bears the cost of the tax?: the owner in most cases, the user in some cases (i.e. UK company car tax). But note that different types of customer for the same segment or product can bear a very different level of tax in the case of company cars.

– What is the basis for establishing the monetary level of the tax paid? The criteria for CO_2 is quite systematically the CO_2 certification value corresponding to the NEDC (New European Driving Cycle) used for type approval of new vehicles. The value itself can depend only on the CO_2, or on a calculation that can include the price – or the engine capacity in some cases, even if this criteria is becoming less frequent:

- The value of the tax/incentive is directly related to tested CO_2 emissions ratings in France, the UK and Portugal. (Progressive implementation, initially a tax based on engine capacity only.)

- The tax is a percentage of the price determined by CO_2 emissions ratings in Spain, the Netherlands (progressive implementation) and Belgium.

- The rate of tax is determined by a mix of criteria such as CO_2 and engine capacity; an example is the new taxation scheme in Germany.

– The system can be "fuel neutral", or otherwise:

- The system can be based specifically on the CO_2 certification value, which is neutral *vis à vis* fuels, or differentiated among fuels. This adds much complexity for manufacturers: very different fuel mixes exist among EU Member States, even at segment level, independently of differences in fuel prices.

- This policy choice, fuel neutral taxation or not, is often driven by considerations of non-CO_2 emissions. We can anticipate that the difference in non-CO_2 emissions between gasoline and diesel ought to narrow in the future with Euro 5 and Euro 6 standards.

In terms of format, these systems are not linear and rarely continuous. Most of them include thresholds, with sometimes highly discriminating gaps when passing from one band to the next (i.e. on registration taxes: for instance, up to 1 000 EUR in France, up to 1 500 EUR in Spain for a 30 000 EUR car passing a threshold adding 5% to the tax rate). These thresholds are not co-ordinated among Member States at all. They create strong discrimination between products and versions of vehicles, and are the source of an extreme diversity in EU markets. They are one of the most complex issues for manufacturers because of the following factors:

– Optimisation in the different countries is quite impossible, as it requires specific adaptations of the vehicles;

- No, or limited, visibility exists on these thresholds, except for some countries. Therefore, product planning cannot be established on the basis of a robust scenario related to taxation and incentives, including for relatively low-volume products like LPG or CNG requiring specific investments -- a current example: discussions in Italy on thresholds for CNG and LPG, and for a scrappage scheme.

- Such thresholds can have a very strong effect on consumers, who either want to reduce the cost of vehicle ownership and usage, or in some cases place a specific importance on avoiding paying a tax, in particular if the threshold acts as a "lower trigger" for the tax; you pay nothing if you are below, you pay the full tax if you are above the threshold. This is the case in the Netherlands and Germany, and to a lesser extent in France and Spain.

- The way they impact the market is very uneven between the different car segments of a given market, as well as on a given segment between the different markets.

  - In the case where a significant threshold cuts a product segment in two parts, it can fully orient demand to the lower CO_2 vehicles.

  - When thresholds are established or changed, they can cause versions or even the model line to become instantaneously unmarketable. Such policy instruments may accelerate the obsolescence of products, and manufacturing capacities for vehicles or engines.

- Some examples of thresholds:

  - *Spain*: Registration tax rate of 0%, 5%, 10%, 15% of the price of the car, depending on the CO_2 value: lower than 120g; between 121 and 159, or 160 and 199 g; or higher than 199 g.

  - *France*: the different fiscal instruments on cars – TVTS (ACT for company cars), bonus/malus, technology incentive for HEV/LPG/CNG among others – have thresholds. (Note: the thresholds of the Bonus/Malus, the TVTS and for CO_2 labelling are not the same, and they do not evolve consistently; this complicates communication towards customers on CO_2.)

  - *Germany*: continuous ACT, but a low trigger, that significantly influences competition in the lower (A/B/C) classes.

- A number of specific cases for passenger cars (M1 vehicles) among EU countries:

  - Technology incentives for hybrid or alternative energies (CNG, LPG in particular) that are sometimes very high and directed to specific products, with or without CO_2 criteria.

  - Specific incentives on cars compatible with certain biofuels or on environmentally friendly vehicles.

  - Exemption of taxes or fees related to the usage of the vehicles; i.e. exemption for "clean vehicles" from the congestion charge in London or from the public parking fee and congestion charge in Stockholm.

– Additionally, Light Commercial Vehicles (LCV/N1 vehicles) are, so far, rarely subject to CO_2 taxation in the EU. For professional users, the importance of the cost of usage, whichever way they assess it, and the share of fuel cost in the global cost ownership create a strong incentive towards fuel economy for LCVs. Therefore CO_2 taxation of the LCV/N1 segment would not have as great an effect in stimulating fuel efficiency as for private cars. In the EU, some small LCV vehicles and the powertrains of most of the LCV are derivates of M1 vehicles/powertrains, and benefit from their improvements directly.

2.2.3 Great diversity in the intensity of tax incentives

From a manufacturer's perspective, two key parameters emerge from a taxation scheme: the overall level of the taxation and the intensity of the CO_2 differentiation. The rhythm of evolution varies also along Member States. The net effect on markets and customers results from the sum of these intensities combined with fuel prices, which also depend on taxes and vary quite widely between countries and between fuels.

Overall level of taxation

Depending on the country, the level of average tax per vehicle can vary considerably, as well as the level of CO_2 tax. Examples:

– Some countries have particularly high registration taxes that are not CO_2- related: Denmark and Greece, for example.

– In the Netherlands, the average level of RT is high; it combines a high percentage (27.4% in 2010) of the retail price, elements related to energy and emissions, and a share based on CO_2 that will progressively increase. This is also the case of the RT in Portugal that is indexed on CO_2 mainly.

– On the contrary, in France, the only heavy economic instrument that applies to cars owned by private customers is a registration fee/rebate. The "bonus/malus" system eventually led in 2009 to a public expenditure of more than 500 million EUR, equivalent to 0.5 % of the total turnover of the new car market.

CO_2-related or not, the large differences in levels of tax affect the manufacturers in terms of product development and marketing, as they modify the retail price of the same vehicle from one country to another, and therefore the mix of products and fuels demanded, as well as the rhythm of renewal of the fleet. To illustrate and quantify this effect, in the Renault case, two examples based on the above-mentioned countries follow:

– The taxes on a Twingo (gasoline version /1.2 l/120 g/km) range in 2010 from a bonus of 700 EUR (France) to a cost of 1 800 EUR (NL), including a CO_2 part of 340 EUR. The total difference of 2 500 EUR for a car of around 10 000 EUR, that is, 25% of the basic retail price, makes the marketing of this simple vehicle very different in the two countries.

– The same year, the taxes on a Scenic (diesel version /1.4 l/135 g/km) are in a range of 0 EUR (France) or 120 EUR (UK) to 7 500 EUR (NL), i.e. 30% of the basic retail price of the car.

Intensity of CO_2 differentiation

This parameter is of utmost importance, as it drives the choice at the point of purchase, and can even drive the decision to purchase a new car to replace an existing high emission vehicle: whether the differentiation is strong or not, it impacts the choice of new cars, with various ways of evaluation by customers.

Comparison of incentives cannot be direct because of the wide differences between national systems. But starting from estimations of the slope in EUR/g of CO_2 at certification, one way to compare incentives consists in defining the equivalence of a taxation in EUR per tonnene of CO_2 saved, on the basis of some simplifying assumptions: taking a range of CO_2 values covering most of the market, i.e. 100 to 200 g/km, for cars driven mileages of 200 000 km over the average vehicle life-time and 15 000 km/year. This does not take into account effects of thresholds on specific segments or products, but allows a first, simple comparison among countries and between measures.

Measures exist already that are very intense and highly discriminating in the market. In some cases, they correspond to a value of the tonne of CO_2 much higher than in current trading systems, and up to EUR 1 000. In summary:

– Spain, Portugal and the Netherlands apply, on average, high registration taxes, with significant intensity amplified by thresholds making their effect stronger and uneven among segments.

– France and the UK apply high company-car taxes, in a range of EUR 1000/tonne. While the intensity in France is quite even among segments, this may not be the case in the UK, with a high intensity on upper segments resulting from the application through personal income taxes.

Some examples:

– In France, the purchase bonus/malus is a registration tax equivalent to 150 EUR/tonne, and the TVTS tax on company cars (paid by the companies) reaches EUR 3 400/year for vehicles emitting 200 g/km, and even EUR 2 400/year for those emitting 160 g/km. It is equivalent to EUR 1 000/tonnes of CO_2.

– In the Netherlands, a complex registration tax scheme is being introduced progressively, with a CO_2 share that is today equivalent to 200 EUR/tonne, but that will become three times higher by 2013. For a gasoline car, this CO_2 part is today EUR 0 for CO_2 if $CO_2 \leq$ 110g, EUR 2 400 if CO_2 = 180 g, EUR 7 000 if $CO_2 \sim$ 220g; and in 2013, EUR 7 000 if $CO_2 \sim$ 180 g.

– In Portugal, where the registration tax based now on CO_2 and engine capacity reaches EUR 10 000 for a diesel car emitting 200 g/km, the intensity of the RT is estimated as high as ~ 500 EUR/tonne on diesel and ~ 300 EUR/tonne on gasoline.

This level of differentiation: (1) may change in time – this was the case in Portugal, with a progressive shift from a tax based on engine capacity and energy to a CO_2-based one; and (2) has to be appreciated in connection with other taxes/incentives applying in the country, as some of them have settled a package of measures, including different tax policies on fuels.

2.2.4 Technology incentives

Depending on national policies, we can identify technology incentives in particular for hybrid vehicles. As a matter of principle, technology incentives are not generally supported by manufacturers, because they discriminate among technologies without considering their actual efficiency, and because they may impede the development of other, possibly more promising, technologies in competition with those benefiting from the incentives. (Issues related to very low CO_2 and electric vehicles are developed in Section 3.)

In some cases, evaluating the value of the CO_2 attached to these incentives reveals very high levels (France: EUR 2 000 for a hybrid car corresponds to more than 600 EUR/tonne of CO_2, compared to similarly CO_2-efficient vehicles, when comparing CO_2 emissions with life-time usage).

A large diversity of such incentives exists in the EU, with a wide range of values. This diversity does not help the development of these cars. Market penetration is low and the product offer has been slow to develop despite high levels of incentive: these policies are not very effective.

Furthermore, the potential of technology incentives for CO_2 improvement remains questionable in the EU where a majority of the market is for small and medium-sized cars, with already a high CO_2 efficiency and quite low prices. In such conditions, massive CO_2 reductions rely basically on improving the CO_2 efficiency of conventional vehicles, with technologies that are affordable, in a very competitive market where prices are the major deciding factor for most customers and fuel efficiency the second most important criterion.

2.3. Visibility or not?

2.3.1 Why visibility is crucial for manufacturers

For manufacturers, taxation becomes a major driver regarding product planning, marketing, manufacturing investment and production:

- in the mid- and long term, when defining the product plan and designing new vehicles and powertrains: how to anticipate the fiscal environment of the vehicles in a time frame up to 10 years is crucial, as CO_2 taxation will impact the competitiveness of the product or possibly render some products unsellable. How fiscal measures and regulations will interact together is also key;

- in the short term, when preparing the marketing of the vehicles in each country, as CO_2 taxation now weighs on the market and competition more than ever, and in different ways depending on customers.

2.3.2 Unpredictable procedures

Depending on the countries and the kinds of measures, the legal form of schemes can be very different. This form can be either a law or another form of government decision, such as a decree. As an example, in France, the "bonus/malus" system requires two different texts: a law, adopted under the annual fiscal law, for the "malus", which is a tax and a decree for the "bonus", which is not a tax but an incentive and does not need a law in order to be set up.

Lack of visibility is a direct consequence of this diversity in the nature of texts and procedures. Car taxation, as with other laws related to taxation, is often established or revised in the annual fiscal budget under the full control of parliament. This procedure means that manufacturers only receive the information belatedly, and it remains subject to last-minute changes, in some cases after adoption of the budget in principle. Other government initiatives can render the preparation of measures more transparent.

In some cases, due to the nature of the measure, the government may delay the announcement of its intentions; this can even happen in agreement with manufacturers and distributors if the measure is expected to have a strong, negative impact on the market. In Spain, a new format for the registration tax, to be applied as from January 2009, was announced in September 2008, and manufacturers were required to offer compensation to new car buyers until the end of 2008, for a future bonus for lower CO_2 emitters.

2.3.3 Improvements to visibility: dates and thresholds

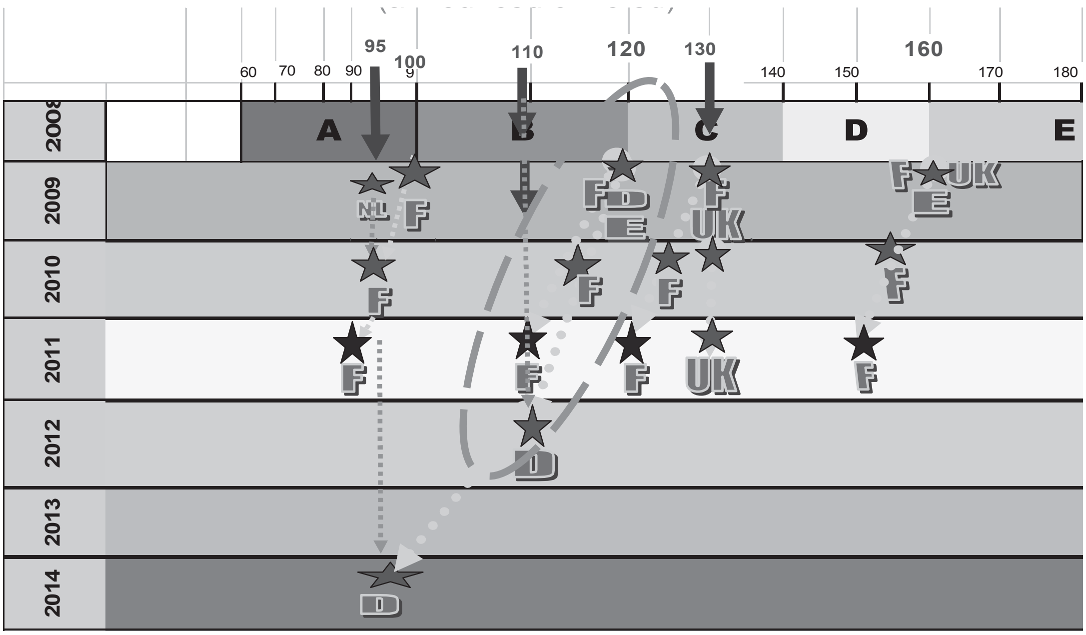
From a manufacturer's perspective, predictability is vital. Manufacturers experience the most predictability in a strong policy setting, and the countries below have announced plans for their schemes in advance:

- Germany: up to 2014.
- The Netherlands: elements announced up to 2013.
- France: from 2008 to 2012.
- UK: from March 2011 to March 2014.

In these cases, the key thresholds structuring the schemes have been defined for several years (see Figure 5 below). But note that, for instance, France has recently modified elements (values and, more important for manufacturers, thresholds) that were fixed end-2007 for application in 2012, in order to limit the cost of the "bonus/malus" system to the State. In the end, there is no such thing as full regulatory certainty for these schemes.

It is also worth mentioning that some convergence is apparent on lower thresholds, which might have been influenced by the 2020 target value adopted in the EU regulation on car CO_2 emissions reduction – a target of 95g/km, subject to review before it becomes binding. Several countries use 95 g/km as a criterion in their taxation, in the same way as some countries earlier used 120 g/km, as a point of reference. The graph below indicates how the thresholds in some key EU countries will move, between 2008 and 2014, insofar as they are defined today.

Figure 5. **Thresholds sliding in France, UK, Germany, the Netherlands**
(announced or voted)



2.4. Why this diversity?

Without contesting the total sovereignty of European Member States for fiscal and taxation policy, this diversity merits question. To date, the bodies and institutions with legal rights in regard to taxation have worked without considering that their individual policies would totally fragment the market, with a risk for the possible efficiency and effectiveness of their CO_2 policies, or at least of high costs for the industry.

2.4.1 European level

With the exception of the 2005 draft directive, the European Commission has not appeared to consider convergence among Member States to be important. The draft directive contained three items:

- Move taxation of vehicles from current criteria to CO_2 emissions, with reference to the type approval test certification value;
- Use annual taxes on vehicles rather than purchase taxes; this is considered by many politicians to be more effective towards CO_2 emissions reductions, and more consistent with the Single Market;
- Install a system of compensation payments when people move from one EU Member State to another, in order not to impair the free mobility of goods in the Union.

This third, very specific item relative to the Single Market probably made the Commission's proposal unnecessarily complex, and did not help during the later discussions.

While manufacturers systematically requested that the diversity of taxation schemes across the EU be reduced, they did not obtain any support, in particular from EU bodies, for such a reduction. In terms of institutional procedure, one way forward could be through a sufficient number of countries accepting to establish "concerted co-operation".

2.4.2 National developments

In some cases, a fiscal scheme based on CO_2 has been developed as a continuation of an existing system. This is particularly the case in Portugal and to a lesser extent in Spain, with a shift from one previous criterion, often engine capacity, to CO_2. Therefore, the earlier diversity among countries continues even if they modify their schemes.

However, in a number of countries, the CO_2 scheme was developed independently of a previous system. This was the case in France, Belgium and Slovenia. In these cases, systems were established without any concern for consistency or similarities with other countries, thus leading to this vast diversity of schemes.

2.4.3 Regional implications

Additionally, other diversities sometimes appear at regional level. This leads to even more fragmented markets, with quite unique specificities.

In Belgium, there is one system at the national level and another at the level of the Wallon region.

In some countries, taxes rates differ by region. This most often concerns registration taxes but generally differences are not very significant. However, this may have some impacts at the marketing level for distribution companies.

2.5. Specific and new domains of taxation on vehicles

In addition to the above items, there are other elements subject to economic incentives or taxes, with an impact on the orientation of markets. These cover alternative fuel vehicles and taxation of fuels, in particular in connection with biofuels. These two items impact significantly on manufacturers because they require specific development of engines, with resource implications. The visibility of these policies is rather low, and they correspond to national choices creating further significant fragmentation in the EU market.

2.5.1 Alternative fuel vehicles

Numerous countries have specific incentives for alternative fuel vehicles, without any common scheme, resulting in a very fragmented market among the EU states. The continuation and ending of such schemes is a permanent uncertainty, in particular when state budgets are constrained drastically.

The motivations for Member States to develop these fuels are either:

– energy diversification, in particular in countries that have specific energy resources; or

- environmental benefits. It is to be noted that certain alternative fuels allowed significantly lower polluting emissions in the past, but the difference with conventional fuels was reduced after introduction of the new Euro standards.

Alternative-fuel vehicles remain not actually marginal, but represent low volumes in these countries in most cases. It is difficult for manufacturers:

- to anticipate which policies the Member States will implement, and to what extent these policies will be robust and continuous, leading to a viable market or not, with several examples of aborted alternative fuel policies (biofuels, CNG, LPG);

- to arbitrate in their development of engines, in a context of limited resources both in the work force and for investment. Eventually, they are forced to adopt strategies limiting market risks, which may be far from optimal.

2.5.2 Energies, biofuels taxation developments

Road fuel taxation brings in important tax revenue for EU Member States, with commonly two-thirds to three-quarters of the final fuel price being made up of taxes. Fuel prices vary considerably, however, between countries, with specific policies and exemptions adapting to national situations, i.e. lower-than-average purchasing power, or specific dependency on road transport for essential citizen mobility, or national energy sourcing policies. Depending on the country, differences among fuel prices, i.e. between gasoline and diesel, or between LPG and gasoline, can vary significantly among countries, some having specific policies for or against a given fuel, beyond average fuel taxation.

Fuel prices directly influence the cost of vehicle use, and are therefore an important criterion for customers, while manufacturers permanently monitor and forecast them in order to assess their impact on the competitiveness of their products.

The purpose here is not to oppose fuel taxation, which is unavoidable for various reasons, but to reaffirm that a minimum of visibility on fuel prices and consistency within the European Union regarding the taxation of the different fuels is important for manufacturers, independently of the impacts of oil price variations. This parameter indeed directs the balance between types of powertrain on the market, sometimes over the short term, and manufacturers feel the impacts in terms of both engineering and marketing.

The overall tax rates on the major fuels do not usually show strong variations over time in most countries but the oil price itself strongly adds to the instability of fuel prices. Regarding taxes on and the price of road fuel, three evolutions are currently possible, which eventually would have significant impacts.

Taxes supporting biofuels

Consistent with EU climate policy, Member States are implementing policies to develop biofuels. Without expanding on the controversial subject of biofuels, or on the car technology aspects related to them, it is worth mentioning that:

- There is no common or visible policy in the EU in regard to these fuels, except for average incorporation targets to be met at national level;

- The existing standards for biofuels, in particular for blending biodiesels in diesel fuel, are insufficient to guarantee a sufficient fuel quality;

- As a consequence, various fuels, not always fulfilling all standards, are already distributed in the EU, and manufacturers are forced to develop their product offer without being able to anticipate the future development of the market. Examples are B 7 and even B 20 or E 10, which are available in some countries.

- In some countries, biofuel development policy relies on tax/penalty systems that ultimately increase fuel prices: for example in France, where the UFIP (*Union Française des Industries Pétrolières*, French Federation of Oil Industries) indicated that prices would increase by 0.02 to 0.03 EUR/litre in 2010.

Commission draft amending the Directive on Energy Taxation

Current taxation of energy in the EU is based on a specific Directive (2003/96/CE) from 2003, which fixes minimum taxation levels for each type of fuel. The Commission is currently preparing a draft revision of that Directive, with a view to aligning taxation with the overall CO_2 emissions reduction policy.

Some elements have already been discussed. In particular, the taxation of road fuels would be based on two parameters: the carbon content and the energy content of the fuel, on a volumetric basis. A progressive alignment of national taxation would therefore be required.

This evolution would lead to a significant increase in diesel prices, which is counterproductive to CO_2 emissions reduction. Basically, taxing road fuels on the basis of energy/litre or carbon/litre disregards the significantly (15 to 20%) higher energy efficiency and energy density of diesel. Even if the performance of gasoline vehicles is expected to improve in the coming years through new injection technologies, they are not expected to equal the performance of diesel.

This revision of the Energy Directive might therefore induce significant changes in the medium term in fuel prices; this would add to the difficulties experienced by manufacturers in their planning and investments for reducing CO_2 emissions.

Carbon tax

Several EU Member States have set or are setting "carbon taxes" that also weigh on fuel prices: Sweden, Denmark, Finland, and now France. The concept consists in applying an additional tax, correlated with the CO_2 emissions of the energy used by the consumer. This is an additional price signal for CO_2 emissions reduction. Exceptions exist: for example, industries, including those eligible for inclusion in the European Emissions Trading System (ETS), can be exempted.

This tax raises several issues:

- Competition effects compared to imported products. It should be considered, however, that this would not be the only regulation possibly creating distortions of competition and hampering the competitiveness of the EU.

- Visibility for economic operators, either in the energy supply or with energy-intensive activities. In France, the initial level is set at 17 EUR/tonnes of CO_2, but the initial recommendation was for more than 30 EUR/tonne, and it might reach much higher figures in the middle of the decade.

2.6. Some elements of their effects and some concrete examples

2.6.1 The effects of economic instruments on CO_2 emissions

As mentioned in the introduction, after a certain stagnation since the middle of the decade, average CO_2 emissions from new passenger cars have decreased in the EU since 2007 much more quickly than previously. They decreased by 7 g/km in 2009 compared to 2008, and by 5 g/km in 2008 compared to 2007 (*source*: AAA, preliminary data for 2009, which might be refined in the coming months). Compared to the previous trend, this is a rapid acceleration, as the decrease was previously close to 1 g/year.

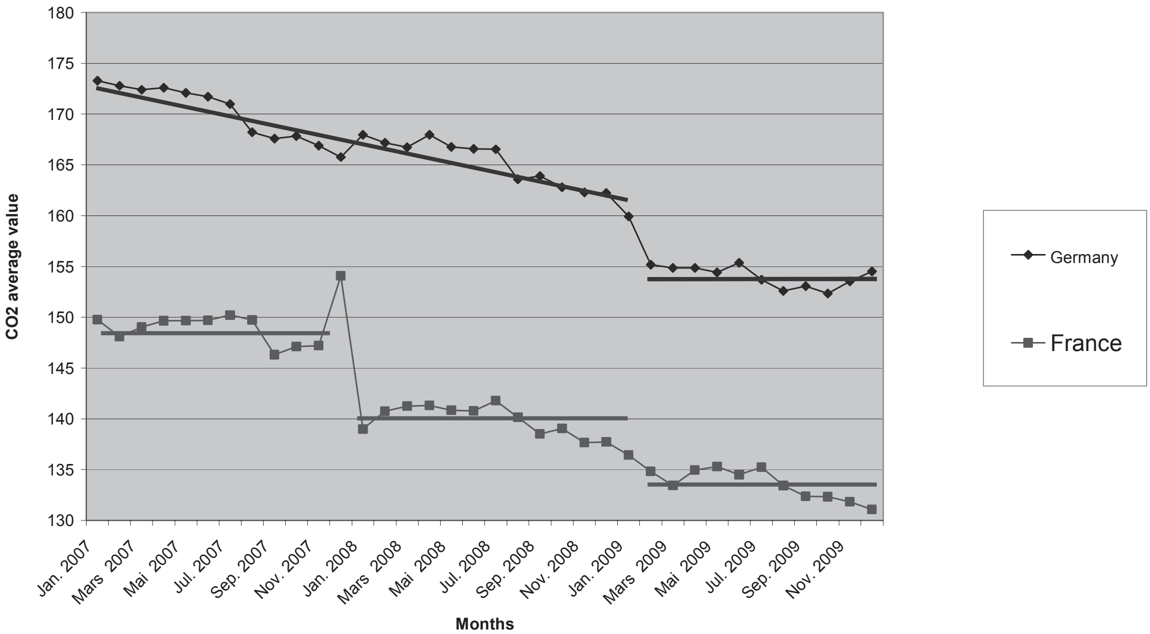
All the elements above – taxation, scrappage scheme, oil prices – have contributed to this significant decrease, and the contribution of each of them is not directly measurable. However, in some countries, several direct effects can be appraised. Two examples are given below, based on monthly average CO_2 figures (see Figure 6).

In Germany, while a significant decreasing trend was visible over 2007-2008, a gap of about 8 g/km can be observed at the setting of the scrappage scheme in early 2009, even if the scheme was not based on CO_2. It will be of interest to monitor how CO_2 will evolve when this measure ends.

In France, the introduction of the bonus/malus and the setting of the scrappage scheme at the end of 2008 are visible, even in a car market with already very low average CO_2 emissions: about 9 g for the bonus-malus, with an additional 6 g for the scrappage scheme.

In both cases, the decrease was mainly linked with a change in technologies. It can be estimated that in 2006-2009, improvements in technology were responsible for approximately two-thirds of the CO_2 reduction in Germany, and three-quarters of the improvement in France, the remainder coming from the change in product mix in the market. What cannot be identified among these decreases is the effect of fuel prices, in particular with the peak of Summer 2008.

Figure 6. **Monthly evolution of CO2 G and F, 2007-2009**



2.6.2 France: multiple developments since 2007, a complex imbroglio

France has introduced several new instruments since 2007. Before this period and since 2002, there was neither a purchase nor an annual circulation tax, only a limited registration tax. The current package of taxes treats private owners and companies on a different basis due to a very significant additional tax on companies.

France has defined a target for the total vehicle fleet on the roads of 120 g/km in 2020, compared to approximately 180 g/km in 2007. The different measures are designed with a view to reaching that level.

Table 4 summarizes the key tax elements that apply to gasoline and diesel passenger cars:

Table 4

	2006	2009	2010	Projections
TIPP (60 ct / l)	*200 € / t*	*200 € /t*	*200 € / t*	*Risk with consumption reduction?*
TVTS on company cars		*1000 € / t*	*1000 € / t*	*Maintain revenues?*
Bonus / Malus	*0*	*150 € / t*	*150 € / t*	*Continuity / reinforcement and thresholds' evolution?*
Carbon Tax	*0*	*0*	*17 € / t*	*35 € / ton in 2012 and 60 to 100 € / ton in 2020?*
Total without TVTS *Total with TVTS*	*200 € / t* *200 € / t*	*350 € / t* *1350 € / t*	*370 € / t* *1370 € / t*	

2007: TVTS

The annual TVTS tax applies to passenger cars (M1) owned by companies, with various, total or partial exemptions (i.e. single person or small companies). It replaced an earlier tax in 2007 that was based mainly on the "*puissance fiscale*" (administrative power), a coefficient based on a mix of Engine Power and CO_2 emissions, that discriminated between vehicles relatively lightly, with a threshold approximately in the D class. TVTS is exclusively based on CO_2.

It is highly discriminating as, on the overall market, it is equivalent to EUR 1000/tonne of CO_2 (100 g/km → 400 EUR/year; 200 g/km → 3 400 EUR/year). Furthermore, it is strongly discontinuous, with steps of 800 EUR/year at 160 g, and 700 EUR at 140 g.

It slightly reduced sales of D/E classes (upper and upper-medium class cars) in its first year. Combined, from 2008 onwards, with the bonus/malus, it has since significantly impacted upper category car sales, and changed policies towards company cars in large businesses.

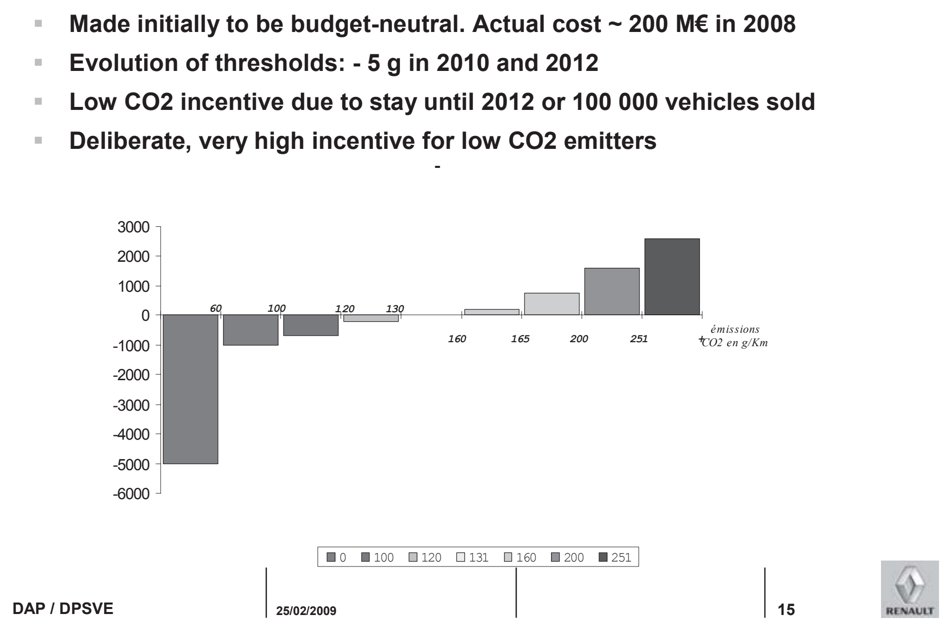
TVTS makes no distinction between diesel and gasoline, with the consequence that almost all vehicles sold in D and upper E classes are now diesel fuelled.

2008: Bonus/malus

This "penalty and incentive" (or fee-bate) purchase tax was introduced on 01/01/2008, following the "*Grenelle de l'Environnement*" of 2007, a broad consultative political forum that addressed numerous environmental policies. The measure was designed to cover an initial period from 2008 to 2012, with a lowering of all the thresholds set by 5 g/ km every two years to preserve incentives and fiscal balance as the new car fleet adapts. Lowering the thresholds has been brought forward; the average CO_2 emissions from new cars has fallen faster than anticipated, creating a significant budgetary cost.

Bonuses and penalty charges apply upon registration of new M1 vehicles. They are set as absolute values that depend only on the CO_2 type approval test emissions figure. Charges range from a bonus payment of 1 000 EUR for cars rated < 100 g/km, to a fee of 2 600 EUR for cars rated > 250 g/km. A bonus payment of 5 000 EUR applies for M1 and N1 vehicles with a CO_2 emissions value below 60 g/km.

Figure 7. **France: 2008 Bonus-Malus System**



The incentive provided by the bonus/malus system is broadly equivalent to 150 EUR/tonne of CO_2. But the thresholds, with large bonus or tax steps, have caused major shifts in the market, with (1) downsizing in the segment mix; (2) downsizing in power; and (3) a move to diesel in certain segments, as the system is based on CO_2 certification values. The share of diesel engines in the new car market has attained more than 70%.

The system demonstrated high effectiveness: in 2008, CO_2 emissions from new vehicles in France fell by 9 g compared to 2007, falling from 149 g/km to 140 g/km, most of the decrease resulting from the bonus/malus system. The measure has turned out to have a net cost for the State, as the shift in the market was higher than anticipated: the budgetary cost was ~EUR 200 million in 2008 and ~EUR 500 million in 2009. The measure successfully helped stimulate the market for low carbon vehicles, but created too great a change in the mix of products, with cost implications for industry.

2009: Scrappage scheme with CO_2 criterion

Due to the economic crisis, France introduced a car scrappage scheme at the end of 2008, which was quite early compared to other EU countries. One criterion for access to a 1 000 EUR subsidy for the purchase of a new car was CO_2 emissions of below 160 g/km.

In 2009, CO_2 emissions in France reduced by 6 g compared to 2007, from 140 to 134 g (the lowest level in the EU).

During the year with this scrappage measure, the market increased in volume (+10.7%) while segment mix and CO_2 emissions significantly declined. But it is not certain that the CO_2 threshold itself actually had an effect, as the other CO_2 measures already existed, and beneficiaries of the bonus/ malus system were essentially buying low-range cars also eligible under the scrapping incentive.

2010: A carbon tax, still under consideration for 2010

The law to introduce a carbon tax, agreed at the *Grenelle de l'Environnement*, was passed by parliament but its introduction has been delayed by the Constitutional Council, not for reasons of principle but because its implementation would add to the cost of car use.

Other economic instruments: technology incentives, biofuels, additional CO_2 malus

- A technology incentive of 2 000 EUR for hybrid (HEV), CNG and LPG cars, with CO_2 emissions below 140 g/km;

- Biofuel measures for E 85 and first-generation biofuels, driven by a target for biofuels to comprise 7.5% of auto fuel sales (by energy content) in 2010. For the EU, the target is 5.75%. Measures to ensure compliance include financial penalties for distributors. This has resulted in (limited) fuel price increases in 2009 and possibly in 2010;

- In addition to the bonus/malus system at registration, an annual malus was introduced in 2009 for vehicles with CO_2 emissions higher than 250 g/km. However, the share of such vehicles in France is extremely limited, less than 2% of sales, and the effectiveness of the measure can therefore be questioned.

Effects on CO_2 and on the market?

The chart below presents the evolution of the car market by segment in France in recent years. A significant downward trend is obvious, starting in 2008. The share of "D and above" cars fell from ~22% to ~16%, the share of A+B increased from 46% to 58%.

While environmental effects are well identified with CO_2 reductions there are also other important impacts:

– Economic effects, as the average price of vehicles fell 8% between 2007 and 2009;

– Industrial effects for local manufacturers, in plants that were producing "D and above" cars;

– To a certain extent, trade balance effects as, for reasons of competition, local manufacturers had relocated production of A and B cars to other countries.

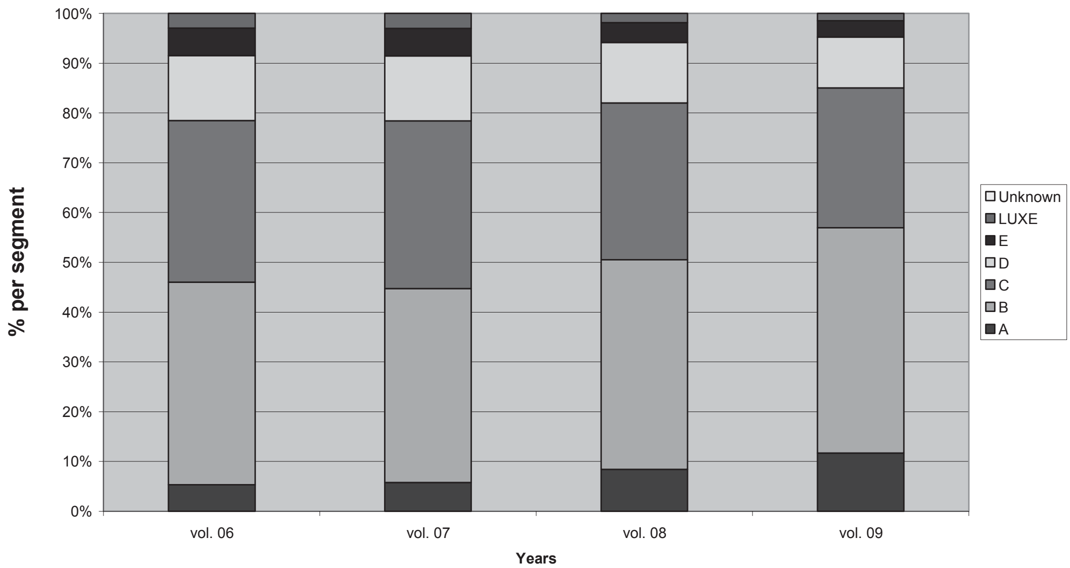
To be noted: the scrappage scheme in France (1 000 EUR for the purchase of a new car emitting less than 160 g/km and the scrapping of a car older than 10 years) had a very positive effect on the volume of cars sold, with the 2009 new car market up 11% on 2008.

How might these taxes evolve?

With the range of economic instruments introduced in the past three years, the question of their evolution is crucial for car manufacturers, and particularly those for which France is a major market.

The bonus/malus system is planned to keep its current configuration until 2012. This stability is very helpful, despite the recent decision to advance the date for lowering the limit values. For other components of the package there is no indication of the extent to which they will remain unchanged, or be strengthened; and if strengthened, by how much. Manufacturers have to analyse the possible evolution of these instruments at their own risk (see 3.2).

Figure 8. **Evolution of the mix of sales on 2006-2009: France**



2.6.3 Germany: a long-awaited, cautiously prepared evolution of the current scheme

Former system

German car taxation formerly relied on an annual circulation tax, proportional to engine capacity, the value of which is correlated with the emissions standards and fuel type, with significantly higher taxes for diesel vehicles. No company car tax exists in Germany, a major difference to France and the UK.

The rate of the tax is linked to the Euro emissions class of the vehicle and effectively links it to the age of the vehicle, as Euro standards are revised every few years. The tax therefore provided an incentive for renewing the oldest vehicles.

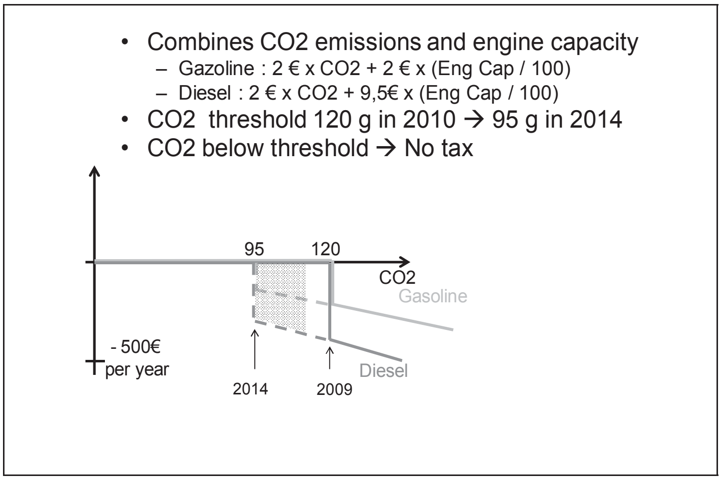
New system

The new tax systems rely on both CO_2 and engine capacity, with a differentiation between diesel and gasoline. The CO_2 part remains relatively low compared to the part related to engine capacity, in particular for diesel vehicles.

A threshold acts as a “trigger”: vehicles below that level pay no tax at all. This threshold starts at a level of 120 g/km and will decrease with time, to 95 g/km in 2014. This provides visibility until 2014. Except for the threshold, the scheme provides linear incentives.

Looking at the way this scheme will function for manufacturers, the threshold will discriminate only between segments and products that reach it and those that do not: in the short term, A, B and C. Some higher range vehicles may fall below the threshold in the future (Hybrids or Plug-in Hybrid Electric Vehicles) that might anyway be more expensive. This scheme might therefore strongly increase the competition in the lower range of products, eliminating those that exceed the trigger value, with a potential effect of "dieselization" in that segment.

Figure 9. **Germany: New Annual Circulation Tax**



2009 scrappage scheme

In response to the economic crisis, a car scrappage and replacement scheme was introduced in 2009, which had a powerful effect in boosting sales on the German market:

– Support was provided for the purchase of 2 million vehicles, leading to a new car market of 3.8 million, whereas initial forecasts were in the order of 3 million vehicles.

– There was a strong impact on the mix of vehicles sold, with A+B cars close to 40%, compared to below 25% in previous years, and "D and above" below 30% instead of nearly 40% of the market, with corresponding impacts on manufacturers' economic and industrial organisation.

– Comparing the second half of 2008 to the average for the year 2009, we observe a decrease of 9 g/km in the specific CO_2 emissions of new vehicles sold.

Figure 10. **Germany: Monthly average CO2 emissions – mid 2008 to end 2009**

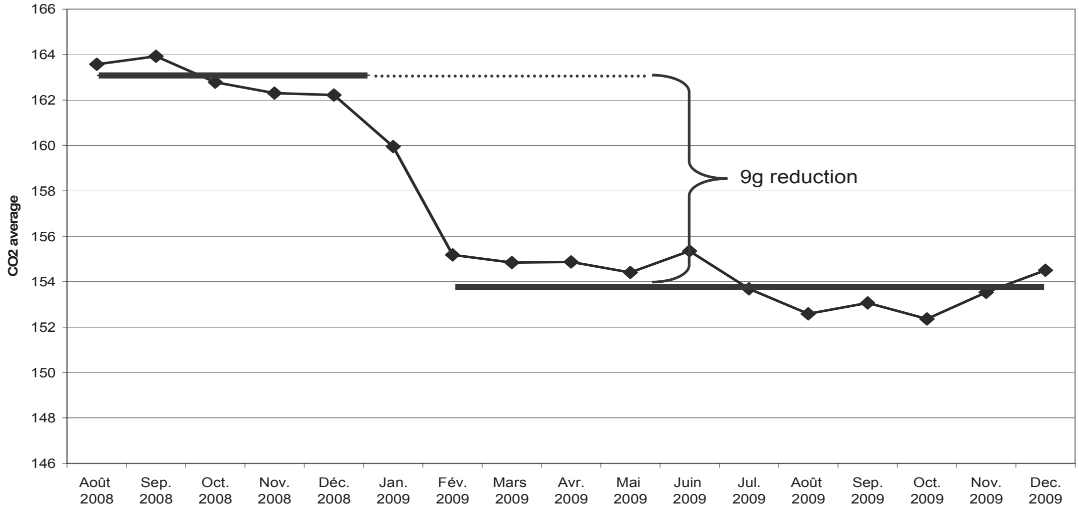
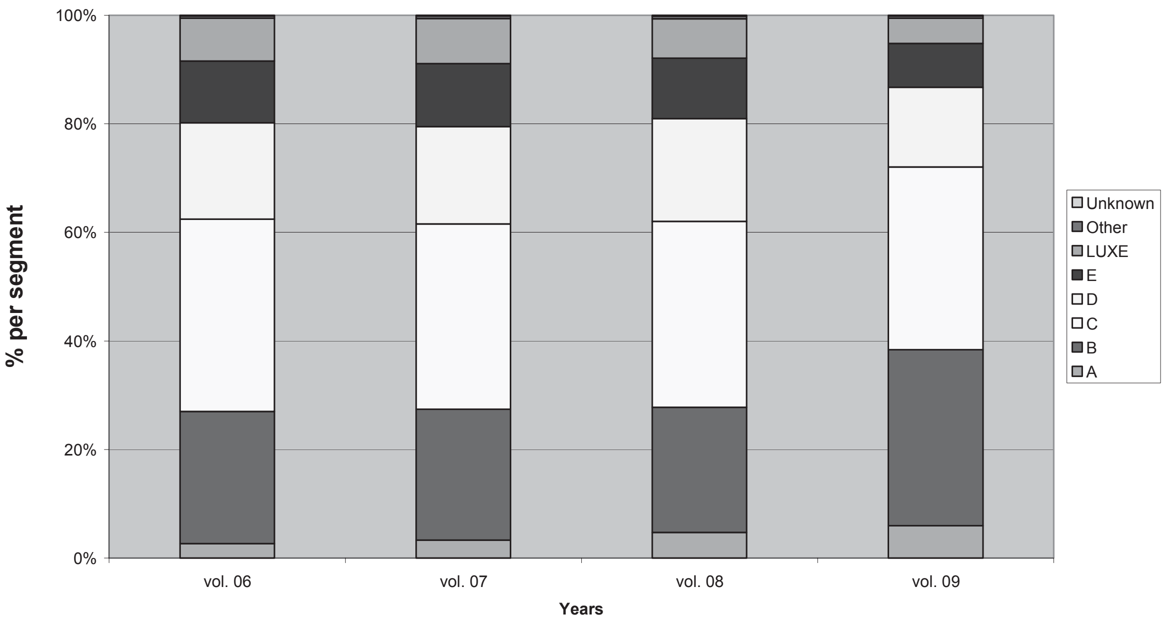


Figure 11. **Evolution of the mix of sales, 2006-2009: Germany**



2.6.4 UK: a strengthening of the current ACT and a tough company car tax

Two elements characterise car taxation in the UK: an annual circulation tax and a company car tax.

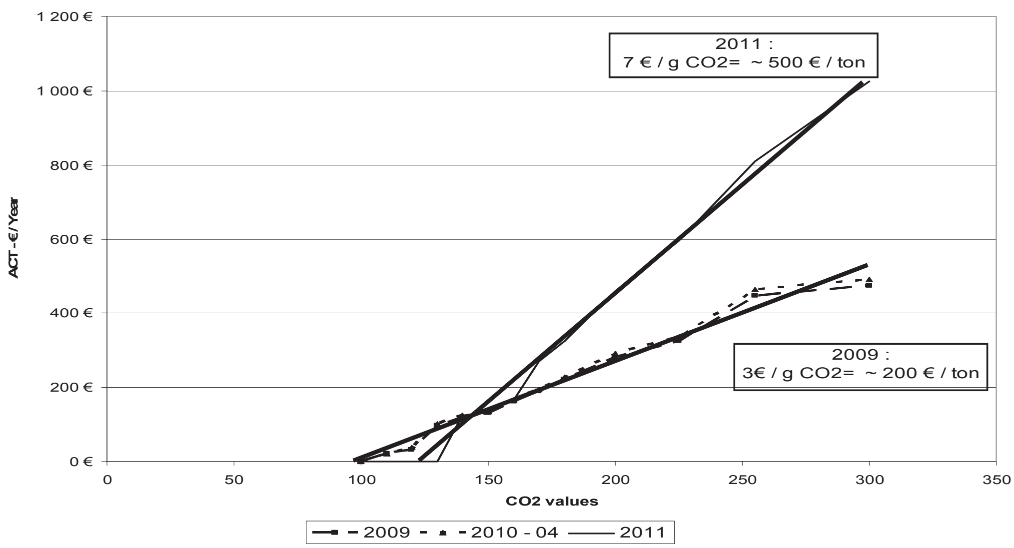
The annual circulation tax is scheduled to be significantly reinforced for vehicles first registered in 2010, especially for vehicles rated above 160 g/km.

Currently, the ACT has increased progressively from 100 g/km to beyond 255 g/km, with the slope of the increase corresponding to approximately EUR 3/g, that is equivalent to ~ EUR 200/tonne (see Figure 12 below).

The threshold for the new scheme has been increased to 130 g/km with a significantly steeper slope, corresponding to approximately EUR 7/g, equivalent to ~EUR 500/tonne.

Company car tax in the UK applies on the person benefiting from use of the vehicle. Its calculation depends on the retail price of the vehicle, on its CO_2 emissions and on the income tax band to which the beneficiary is subject, which depends in turn on revenue. Making some assumptions for these parameters, the intensity of car company tax is estimated on average at around ~ EUR 1 000/tonne, but is significantly lower on smaller vehicles and higher on D and upper segments.

Figure 12. **UK: Annual Circulation Tax Evolution**



2.6.5 The Netherlands announce several steps towards a radical change in road pricing until 2013

For several years, the Netherlands has implemented environmental policies for cars with a strong influence on the market. Several instruments are employed, including a labelling scheme and a tax on high CO_2 emitters. The main instrument is a registration tax (BPM) as well as an annual circulation tax (MRB). In the last three years, average emissions from new cars sold decreased by 17 g, from 165 g/km to 148 g/km.

Overall taxation is high compared to other EU countries, France and Germany in particular. The registration tax system is shifting from a tax based on the retail price to a tax based only on CO_2 with a high intensity. The change will be implemented progressively between 2009 and 2013. BPM was set at a basic rate of 40.2% in 2009. In 2010 this was reduced to 27.4%, with the difference taken up by a

CO_2 element. The average intensity based on the CO_2 share is expected to grow from ~150 to ~500 EUR/tonne CO_2 between 2009 and 2013,

The annual circulation tax will increase in the coming years, and the Netherlands is considering moving to a kilometre-based, so-called “pay as you drive” tax.

The system is currently strongly divided between diesel and gasoline vehicles, with significantly higher taxes on diesel; this distinction will continue and increase in the future. The system is characterised by a “trigger” threshold of 110 g/km for gasoline and 95 g/km for diesel.

If vehicles are under that threshold, they are not subject to the tax (27.4% of the retail price plus CO_2 charge). Therefore the trigger effect produces vehicles that are in fact fuel efficient but, when just above the CO_2 threshold, unmarketable.

2.6.6 Other countries with interesting features

Portugal

Portugal has developed its registration tax with a progressive shift of the basis of taxation from engine capacity to CO_2 emissions, with a high diesel/gasoline differentiation. The CO_2 incentive is intense, pushing products with medium or high CO_2 emissions out of the market.

Purchasing tax on a diesel car emitting 200 g is as high as EUR 10 000. At these levels, some products are no longer marketable and some customers cannot afford products to meet their requirements. The intensity of the Portuguese registration tax corresponds approximately to EUR 500/tonne, which is very high in relation to the modest purchasing power of the population.

Spain

At the end of 2008, Spain introduced a new registration tax. The previous system was based on engine capacity classes; the new system is based on CO_2 classes, with more differentiation. It is difficult to analyse the effect in 2009 due to the crisis that strongly affected the market, but 2009 showed renewed improvement in CO_2 emissions from new cars (2006-2008: -4 g; 2008-2009: -7 g).

Belgium

Without entering into details, it is worth mentioning that the two Belgian regions have each adopted different fiscal rules in relation to CO_2. This makes the selling of vehicles in that small market more complex and the rules possibly less efficient.

2.7. Conclusions

In summary, taxes can be a powerful tool to reduce CO_2 emissions but, as they are not managed with a view to harmonization in the EU, they render the idea of a single market for cars in the Union meaningless. They generate high costs and perturb manufacturers’ planning to such an extent that cost-effectiveness is seriously undermined.

In terms of the effect on competition, models that are brand new and recently engineered can benefit from CO_2 incentives as long as they fall the right side of thresholds and steps in the system of incentives. Consider now a manufacturer selling in a particular country a model engineered some years ago but still with a planned life-time of several years. New tax rules may force either additional investment to adapt the car, or a decision to stop the sales of the model there. In either case, the manufacturer will endure an economic loss on that model as a result of a tax that was unknown at the time the car was designed. This is an example of an unpredictable, very severe change that accelerates drastically the obsolescence of vehicles, with negative economic and commercial impacts on the Original Equipment Manufacturer (OEM).

Taxes impact manufacturers very differently, depending on their mix of products, of customers and of the markets in which they operate. They cause CO_2 competition particularly in the lower vehicle ranges, which tend to be more price-sensitive. In some cases, high taxes favour upper-range vehicles, as customers for these vehicles have fewer budgetary constraints.

Manufacturers accept taxation on the basis of CO_2 emissions, but contest the way taxes have been implemented nationally with a diversity that generates economic inefficiency, and not only from an industry perspective. What is required of CO_2 taxation is linearity, continuity, transparency and harmonization.

3. HOW CAN OEMs MANAGE THE TAXATION?

Markets are now strongly orientated by the very diverse economic instruments implemented by a majority of Member States in the EU. Three issues require attention in analysing how manufacturers respond: how customers behave in response to taxation, how manufacturers adapt in the short term, how manufacturers try to adapt to uncertainty over the evolution of taxes in the future.

3.1. Diverse customers with very diverse behaviours in relation to CO_2 incentives

3.1.1 Customer diversity

The first issue for manufacturers is to analyse how customers will evaluate taxation and incentives related to CO_2 emissions in their purchasing decision process, in addition to the effect of the fuel costs, which are also CO_2 related.

Professional users and leasing companies are “simple customers”:

- They base their assessments on systematic, predictable, rigorous assessment processes, including all the costs of usage of the vehicle and assumptions on the resale value based on statistics. The resale value also depends to a degree on fuel consumption and fuel prices.

- They base this assessment on given ownership duration and mileage. In their assessment, they usually include what they know about current taxation, and about future values if available.

– Most of the professional users and leasing companies keep their vehicles for about three years, in order to optimize the resale or buy-back value against maintenance costs.

In contrast, private users are "very diverse and complicated customers":

– They do not have precise assessment methods, and have very different ownership duration and mileage patterns, which vary by country and product segment.

– They tend not to weigh annual taxation and even fuel consumption over their total ownership period in their purchase decisions, which makes registration taxes much more important in their decisions than fuel or annual taxes.

– More importantly, for most of the buyers of lower-range and economical cars, the purchase price will outweigh a fully rational, economic assessment, in an EU market where competition is very broad and price competition on these products very stiff.

– The economic situation of buyers strongly influences purchase patterns, in particular when considerations of social status play a role.

3.1.2 The impact of economic instruments

CO_2 vehicle tax incentives affect costs for motorists in EU markets as much as fuel prices. In other words, a consumer purchasing a car should assume on average that CO_2 taxes can cost as much as fuel tax. But if this is valid on average, some customers may pay no tax beyond fuel tax, while others may have to multiply what they pay in taxes by more than three or four to arrive at what they will pay in fuel tax and CO_2 vehicle tax together.

3.1.3 Diversity of customers in relation to price and affordability

In lower segments, the dominant purchase criterion for customers is price. This leads the large number of manufacturers competing on the lower range of the market to fight firstly on costs, to optimise the affordability of their products. Upper segments are driven by performances, safety, technology and, to a lesser extent, overall cost of ownership and use more than price, in particular for company cars.

As a consequence, in countries that have adopted high intensity CO_2 taxation, there is more response in upper range cars with versions strongly improved regarding CO_2 emissions, sometimes at significant additional cost with the price premium off-set by taxation benefits. Rapid improvement of upper range vehicles is a significant trend that will merits attention in CO_2 monitoring in the future).

3.2. How to adapt in the short term

3.2.1 Continuous monitoring of taxation in all countries

Due to the weight of the economic instruments on markets and their unpredictability, manufacturers must continuously monitor policy in the EU countries. They can rely either on consulting companies for this service, or use their own organisations and distribution networks. Results are considered commercially sensitive.

This kind of monitoring may involve different departments of OEMs in particular finance and public affairs departments. Depending on the size of the country, on whether the OEM is important or not, in particular whether he has industrial activities, the monitoring can be easier.

One recurrent difficulty is qualifying the accuracy of information as the process from proposal to entry into force of a new tax is often long and uncertain. When marketing or engineering decisions are dependent on a new tax or changes to an existing tax accuracy is critical and requires sufficient understanding of the decision making process and of the grounds for the taxation. Some decisions are hidden and made in a very short time, others are the result of a long public consultation process. Examples of both are cited above.

3.2.2 Short term adaptation to taxation

Industrial lead-times are well understood and vary little. With current trends in regulation, and to respond to the economic crisis, the engineering departments of OEMs have significant workloads, if they are not overloaded. Challenges include Euro 5/6 regulations, CO_2 regulation requiring thermal engine downsizing and new emission control technologies. OEMs can adapt their products, but rarely have a large potential for adapting to short term changes that hamper product competitiveness. In some markets where the volume to production of a vehicle or a version is limited, there is no economic justification for an engineering investment to adapt the vehicle to new regulations.

To a certain extent, manufacturers are forced to adjust to short-term changes in taxation. Several responses are possible: changes in the mix of the products or in the mix of versions within a product line; increase or decrease of manufacturing capacities; adjustment of retail prices or commercial policy. In these cases, taxation's role as an economic agent determining company behaviour is direct and profits decline if products do not fit the new market conditions.

Not only is there an effect on product margins but on engineering and industry planning costs. This makes unpredictability in changes in taxation a significant burden on industry, and in particular on OEMs more involved in the lower range of the market where cost and price competition reduces the flexibility to anticipate changes.

3.3. How to deal with economic instruments in the future?

3.3.1 Projections

Looking at products entering the product planning and the engineering departments today:

- Their sales will start in three years, end of 2012/beginning of 2013, at the time of the start of implementation of EU CO_2 emissions standards for fleet average of new cars (130 g/km from 2012 with a phase-in period to 2015).

- Their sales will end, normally, 6 to 7 years later, close to 2020. This is the date for the long term target for average new car fleet emissions in the EU, set at a level of 95 g/km, associated with penalties of 95 EUR/g/km for each vehicle, equivalent to ~ 500 EUR/tonne of CO_2 approximately.

This illustrates how the car landscape might evolve in the next ten years, with high risks for OEM in particular regarding the commercial life of their products: if taxation and oil prices increase significantly, products might become obsolete much quicker than in previous periods, with significant consequences for profitability and industrial restructuring.

Economic instruments have demonstrated their effectiveness in the EU market, particularly over the past two years: they significantly oriented the market towards low CO_2 emitting vehicles, accelerating the trend in reducing average new car emissions. They acted in parallel with other key drivers: the crisis, measures to support industry pass through the crisis, oil prices, the growing awareness of citizens and consumers about climate change and oil price risks.

These different criteria will continue to weigh on the market and fuel competition. Among these drivers, taxations and incentives related to CO_2 may become dominant. No one anticipates a weakening of policies to limit CO_2 emissions from transport.

Manufacturers must define their product and technology policies with very thorough economic assessment and complex arbitrages: they have limited resources; the competitiveness of the market does not allow for overburdening the cost of producing vehicles, particularly in low range segments. Therefore, manufacturers must anticipate the potential impact of economic instruments over the longer term, and try to protect themselves against the uncertainties that result from these public policies.

3.3.2 Own appraisal of possible changes

For a manufacturer, its evaluation of the future evolution of taxation is confidential and has competitive value, as it drives product, technology and marketing strategy. When looking at the CO_2 strategies of OEMs for products launched over the past two years, very different strategies can be identified, some of which benefit greatly from recent tax changes. This is particularly visible for groups operating in upper segments with more flexibility on prices.

Because information on potential changes is not available, some car manufacturers elaborate scenarios for future taxation, to provide guidelines for the engineering of future products. When analyzing potential evolution of taxation in a country, different criteria can be taken into account, depending on local circumstances:

- Factors for the continuity of policies, in terms of schemes and levels of taxation: stability of revenues for the State, management of the cost of mobility for citizens that is politically sensitive, importance of the car industry in the country.

- Factors for increasing the stringency of the policies: climate policies; potential increase need for tax revenues (but even maintaining tax revenues may require increased stringency as products change and markets shift to lower carbon vehicles; energy policy and trade balance; willingness to progressively restrict individual mobility for several reasons encompassing various environmental and transport concerns.

Significant changes in the structure of taxes are very difficult to anticipate, and can require more lead-time for their implementation than simpler tax evolutions. This is true of new policies like the future introduction of congestion charging. This does not mean that all severe changes can be anticipated. In France, the TVTS, stringent Company Car tax, was defined late in 2006 for quite immediate implementation.

In general manufacturers do not anticipate a decrease in the intensity of the CO_2 taxation, and consider that a progressive increase in the overall taxation on CO_2 will be driven by both the strengthening of climate policies and compensation for an overall reduction in fuel consumption in transport.

4. ECONOMIC INCENTIVES FOR FUTURE EVs AND VERY LOW CO_2 VEHICLES?

4.1. Policies regarding very low CO_2 vehicles

Numerous national governments and regions worldwide have announced support measures for the development of Electric Vehicles and low CO_2 emitters. These measures address, depending on the countries, some or all of the different items that will contribute to market take-off: R&D, engineering, industrialization, for electric vehicles (EVs) and plug-in hybrid electric vehicles (HEVs), charging infrastructure and batteries. As with economic instruments for conventional vehicles, there is already a wide diversity of measures:

– Support for market development (numerous countries);

– Development and industrialisation of batteries (France, Portugal, the UK, Germany);

– Development and industrialisation of vehicles and their specific components (France, Germany and, to a lesser extent, Spain);

– Network deployment (numerous countries, but also regions and cities);

– Experimental programmes (numerous countries, but also regions and cities).

Depending on the particular state, measures rely on direct aid (most cases of market support), financing of R&D and engineering for vehicle development, components and batteries, or loans for specific, heavy investments such as infrastructure and battery manufacture. The choice by Member States as to whether to support one or another item depends on a variety of elements:

– The ambition of the country regarding low CO_2 car development;

– Its situation in terms of engineering and manufacturing of vehicles, and its vision and interest for the future automotive industry;

– The mix of energy supply performances, in terms of CO_2 emissions, involved in its energy production and capacity in renewable energies, in particular for electricity.

Levels of support from economic instruments for these vehicles also vary widely, from nothing to incentives as high as EUR 9 000 for an electric vehicle in Belgium, and even more in Denmark with tax relief at purchase.

4.2. How incentives will impact the EV and low CO_2 car market

4.2.1Which comparison is relevant?

Incentives supporting the development of sales of low CO_2 cars differ from one country to another. What is important for market introduction (and for the manufacturers) is not the incentive itself, but the difference in incentive between EVs and P-HEVs and its competitors on the market. For instance, looking at a B-segment EV, the difference of taxes with the most efficient B car on the market is the figure that matters.

To illustrate the point:

– In France, all cars with CO_2 emissions below 95 g/km at present, 90 g/km in 2011-2012, will benefit from a 1 000 EUR incentive, reducing the real value of the 5 000 EUR incentive available for an EV to 4 000 EUR.

– In Spain, the most recent Spanish tax scheme exempts cars emitting less than 120 g CO_2/km from the registration tax. As can be seen in Figure 13 below, the more the car emits and is expensive, the higher the tax advantage. That makes incentives very attractive for expensive/upper range cars, while the market for low-emission vehicles receives smaller incentives, comprised of:

  – An incentive for electric vehicles, representing 15% of the retail price;

  – Differentiated registration tax, which is also proportional to price, and at the same time increases with CO_2 emiss**ions.**

Figure 13. **EV versus conventional cars, 2009 Spanish tax regime**

Retail price of vehicles (EUR)		CO_2 emissions from conventional vehicles as a reference							
		< 120g		120g >160g		160g>200g		200 and more	
		0%		4.75%		9.75%		14.75%	
10 000	Registration Tax of conventional cars	0	1500	500	2000				
	Fiscal Incentive for Electric Vehicle	1500		1500					
15 000	Registration Tax of conventional cars	0	2250	750	3000	1500	3750	2250	4500
	Fiscal Incentive for Electric Vehicle	2250		2250		2250		2250	
20 000	Registration Tax of conventional cars	0	3000	1000	4000	2000	5000	3000	6000
	Fiscal Incentive for Electric Vehicle	3000		3000		3000		3000	
30 000	Registration Tax of conventional cars	0	4500	1500	6000	3000	7500	4500	9000
	Fiscal Incentive for Electric Vehicle	4500		4500		4500		4500	

Uneven incentive per tonne of CO_2 reductions depending on the car segment

DAP / DPSVE 25/02/2009

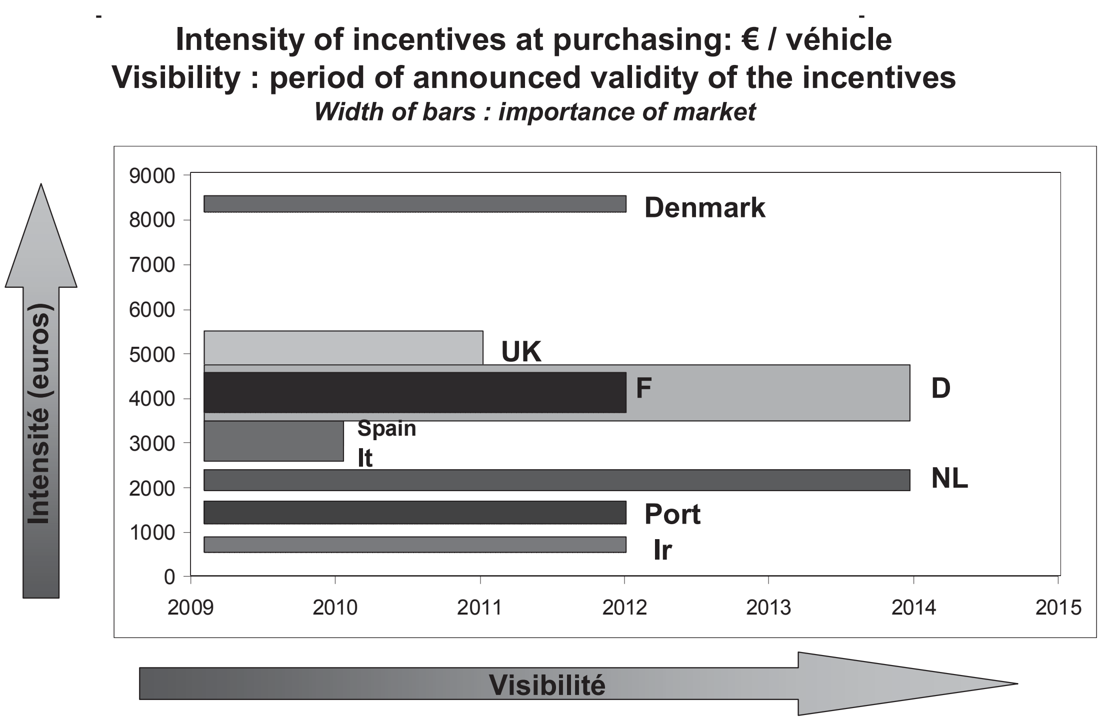
4.2.2 Already a great diversity of incentives

As mentioned above, a large diversity in incentives is already anticipated. To illustrate this diversity, Figure 14 below presents current expectations in nine EU countries in relation to two criteria:

- Vertically, the intensity of the incentive for purchasing an electric vehicle ("zero emissions from tank to wheel") as against the comparably CO_2-efficient ICE vehicle, usually among diesel vehicles with low CO_2 emissions, which currently either benefit from incentives or are minimally taxed.

- Horizontally, the expected duration of the incentive. This point is crucial for manufacturers as durable incentives are essential for creating a market for low-CO_2 vehicles.

Figure 14. **Comparisons of incentives for buying comparable EV and ICE cars**



4.2.3 Many uncertainties for the future

For manufacturers involved in developing very low CO_2 vehicles and EVs, three uncertainties are cumulative when assessing the impact of economic instruments:

- How will the economic instruments for EVs evolve? As seen in the above figure, countries are planning policies up to 2012 or 2014. EVs will start to enter the market by late 2010 or 2011, and significant volumes are not expected until 2012.

- How will economic instruments for conventional, CO_2 efficient vehicles evolve? If significant incentives are maintained, the attractiveness of EVs may be reduced.

- How will oil prices, taxes on fuels and total fuel prices evolve? Again, this parameter might impact on the attractiveness of the EV.

But most importantly, a key parameter is transparency on how long the economic instruments will continue to operate:

- While the first electric vehicles will be launched in Europe in 2010 in limited volumes, the EV market will only really stabilize later, by 2015 at the earliest.

- The engineering and other investment costs for vehicles, batteries, infrastructure and new components will be extremely high and the decision to produce EVs represents business risks requiring sufficient transparency and, probably, public support.

4.3. How states should evaluate the policy value of these vehicles

When considering support for EVs and P-HEVs, governments must assess whether long-term support is justified on the basis of direct environmental benefits. This does not seem necessarily to be the case.

Beyond conventional assessment, a study was made by the CIRED (*Centre International de Recherche sur l'Environnement et le Développement*, Paris) at the end of 2009, under the guidance of Dr. Jean-Pierre Hourcade, on the effects of a policy anticipating the introduction of EVs. This study was based on modelling analysis (Model IMACLIM-R). It concluded that supporting anticipated EV deployment would provide high benefits through the potential effects that such a policy would have on climate change. The risks of deploying these vehicles quickly would be largely offset by the gains of achieving earlier emissions reductions (always assuming EVs use low carbon electricity). There may be benefits from ambitious strategies for the deployment of EVs and very low CO_2 emitters in terms of alleviating mitigation measures in the long term.

4.4. Which public policies to support the deployment of very low CO_2 vehicles and EVs?

At this stage, considering that the development of EVs and very low CO_2 emitters will start soon, and assuming that governments confirm the benefits of accelerating deployment, three key recommendations should be taken into account by states that intend to develop these products, when setting their incentive policies:

- Sufficient visibility as to the duration of incentives. The development of these vehicles in competition with products that are economically and technically optimized will depend on progressive cost reductions of key new components. Considering the likely production volumes of these vehicles, sufficient market and fleet size does not seem likely by 2012 or even 2015. Long-term policy incentives are therefore indicated.

- Sufficient incentives for these vehicles in comparison to conventional cars. Schemes should provide sufficient incentives for EVs and very low emitters to make them attractive in comparison with the most CO_2-efficient ICE vehicles. These conventional vehicles will also improve over time.

– Link incentives directly to the CO_2 benefits resulting from using these vehicles. The form of incentives/taxes should relate more to the benefits expected than the cost of a product or a specific technology. The effectiveness of a policy will depend on massive development of efficient products.

With the changes that will occur in the market regarding lower CO_2 emissions from conventional cars and the emergence of very low or zero CO_2 emitters, current economic instruments need a profound review to adequately support new products and at the same time maintain balance in state budgets.

5. CONCLUSIONS

This paper describes key features of EU car taxation and its consequences for manufacturers. Some elements of the analysis, in particular those related to very low CO_2 emitters, are also valid for other countries. Some conclusions can be drawn.

– **Current economic instruments create strong environmental incentives, generating a decrease in CO_2 emissions from the new car fleet.**

In sum, the various taxes applying to fuels and vehicles create a strong economic incentive to reduce CO_2 emissions. The size of incentives is much higher than the comparable policy instruments applied to other sectors of the economy. In some cases, they can be considered disproportionate.

Beyond its role of generating revenue for state budgets, the taxation of fuels represents the first element weighing on vehicle choice and vehicle mileage.

The total cost of taxes on automobiles varies by country across a very wide range. New, average car CO_2 emissions vary according to the intensity of incentives in comparison to national incomes and income distribution. The recent economic crisis and the measures implemented to limit its impact on industry induced a strong acceleration in new car CO_2 emissions reductions, which might partially reverse in the short term.

Trends in EU Member States reveal the strong effectiveness of taxes in advance of any effect from the EU Regulation on new car CO_2 emissions, finalised in late 2008 for implementation from 2012. If tax incentives had been developed more widely early after the industry's Voluntary Commitments had been agreed, they would have greatly enabled the efforts of industry. The absence of fiscal incentives in most EU Member States between 1998 and 2008 weighed against effective CO_2 reduction, in the absence of regulatory CO_2 limits during that period.

– **The current fragmentation of incentives has a significant cost**

The diversity of incentives created by economic instruments within the EU is such that no "single market" for cars exists from an OEM perspective: products and marketing strategy require differentiation between Member States.

Due to the diversity of instruments and the unpredictability of changes in taxes and tax systems, OEMs have no robust basis on which to arbitrate between the costs and benefits of investing in CO_2 and fuel consumption reductions in their project planning. The first purchase criterion for a majority of consumers remains the price of a car, particularly in the lower segments of the market.

This unco-ordinated situation forces OEMs to implement short-term adaptations in marketing for CO_2 improvements that are not cost-effective for industry. Competition between OEMs has driven down CO_2 emissions, but a more predictable framework with co-ordinated incentives would have been certainly less costly and possibly resulted in larger emissions cuts.

– **Incentives should, as directly as possible, correlate with the CO_2 and environmental performance of vehicles**

Taxes and environmental performance are not always systematically linked, in particular incentives for specific technologies or alternative energies. In the long run, instruments that are not calibrated to benefits fail to be cost-effective *vis-à-vis* environmental results.

The various thresholds introduce discontinuities that do not correspond to the functioning of the industry, which is basically linear, and can create market disruption.

Bonuses related to the retail price of a vehicle may introduce bias, as they over-incentivise more expensive vehicles, which in some cases is not consistent with the intended policy – one example is provided by the system of registration taxes and bonuses in Spain.

When considering CO_2, incentives and taxes, in particular on fuels, one should not disregard the intrinsic efficiency of diesel technology. Current projects to base taxation of fuels on energy per litre will work against CO_2 reduction.

– **In a mature industry producing competitive conventional vehicles, new, innovative technologies will require extensive support**

Electric and very low CO_2-emitting vehicles will enter the market in the next two years in competition with conventional vehicles at an advanced stage of development. The new products will require new batteries and components that will compete with extremely optimised, mass-produced vehicles.

The initial cost of these new vehicles will be significantly higher than conventional vehicles and the pace of cost reduction is unpredictable. The overall initial expenses to ensure their launch and market development will be extremely high.

Member States that (1) fight for EV industry localisation in the future and (2) foresee considerable benefits from accelerated deployment of these vehicles, should consider continuous, long-lasting support policies. They may ultimately have to consider rebalancing their fiscal systems to finance such support in a period where fuel consumption should start decreasing with the improvement of the average CO_2 efficiency of the whole vehicle fleet.

THE DEMAND FOR AND THE SUPPLY OF FUEL EFFICIENCY IN MODELS OF INDUSTRIAL ORGANISATION

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SUMMARY

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ABSTRACT

This report organises and discusses empirical estimates of the effects of fuel prices and fuel emissions standards on consumer and firm behaviour. Model-free estimates are only briefly touched upon. The focus is on results based on explicit models, taken mostly from the industrial organisation literature. First, studies are reviewed that identify the willingness to pay for fuel efficiency using static and dynamic models of vehicle demand. Next, the fact that firms will adjust their product portfolios and the characteristics of the vehicles they offer is taken explicitly into account. These decisions will have an impact on the choice set from which consumer demand is estimated and on the trade-off that consumers face between fuel efficiency and other desirable characteristics. Finally, models are discussed where firms choose to invest in innovations to achieve fuel efficiency gains without sacrificing characteristics.

1. INTRODUCTION

A vast literature is devoted to identifying and estimating the effects of fuel prices on vehicle demand and fuel use in transportation. The discussion in this report is limited in two respects. First, after only a brief overview of a few survey articles and recent studies that investigate the effects of fuel prices or fuel efficiency standards in a theory-free setting, in Section 2, we turn to studies that are based explicitly on models of industrial organisation. Second, with only a few exceptions, only papers published in the last 15 to 20 years are included. There was a flurry of research in this area following the oil shocks of the 1970s, but the recent advances in empirical methodologies make it hard to incorporate that work in the organising framework proposed.

The remainder of the paper is organised as follows. We start with an overview of standard vehicle demand estimates in Section 3. Models are differentiated on many dimensions and consumers consider fuel efficiency as one desirable characteristic when making their purchase decision. Random utility models of demand are ideally suited to identify the average taste for fuel efficiency in the population. If data of individual purchases is available or if a model with random coefficients is estimated, these tastes can be allowed to vary across consumers. The standard estimates from the literature are reviewed first in subsection 3.1.

Some of the dynamic features of fuel use in motor vehicle transportation are incorporated in subsection 3.2. Consumers have to make a two-stage decision whereby, first, a durable good is purchased and second, its intensity of use is chosen. From the demand perspective, two issues stand out. First, the error terms in both decisions are likely to be correlated and this needs to be incorporated for consistent estimation. Second, consumers have to be forward-looking to some degree in order to value fuel efficiency.

Most of the industrial organisation literature relies on observational data and uses instrumental variables to identify the demand function. Exploiting quasi-exogenous changes in taxation or regulation, for example, the Corporate Average Fuel Efficiency (CAFE) standard, could provide identifying power. This is discussed in subsection 3.3; and in subsection 3.4 a number of studies are listed that evaluate the relative merits of fuel taxes and emissions standards.

In the next section, we turn to the supply side. Firms will respond to changes in fuel prices or fuel efficiency standards in several ways. In subsection 4.1, adjustments to vehicle characteristics are incorporated. Conditional on vehicle technology, firms face the trade-off that offering enhanced fuel efficiency comes at the expense of other desirable characteristics, such as size and horsepower. Products are positioned along this frontier and optimal positions will shift over time, for example, when fuel prices change.

In subsection 4.2, we consider innovative decisions that have the potential to shift the entire frontier over time. Technological breakthroughs make it possible to improve fuel efficiency, even holding other characteristics constant. When firms decide on their optimal innovation policy, strategic interactions with their competitors and spillovers from technological progress take centre stage.

Conclusions are summarized in subsection 5.1. The author mainly focus on improvements necessary to make counterfactual simulations more reliable. Two key areas for improvements are demand estimation methodology, especially robust identification, and behavioural models of the supply side.

2. THEORY-FREE ESTIMATES OF THE IMPACT OF FUEL PRICES ON FUEL EFFICIENCY STANDARDS

There is a large literature, including many contributions from fields outside of economics, that investigates the direct effect of fuel prices on several variables of interest in the motor vehicle industry, such as total sales, composition of sales, etc. While some studies rely on price changes over time as a source of variation to identify effects, others exploit the introduction or the tightening of fuel efficiency standards or other types of regulation. In this section, a few findings from both approaches are highlighted but, for a more elaborate discussion, other (survey) articles are referred to.

One issue that even studies not explicitly structured by an underlying theory need to take into account, is the fact that vehicles are durable goods. As a result, the short- and long-run price elasticities of fuel use will differ as more decisions can be adjusted in the long run. Consumers can immediately adjust the intensity of vehicle use, but adjusting commuting modes will take longer. Adjusting vehicle portfolios in a firm or household will take years, and introducing different types of vehicle in the marketplace even longer. The elasticity will be (strongly) increasing in the time-frame allowed for the response. This limits the comparability of estimation results from studies that do not identify primitives – technological or behavioural relations – but estimates reduced form effects directly.

2.1. Identification from observational data

The most straightforward approach is to simply follow fuel price changes over time and track how other variables co-vary with them. The conditional relationship of one endogenous variable (fuel price or average income) on another endogenous variable (vehicle sales) can be informative to understand the interactions in the adjustment process. Properly specified reduced-form equations are sufficient to trace the evolution of equilibrium outcomes.

Two surveys of studies estimating price elasticities in the transportation sector, Goodwin (1992) and Oum, Waters and Yong (1992), pay particular attention to the type of elasticities that can be identified and how. Especially in the aftermath of the oil shocks of the 1970s this was a very active area of research.

Dahl and Sterner (1991) provide an even broader survey of different estimates in the literature. They settle on an average short-run price elasticity for gasoline demand of -0.26 and an average short-run income elasticity for gasoline demand of 0.48. From a meta-analysis of past estimates, Espey (1998) reaches similar conclusions: a median short-run price elasticity of -0.23 and a median short-run income elasticity of 0.39.

Following up on this earlier work, Hughes, Knittel and Sperling (2008) provide evidence suggesting that the short-run price elasticity of fuel demand for motor vehicle use has fallen in recent years. As their data spans the entire 1975 to 2006 period, they can use the same model throughout to see how elasticities have evolved over time. The short-run price elasticity they find for the period from 1975 to 1980 ranges between -0.21 and -0.34, in line with the previous results from the literature. For the period from 2001 to 2006, the similarly estimated price elasticity has declined to a range from -0.034 to -0.077. The estimated short-run income elasticities are not significantly different between the two periods.

Different land-use and commuting patterns are flagged as potential explanations, in addition to the different stock of vehicles. Consumers seem to have increasingly ignored fuel efficiency considerations in their vehicle choice, following the drop in fuel prices to historically low levels in the 1990s.

A long-run elasticity of fuel use would include the adjustment of the vehicle fleet to fuel prices, but the short time span of high fuel prices in the data used by Hughes, *et al.* (2008) makes it impossible to identify this effect. Studies that accomplish this are reviewed below. It requires an explicit demand model, because vehicle prices cannot be taken as exogenous. For example, McManus (2005) provides evidence that the greater popularity and higher sales of more fuel-efficient models, in response to fuel price changes, are concealed in the data. Fuel price increases have been accompanied by price cuts, disproportionately aimed at less fuel-efficient vehicles.

A final paper worth mentioning with theory-free estimates of the responses to fuel price changes is Busse, Knittel, and Zettelmeyer (2009). Using an explicitly derived reduced form model, they evaluate the equilibrium adjustment to higher fuel prices on both vehicle prices and quantities. No consumer preferences or cost primitives are uncovered, but also no assumptions on the nature of consumer choice or firm decision making have to be imposed.

Most interestingly, they find that the adjustment differed markedly in the new-vehicle and the second-hand markets. Most of the adjustment for new cars occurred through a shifting composition of sales, a boom in the small car segment and a bust for SUVs, with small changes in relative prices for fuel-efficient and inefficient vehicles. For second-hand vehicles, on the other hand, almost the entire adjustment takes place through prices. Reallocating the stock of existing vehicles to match fuel-efficient vehicles to high-mileage drivers seems to be a marginal process.

2.2. Identification from changes in fuel efficiency standards

Chouinard and Perloff (2007) have studied which sources of variations matter most in retail fuel price differences between regions and over time. In terms of the variation over time, the dominant factor by far is the price of crude oil[1]. The advantage is that from the perspective of motor vehicle users and car buyers this is an exogenous factor, and endogeneity is not an issue to identify short-run effects from price changes above.

However, fuel prices are notoriously hard to predict. When consumers purchase a vehicle, it is not obvious how they form expectations of future prices, which is nevertheless important. For example, if consumers treat the price process as a random walk, any price increase will be considered permanent, with strong demand adjustments. On the other hand, if price shocks are assumed to decay rapidly, a given price shock will have less of an effect on demand and measured price elasticities will be lower – irrespective of the true underlying weight of fuel efficiency in consumer demand.

Moreover, firms will also respond to fuel price changes. In the short run, they can adjust the relative price of vehicles to match sales to their production capacity. In the longer run, they can introduce vehicles with different fuel efficiencies. An exogenous change in fuel prices thus triggers endogenous changes in the consumers' decision environment.

More recently, many governments have imposed or tightened fuel efficiency standards and such changes can provide an alternative source of variation to identify impacts. For one, these changes tend to be viewed as permanent and consumers are likely to take them into account completely and immediately when purchasing vehicles.

An overview of current fuel efficiency standards in different jurisdictions is provided in ICCT (2007). The flurry of changes that have been proposed and introduced recently will certainly lead to an active area of research in the coming years. In addition, governments increasingly provide incentives for higher fuel efficiency through the tax system, e.g. by making annual registration fees a function of fuel efficiency. Even discrete subsidy programmes have proliferated.

Following the absence of important policy changes in this area over most of the 1990s, it will take time to obtain reliable estimates of these newly-introduced incentives on fuel demand. Instead of detailing point estimates that will quickly be outdated, only a few studies are listed that investigate various aspects of the North American system of Corporate Average Fuel Efficiency (CAFE) standards.

- Holland, Hughes and Knittel (2009), A theoretical analysis of the effects of low carbon fuel standards on greenhouse gas emissions;
- Jacobsen (2008), Estimates of the effects of higher CAFE standards in a model with heterogeneous consumers and producers;
- NHTSA (2009), Prospective estimates of the likely effects of higher CAFE standards from the National Highway Traffic Safety Administration (US Department of Transportation);

- Kleit (1990, 2002, 2004);
- Parry and Small (2005), Comparison of the existing gasoline taxes in the UK and the US with the optimal fuel tax. Impacts on the average fuel efficiency in the fleet and driving patterns are included in the comparison.

3. DEMAND-SIDE EFFECTS

3.1. Static estimates of the car demand elasticity with respect to fuel efficiency or fuel cost

We now review studies that use the random utility framework to estimate demand for differentiated products. The automotive market has been an active testing ground for models that describe the available products in a consumer's choice set, using a limited set of characteristics. Implicitly, these studies are thus estimating the elasticity of demand with respect to different car characteristics. The fuel efficiency per distance travelled or the monetary (fuel) cost of operating a particular vehicle is the specific characteristic we focus on.

Unfortunately, several well-known studies that estimate a random utility model of car demand do not include a measure of fuel efficiency in their list of vehicle characteristics. Those will not be discussed here[2].

An important issue to keep in mind is that the set of other characteristics that are included in the demand regressions will vary across studies. Because of data availability and collinearity between many characteristics, each study includes only a few variables in the demand specification. As a result, the estimated fuel efficiency elasticities will hold different other characteristics constant, e.g. different measures of size, weight, horsepower, etc. As many characteristics that influence vehicle demand will be correlated strongly with fuel efficiency, for technological reasons, the comparability of the point estimates across studies is not perfect. This dependency will be explored further in subsection 4.1.

Another complication arises from the variations in the way fuel efficiency is measured. Some studies use a technological measure of fuel use per distance travelled, litres per 100 km (l/100 km), while in North America the inverse measure, miles per gallon (mpg), is more common. Especially if the variable does not enter the demand equation in logarithms, this will also influence the estimates (Larrick and Soll, 2008), as simple linear functional forms are the standard.

Even more importantly, the technical fuel efficiency is often converted into a monetary value by dividing mpg or multiplying l/100 km by the fuel price. In such a specification, the variation of fuel prices over time now contributes to the identification of the demand elasticity with respect to fuel efficiency. To give these estimates a structural interpretation, an assumption of consumers' future fuel price expectations is still needed.

Estimates using different explanatory variables cannot be compared directly. Using an average fuel price and the appropriate miles per kilometre and litres per gallon ratios, the interested reader can express all measures into the same units.

Table 1 contains a list of fuel efficiency coefficients from discrete choice models, estimated for different countries. The top panel (a) lists studies that estimate (semi-)elasticities using data on vehicle choices from individual consumers. In these studies, heterogeneity in the elasticities can be incorporated straightforwardly by interacting fuel efficiency with vehicle or consumer characteristics.

Results in the next panel (b), are for studies using market-level data that incorporate a random coefficient on the fuel efficiency effect. These models still allow for heterogeneity in the taste for fuel efficiency in the population, but they require more functional form or distributional assumptions and they are more computationally demanding to estimate. Finally, in the bottom panel (c) are market-level studies that estimate a single fuel efficiency elasticity that is common to all consumers.

Table 1. **Coefficients on fuel efficiency or fuel costs in random utility demand models**

Study	**Variable**	**Sample**	**Estimate**	**St. Dev.**
a) Individual purchasing data				
Goldberg (1995)	Miles/dollar (=1/MP$)	US small cars big cars luxury & sports	-7.14 -1.38 0.23	(0.74) (0.74) (0.93)
Goldberg (1998)	1/MP$	US (all cars)	21.23	(124.90)
McCarthy (1996)	1/MP$	US	-0.45	(0.05)
McCarthy-Tay (1998)	1/MP$	US	Range of estimate	
Berry-Levinsohn-Pakes (BLP) (2004)	MPG	US	0.49 (av.) + range of estimate	(0.02)
b) Market-level data with random coefficients				
BLP (1995)	Mean effect on MP$ Random eff. on MP$	US	-0.12 1.05	(0.32) (0.27)
BLP (1999)	Mean effect on MP$ Random eff. on MP$	US	0.20 0.42	(0.08) (0.13)
Petrin (2004)	Mean effect on MP$ Random eff. on MP$	US (with micro moments)	-15.79 2.58	(0.87) (0.14)
Verboven (2002)	l/100km	BE-FR-IT gasoline diesel	-17.40 -27.60	(Implicitly defined)
Brenkers (2005)	Annual fuel bill ($)		-13.34	(1.44)
c) Market-level data, estimating mean effect only				
Brenkers-Verboven (2006)	$/100km	BE–FR–GE–IT–UK	-0.04	(0.01)
Van Biesebroeck (2006)	MP$	Canada	0.09	(0.06)
Klier-Linn (2008)	$/mile	US (1970-1985) (1986-2001) (2002-2007)	-10.10 -1.50 -15.28	(3.48) (2.93) (2.58)

Miravete-Moral (2009)	l/100km	Spain	-0.03	(0.01)
Van Biesebroeck-Verboven (2010)	l/100km	Canada	-0.05	(0.01)

Goldberg (1995) uses information on individual car ownership from the US Consumer Expenditure Survey. She estimates a nested logit specification separately for different segments of the car market. The results indicate that the demand elasticity with respect to fuel efficiency declines rapidly for larger and more expensive vehicles. In the small car segment, the coefficient on the "cents per mile" variable, proportional to the inverse of miles per gallon, is estimated strongly negative at -7.143, but this is reduced to -1.381 for larger cars and becomes positive, but insignificant, for the segment of luxury and sports cars[3].

In Goldberg (1998) the same data is used to simulate the effects of the CAFE standards using the same demand system. Estimated on the full sample, including all segments, the fuel efficiency elasticity in the benchmark model is -0.2. When the model is generalised to incorporate the decision on vehicle utilisation, using the Dubin and McFadden (1984) insights discussed below, the point estimate suggests a positive, but highly insignificant, elasticity.

McCarthy (1996) finds a significantly negative coefficient, but does not report the necessary summary statistics to convert the estimate in an elasticity. In a follow-up paper, McCarthy and Tay (1998) further let the sensitivity of demand to fuel efficiency vary by consumer characteristics, and even by fuel price, number of dealer visits and city size. They thus obtain extremely flexible elasticities. Rather than reporting one number, couple patterns can be highlighted: (i) higher income households have a lower demand for fuel efficient vehicles; (ii) female buyers have a stronger preference for efficient vehicles, but older buyers weaker; (iii) a higher gasoline price raises the absolute value of the elasticity.

Berry, Levinsohn and Pakes (2004) generalised their 1995 estimation methodology to incorporate micro-level data and information on secondary choices into the estimation. Their positive point estimate on miles per gallon translates into an average semi-elasticity of only 0.10. The strength of their method, however, is the ability to include interaction effects which allow for different elasticities by consumer demographics.

In their original contribution, Berry, Levinsohn and Pakes (1995) already illustrated that a random coefficient on all vehicle characteristics can be estimated using only market level data. No closed-form solution for the estimation equation is available anymore, but it allows very flexible substitution patterns between different models.

In the context of the fuel efficiency variable, they discuss explicitly how to interpret the estimates with a random effect:

"*The elasticities with respect to MP$ illustrate the importance of considering both the mean and standard deviation of the distribution of tastes for a characteristic. The results here are quite intuitive. The elasticity of demand with respect to MP$ declines almost monotonically with the car's MP$ rating. While a 10 percent increase in MP$ increases sales of the Mazda 323, Sentra and Escort by about 10 percent, the demand for the cars with low MP$ are actually falling with an increase in MP$. The decreases, though, are quite close to zero. Hence, we conclude that consumers who purchase the high mileage cars care a great deal about fuel economy while those who purchase cars like the BMW 735i or Lexus LS400 are not concerned with fuel economy* (p. 878)."

The results thus mirror the changing fuel efficiency elasticity by segment from Goldberg (1995), without a need to specify segments exogenously.

Berry, Levinsohn and Pakes (1999) use the same demand model to study trade policy. The most notable change is that MP$ has been dropped from the marginal cost specification that enters the firm's first order condition for optimal price setting. Implicitly, this also amounts to different instruments in the demand equation. The large change in point estimates illustrates that the choice of instruments is not innocuous, although the qualitative findings are similar.

The results in Petrin (2004) further illustrate the effect of including a random coefficient on the MP$ estimates. Estimating the simple logit model with instrumental variables or with OLS yields an insignificant, but positive estimate on the effect of MP$ on demand, respectively of 0.05 (0.07) and 0.18 (0.06). If a random coefficient is introduced for this variable, the mean effect becomes negative, at -0.54 (3.4), and the random effect is estimated at 0.04 (1.22). Adding the micro-moments raises the absolute value of both coefficients and all coefficients are estimated a lot more precisely. For some consumers, increased fuel efficiency is very valuable, but for many others not. Negative tastes for fuel efficiency can be explained by the negative technological relationship between fuel efficiency and other desirable characteristics such as size, which will be discussed below.

Verboven (2002) and Brenkers (2005) use market-level data from a number of EU countries and they estimate a conditional demand model. Consumers are assumed to value fuel efficiency as an increasing function of their annual mileage. In Verboven (2002), drivers with annual mileage above a model-specific cut-off will prefer diesel cars that are more expensive, but use less and cheaper fuel. In Brenkers (2005), data on average mileage is supplemented with a random taste for fuel efficiency. The estimation strategy incorporates explicitly that a dollar is a dollar whether it enters through the vehicle purchase price or discounted present value of fuel savings. The relative weight on the annual fuel expenses can be used to derive an implicit interest rate that consumers use. Table 1 shows the implied coefficients for one of the usual fuel efficiency measures.

In the bottom panel, a number of studies are collected that estimate a constant taste parameter for fuel efficiency that all consumers share. All point estimates have the right sign: on average, consumers prefer more efficient cars.

Brenkers and Verboven (2006) use market-level data from a number of EU countries and estimate a nested logit specification. As they do allow heterogeneity in the price coefficient across consumers, the monetary value of the willingness to pay for fuel efficiency will still vary across consumers.

Finally, Klier and Linn (2008) estimate demand using OLS on first-differenced monthly data. They show in particular that the value consumers place on fuel efficiency has bounced around over time. In the 1970-85 period, the point estimate was -10.10 but over the 1986-2001 period of falling fuel prices it was only -1.50. In the most recent period of rising fuel prices, the point estimate has increased in absolute value to -15.28 and has become highly significant.

3.2. Incorporating dynamic aspects into the demand model

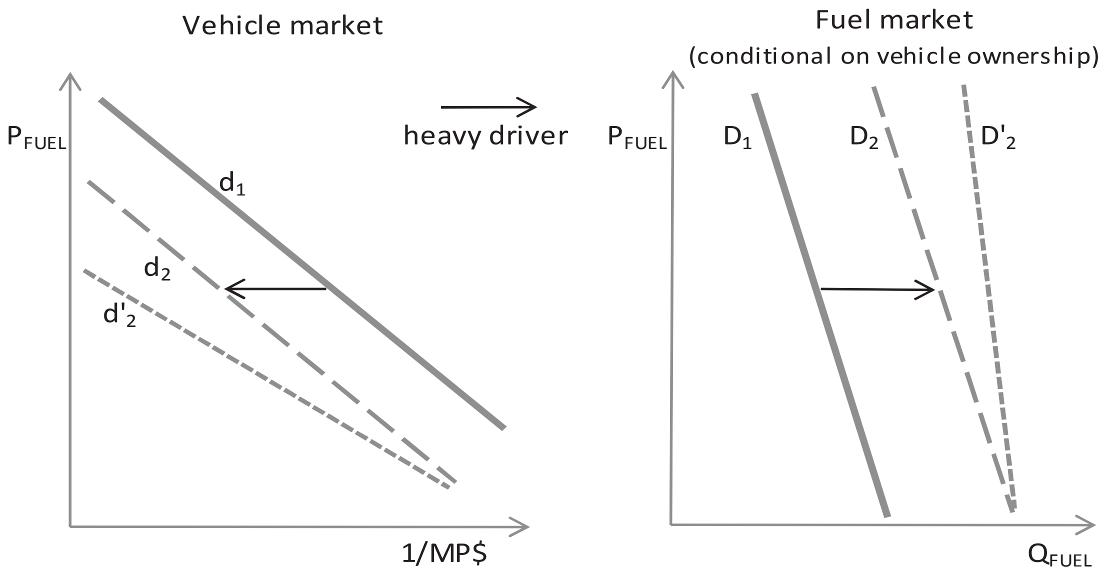
The durable goods nature of a car will matter greatly for the fuel efficiency estimates. Consumers have to solve a two-stage decision model. First, they choose a vehicle which they will keep for many years. Their driving habits will play a role, but also their expectation of the future fuel price. Second, conditional on their stock of vehicles, they choose how intensively to use them, which determines fuel consumption.

The studies in the above section only considered consumers' taste for fuel efficiency when purchasing a new vehicle. While only one aspect of the total price elasticity of fuel demand, it has received a lot of attention, as the elasticity of the intensity of vehicle use and hence the use of fuel conditional on vehicle ownership, tends to be rather low. However, the second stage environment will still influence optimal decisions in the first stage.

In Figure 1, both demands – for vehicles and for fuel – are juxtaposed. The solid curves represent the benchmark case of an average driver. Demand for fuel as a function of the fuel price, in the right panel, is generally considered rather inelastic. Demand for fuel efficiency in vehicles, i.e. the willingness to pay for fuel efficiency improvements, is an increasing function of the fuel price.

This is illustrated in the left panel, by a declining demand for the vehicle characteristic 1/MPS as a function of fuel price. Keeping the vehicle price constant, manufacturers are able to pack further desirable characteristics in their vehicles if they are willing to compromise on fuel efficiency. This will be especially desirable if fuel prices are low, hence the lower demand for fuel efficiency.

Figure 1. **Demand for vehicles interacting with fuel demand**



The short-run responses on aggregate fuel use by motor vehicles, as discussed in subsection 2.1, represent the elasticity of demand in the right panel. The elasticity of the demand relationship in the left panel is what was estimated in the studies reviewed in subsection 3.1.

To estimate the full elasticity, heterogeneity in the population and the connection between the two demand systems has to be accounted for. A "heavy" driver will have a demand for fuel shifted to the right, D_2 instead of D_1, but it is also likely that the curve will be steeper, like D'_2. Recreational drivers should be able to adjust their fuel use more easily than travelling salesmen.

Similarly, heavy drivers will, *ceteris paribus*, prefer vehicles with a higher mileage at each fuel price; hence their vehicle demand shifts left from d_1 to d_2. At the same time, heavy drivers should realise that they will be unable to adjust their fuel use after they purchase a vehicle. Their lower elasticity of fuel use should increase their elasticity of fuel efficiency demand, like d'_2.

In the estimation, there are at least three issues to be dealt with. First, the error terms in both the vehicle choice and intensity of use decisions are likely to be correlated. To estimate the overall longer term elasticity consistently, this should be explicitly accounted for. Dubin and McFadden (1984) were the first to model the two-level decisionmaking explicitly in a study of appliance choice and electricity use. Using 1975 data for individuals, they find very low elasticities for space and water heaters with respect to natural gas price (+0.35) or electricity price (-0.23)[4].

A priori, the correlation between the error terms in both markets could go either way. If persistent (unobserved) individual tastes are important, people might be ranked along a "greenery" dimension. Green consumers will buy fuel-efficient vehicles and use them frugally. In this case the error terms in both markets should be positively correlated. On the other hand, it might be the heavy drivers who realise greater gains from investing in fuel efficiency, leading to a negative correlation in the two market errors. Yet another model would be to allow for correlation, not in the additive error but between the random component on the taste for fuel efficiency and the fuel use error.

Second, to estimate the total elasticity of fuel demand with respect to the fuel price, the intensity of use should also be modelled. Small and Van Dender (2007) illustrate that the interaction between the two markets also runs in the opposite direction. As mentioned, heavy drivers should have a higher and more elastic demand for fuel-efficient vehicles. At the same time, owners of more efficient vehicles should have a less elastic fuel demand, as fuel expenditures represent a smaller share of total driving costs. This gives rise to the rebound effect. As higher fuel prices lead consumers to adjust their vehicle stock, their cutback in fuel use is diminished, lowering the elasticity of total fuel demand.

A third estimating issue is that people have to be forward-looking to spend more money on a vehicle with higher fuel efficiency. As long as all available vehicles used the same technology this was not a major issue. Fuel efficiency improvement necessarily had to come at the expense of other desirable characteristics. Given the existing technology, it was virtually impossible to boost fuel efficiency without hurting other performance features.

However, when it became feasible to boost the fuel efficiency of a vehicle by introducing different technologies that come at a price, such as diesel or hybrid power trains, the extent to which consumers are forward-looking becomes important.

Verboven (2002) estimates the implicit discount rate that forward-looking people are using when they choose between a diesel engine and an equivalent model with gasoline engine. This involves a trade-off between higher purchase price and lower operating (fuel) costs. In contrast with earlier studies, e.g. Hausman (1979); Mannering and Winston (1985); Dreyfus and Viscusi (1995), which found that consumers behave relatively myopically, he finds implicit discount rates roughly equal to vehicle financing rates.

Verboven (1999) explores implications for the demand model, when consumers only consider the monetary implications of fuel efficiency. It leads to a separating equilibrium where consumers driving less than a certain threshold opt for gasoline engines and heavy drivers use the more expensive diesel technology.

Sawhill (2008) also does not find any evidence that consumers underweight future operating costs. He incorporates more sophisticated fuel price expectations, using an ARIMA model. Exploring information on driving patterns, he does find evidence of large heterogeneity in the population with respect to their sensitivity of operating costs, as would be expected.

3.3. Identification in demand estimation

Identification is a major issue in demand estimation. Especially in a concentrated industry with differentiated problems, it is hard to control for the endogenous price-setting of firms. The problem is that unobservables (to the econometrician) in the demand equation will induce a correlation between price and the error to the extent that firms know more than the researcher. In addition, other characteristics than price might be adjusted strategically.

In practice, studies estimating differentiated goods demand models have used combinations of functional form restrictions and instrumental variables to identify price coefficients. Popular instruments that are expected to be correlated with price, but do not belong in demand include: (i) mark-up shifters such as characteristics of competitors (BLP, 1995); (ii) cost shifters such as price in other geographical areas (Hausman); (iii) region and city variables to capture transportation costs, opportunity costs in distribution, and the strength of local demand (Nevo)[5].

An alternative would be to exploit a natural experimental set-up to identify structural relationships. In the current context, there is scope to exploit policy changes, such as the tightening of fuel efficiency standards to obtain some exogenous variations. Studies that exploited such changes to identify effects directly were already reviewed in subsection 2.2, but policy changes might also aid in the identification of primitives, such as demand for fuel efficiency or product introduction policies.

Results in Atkinson and Halvorsen (1984) and Gramlich (2009), which are discussed below, illustrate the tight correlation between fuel efficiency and other characteristics. It makes the source of identification an important issue that has not received sufficient attention. Lingering bias in any of the parameter estimates will spill over onto the fuel efficiency estimate.

This issue is especially important, as several studies have found the elasticity of vehicle demand with respect to fuel efficiency to be variable over time, see for example Klier and Linn (2008). The author uses an identification strategy that has similarities with Verboven (2002) – exploiting substitution between engines conditional on the choice of car model – to show some additional evidence. A unit of observation is a particular model (engine) in one month and all variables are expressed relative to the base model for sale.

In the demand equation are included both the usual fuel efficiency term, measured in dollars or euros per 100 km, and an interaction term between the same fuel efficiency variable and a time trend. From these estimates, the implied time-varying fuel efficiency coefficient can be constructed, which is plotted in Figure 2 for the US and the Belgian new car markets. Because of the estimation strategy, the units are the direct fuel efficiency elasticities, and are incomparable to any of the estimates reported in Table 1. An estimate of -2 indicates that a 1% increase in dollars or euros per 100 km relative to the base model would lower sales by 2% relative to the base model. Over time, fuel price increases or efficiency decreases are estimated to have increasingly negative effects on the demand for low mileage vehicles.

The sudden reversal in this trend for the US towards the end of the sample seems puzzling at first. However, just as we can model the fuel efficiency parameter as evolving over time, we can model it as a function of the fuel price. Those results for the same two countries are shown in Figure 3.

Figure 2. **Time-variable parameters on fuel efficiency in new vehicle demand**

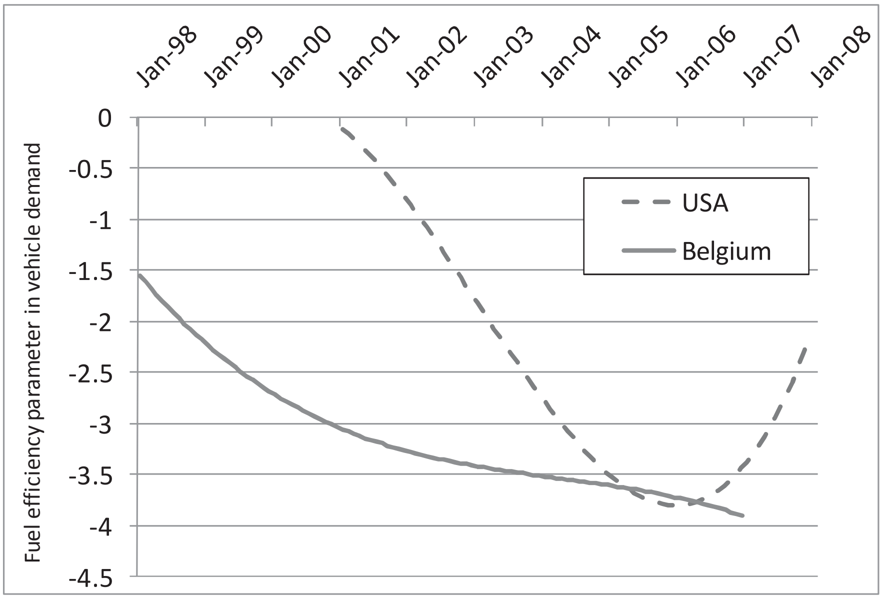
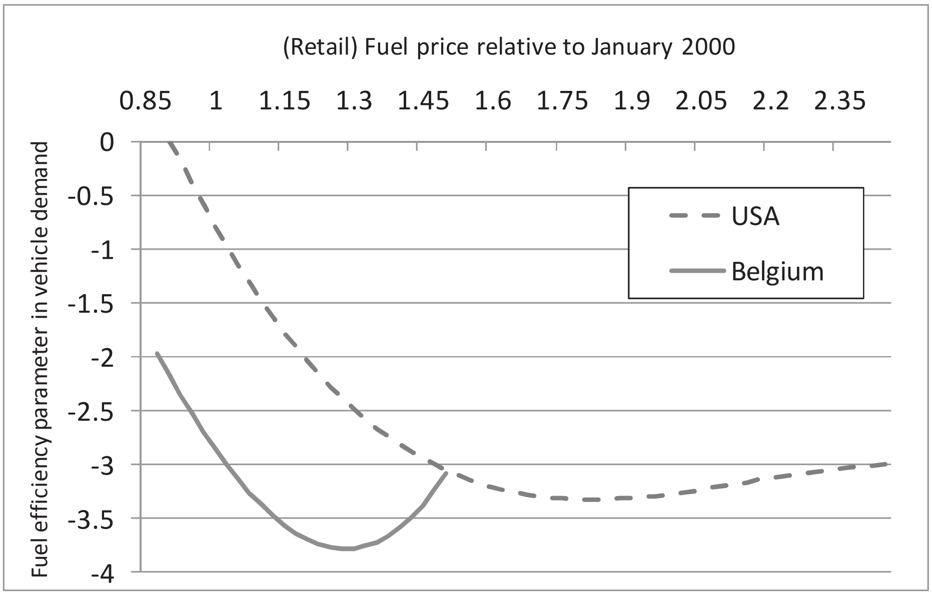


Figure 3. **Parameter on fuel efficiency in vehicle demand varies with the fuel price**



The estimated elasticity is, especially in the US, increasing with the price of fuel. The strong decline in fuel prices after their peak in the summer of 2007 thus again lowered consumers' sensitivity to fuel efficiency. In Belgium, where fuel prices have been much higher throughout and less volatile over time due to high taxes, the effects are estimated less precisely and they take a U-shape.

While these results are somewhat intuitive, they also raise doubts as to what extent the demand equations can be considered representative of underlying primitives. What to make of consumer demand estimates if they turn out to be so unstable? Figure 1 does suggest one channel: when fuel prices are high and expected to stay high, future fuel expenditures are predicted to form a larger share of the total cost of car ownership, and hence should receive higher weight.

3.4. Fuel taxes or fuel standards

Many studies have used demand estimates such as those above to compare policies to increase fuel efficiency for the vehicle fleet, either through price incentives by raising fuel taxes, or through mandated efficiency standards imposed on producers. The two policy instruments have different implications on income distribution, efficiency losses and speed of adjustments. The consumers' price elasticity of fuel use that we have focused on is one important factor[6].

Important studies focusing explicitly on the car market include:

- Boyd and Mellman (1980): an early study using a reduced-form hedonic demand model;
- Gruenspecht (1982): discusses the effects of asymmetrically applying the standards only to new vehicles. It induces consumers to hold on to older, less efficient vehicles, while fuel taxes would have the reverse effect of accelerating the move to a more fuel-efficient vehicle stock;
- Borenstein (1993): studies the same policy trade-off in the context of the phase-out of leaded fuel;
- Koopman (1995): a partial equilibrium simulation of the predicted effects for Europe;
- Goldberg (1998) calculates the cost of strengthening CAFE standards using a demand model that incorporates both the response in the car market and in fuel use, conditional on car ownership;
- Austin and Dinan (2005) re-do the Goldberg (1998) analysis, but incorporate cost estimates for technologies that boost fuel efficiency and the ability to trade fuel-economy credits;
- Kleit (2004): similar analysis.

The Koopman (1995) study highlights the fact that cost-effective limiting of CO_2 emissions requires an instrument that equalizes the marginal cost of emissions abatement across all sources. Economy-wide carbon fees and tradable permit schemes are therefore preferable. He shows in particular that CAFE/gas-guzzler schemes would be approximately 20% more costly to lower emissions by 10%. In addition, the emission reduction relies much more strongly on the improved fuel efficiency of new vehicles and a changed fleet-mix under the CAFE scheme. A consequence is that the cost differential is increasing in the fuel efficiency target. Raising annual taxes on car ownership or purchase tax are even less efficient mechanisms.

Conclusions differed in Goldberg (1998), as her estimates show no evidence of utilization effects at all for US consumers. In response to small increases in fuel prices, consumers did not drive less, making fuel taxes ineffective to lower fuel consumption. Austin and Dinan (2005) use similar, but more recent, US data. They directly estimate the long-run elasticity of fuel demand from the relationship between vehicle-miles travelled and the fuel price[7]. Using their estimate of -0.39, they confirm the finding in Koopman (1995) that a fuel tax would be vastly cheaper than CAFE standards to engineer a reduction in fuel consumption in the motor vehicle sector.

Kleit (2004) reaches similar conclusions, but the difference is even more stark. Estimates in Austin and Dinan (2005) put the cost to society, for a reasonable reduction in fuel consumption through CAFE standards, at three to four times the cost of achieving the reduction through fuel taxes. Kleit (2004) estimates the cost to be fourteen times higher. Furthermore, while the benefits of fuel consumption reduction (as estimated by the NRC) outweigh the costs of achieving them through fuel taxes, this is not the case for CAFE standards.

4. SUPPLY-SIDE EFFECTS

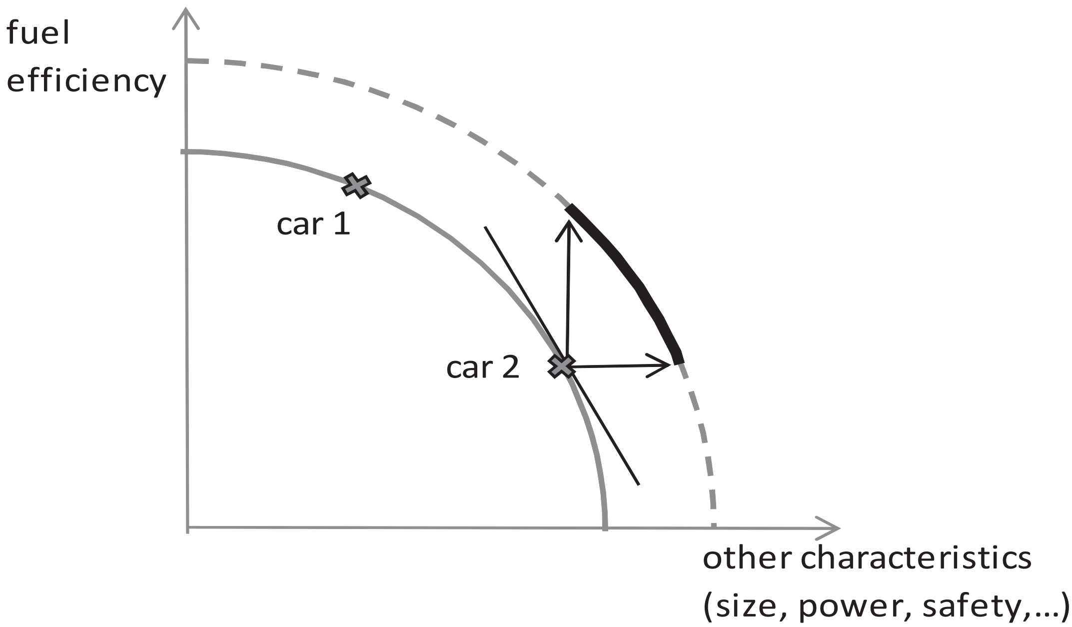
4.1. Product positioning along the technological frontier

Thus far, we have only considered the demand side, but in the discussion of identification it has already come up that this cannot be considered in isolation from the supply side. Firms are not passive actors. They decide on product introduction and pricing, taking fuel prices and competitor actions into account.

Most importantly, there is a technologically determined frontier that determines the trade-off between fuel efficiency and other desirable vehicle characteristics. Given the state-of-the-art vehicle design technology, it is nearly impossible to improve size, horsepower, or even handling or safety features which tend to increase weight, without hurting fuel efficiency. At each point in time, this frontier is fixed and firms have to determine where to position their models along it. At the same time, higher fuel efficiency can only be obtained by compromising on other vehicle characteristics.

In Figure 4, two hypothetical cars are shown, with car 1 a lot more fuel efficient than car 2. It could be smaller or have a worse driving performance, but it has to be inferior to car 2 in some dimension or there would be no demand for car 2.

Figure 4. **Technological production possibilities frontier for fuel efficiency and other characteristics**



Note that we have fixed the vehicle price along the solid frontier in Figure 4. In the past, there was very little scope to improve a car's fuel efficiency holding the other characteristics constant, i.e. moving car 1 vertically towards the dashed frontier was virtually impossible. In principle, cars could be made lighter using aluminium instead of steel, but the high cost made it only viable for niche products. Increasingly, the availability of diesel and hybrid drive-train technologies has made it possible to achieve higher fuel efficiency without sacrificing features, albeit at a cost. This is discussed further in the next section.

Here, we discuss the ability and the incentives for manufacturers to decide on their position along the existing frontier and set accompanying prices. Faced with a choice set, consumers will pick their preferred models based on their willingness to pay for fuel efficiency relative to other characteristics.

Implicitly, there is a relative price consumers are willing to pay for fuel efficiency, which varies across consumers. Everyone will purchase the vehicle closest to the line of tangency of their price line and the frontier. Importantly, changes in fuel prices will change everyone's price line, although not to the same extent. This depends on the demand elasticity with respect to fuel cost which is likely to vary with income, commuting habits, annual mileage, etc.

Following a fuel price increase, the adjustment process of models offered for sale will resemble the process studied in Linn (2008), in an application of manufacturing plants adjusting to fuel price changes. The direct change in energy use was very limited, just as drivers' fuel demand is highly inelastic conditional on vehicle stock. In the medium term, consumers can re-optimize their vehicle portfolio which makes the demand response larger, as discussed before.

In Linn's example, most of the response in energy use only occurred once firms adopted new technologies that allowed lower fuel consumption at similar levels of performance. This goes beyond selecting different machines from the existing menu. It includes changing the menu. In the car market, the composition of vehicle sales will gradually start adjusting right away. After a couple of years, the choice set for consumers will change as well, as firms reposition their (limited number of) models along the frontier.

In a comparison of the fuel price in the UK and the US, Parry and Small (2005) highlight the very different average mileage attained by new vehicles. This discrepancy did not come about overnight. It was a slow process of firms deliberately installing less powerful engines in similarly sized cars as consumers' implicit price line in Figure 4 became less steep.

Such adjustment will not be costless. Bresnahan and Yao (1985) estimate that the cost of complying with efficiency standards in terms of "loss of drivability" exceeded the monetary costs of changing vehicle design, at least in the short run. Desirable characteristics had to be sacrificed to lower fuel consumption, as the technological frontier was fixed in the short run.

The study of pollution control by Gruenspecht (1982), already mentioned earlier, demonstrated that consumers held on longer to older vehicles as stricter pollution standards only applied to new vehicles. The same will happen with mandatory emissions standards, but fuel taxes will spur the opposite pattern of adjustment. Consumers have the greatest incentive to start replacing the least efficient vehicles, which are, by and large, the oldest. The increased demand for fuel efficiency will have a further effect on new vehicle introduction, crowding the space at the top-left segment of the frontier in Figure 4. As a result, many more consumers will find a fuel-efficient vehicle fitting their own idiosyncratic tastes.

In the even longer run, technological advances will shift the frontier in Figure 4, but that will take time. Evidence in Knittel (2009) illustrates that both the average set of characteristics chosen by consumers, such as size or weight, as well as the fuel efficiency per unit of size or weight, have changed a lot. The former represents mostly a shift along the frontier – which tended to be to the detriment of fuel efficiency, as a long period of lowering fuel prices (in real terms) made consumers' implicit price slope steeper. The latter shift represents a shift of the frontier, allowing higher fuel efficiency, even holding other characteristics fixed, but this pattern was swamped by the first shift. Even though technological change improved fuel efficiency possibilities, manufacturers followed consumers' tastes in their product positioning. The introduction of a plethora of SUV models and derivatives in the 1990s was a clear manifestation of this.

In general, it seems inefficient to target fuel efficiency standards at the producers and not at the consumers. The author has argued, in Van Biesebroeck (2009), that the system of CAFE standards has provided the US companies with perverse incentives *against* developing smaller, more fuel-efficient vehicles. Enforcing the standard by averaging the mileage over all vehicles sold by firms ignores the comparative advantage of different firms. Some firms make excellent mini-vans, others excel at making small cars. Charging producers fees on the average mileage of their fleet amounts to cross-subsidizing large vehicle sales by smaller vehicles, but only within the same firm. It has at least two consequences, with dubious merits: (1) it induces firms to lower prices on small vehicles, certainly in relative terms, making them less profitable; (2) it provides incentives to offer a full line of vehicles, in spite of comparative advantages.

The first effect distorts the directly measured profit per vehicle. Selling a fuel-efficient small car has the externality of avoiding a CAFE fine that does not show up in the accounts. Measured profits on SUVs ballooned towards the end of the 1990s, partly because firms raised prices to steer consumers towards smaller vehicles and avoid CAFE fines. At the same time, profit margins on smaller cars evaporated entirely and even turned negative for some models, at least without taking account of the implicit subsidy. Sales of small vehicles were a necessary condition to selling profitable SUVs without breaking the CAFE standards, which was deemed especially costly in terms of company reputation.

As different development teams within each firm vied for resources, the discrepancy between real and accounting profitability weakened the business case for small vehicle programmes. No wonder Ford did not bother to bring the second-generation Focus from Europe to North America, avoiding a costly retooling of its Wayne assembly plant. No wonder Chrysler never invested a lot in a successor to its relatively popular but unprofitable Dodge Neon. And no wonder General Motors relied ever more on its Korean Daewoo subsidiary to provide it with cheaper, foreign-made compact cars. These second-best choices ended up leaving these firms vulnerable in the ensuing high gas price era. Indirectly, the CAFE norms weakened the business case for investing in small cars for these firms. Of course, these firms should take the externality of high SUV profits into account when allocating development funds to small vehicle programmes; but why make it so non-transparent?

Another unintended consequence is that a carmaker with a comparative advantage in highly polluting vehicles, say Porsche, now has an incentive to purchase a carmaker producing smaller vehicles, such as Volkswagen, in order to lower the average fuel consumption of its fleet. Clearly, this does not generate any environmental benefits, but it is individually rational for a firm, especially as fines are increasing convexly. Similarly, it also strengthens the incentive for Daimler-Benz to continue its perennially loss-making Smart brand and to even introduce it in North America. Building city cars does not seem to be this firm’s comparative advantage. It also dilutes development resources as Daimler is now trying to replicate knowledge of how to profitably make small cars that other firms already possess.

Similar side-effects apply also to the EU regulation that targets a fleet’s average emission of 130 grams of CO_2 per kilometre by 2015, a further reduction to 95 g/km by 2020, and possibly to 70 g/km by 2025 (subject to review). To mitigate some of the undesirable consequences discussed above, Regulation (EC) No. 443/2009, approved by the EU on 23 April 2009, included several mitigation mechanisms. First, the emission target follows a “limit value curve”, which allows somewhat higher emissions for heavier cars, while preserving the overall fleet average. This limits the need for all manufacturers to offer a full line-up. Second, firms are allowed to pool their fleet averages. Especially in the first years, when targets are not exceedingly strict and when fines are convex in the amount of emissions, this mechanism would be beneficial. It can spread the incentive for further reductions to firms that already meet the standard and it can allow for more efficient abatement cost allocation by equalizing the marginal penalty. Third, to avoid excessive costs driven by the extremely fast timetable for adjustment, penalties to exceed the legislated standards are lowered until 2018 and very low-emission vehicles receive an additional weight.

The Canadian fee bate programme illustrates another unintended consequence. Initially, the Honda Fit exceeded the 6.5 l/100 km fuel consumption threshold for subsidies by the smallest of margins. Honda could have omitted the airbags from the Fit’s base model, lowering its weight and qualifying new owners for a $1,000 government rebate. These savings would have been more than sufficient for customers to re-select the airbags from the options list, should they so choose, for no environmental benefit and a nice taxpayer subsidy. Crandall and Graham (1989) have illustrated that the CAFE norms more generally had an effect on vehicle safety, as should be expected from the trade-off in Figure 4.

While the trade-off in vehicle characteristics is important in its own right, it also affects demand estimates, in particular the elasticity with respect to fuel efficiency. Atkinson and Halvorsen (1984) show that a tight (negative) correlation between fuel efficiency and other desirable vehicle characteristics, such as size and driving performance, leads to a multi-collinearity problem. As a result, consumers' willingness to pay for fuel efficiency is often estimated as very low or even with the wrong sign.

Their solution is to augment the hedonic model – the same could be done with a demand equation – with the technological relationship between fuel efficiency and other characteristics. Both equations can be estimated directly, obviating the need to include fuel efficiency in the demand equation. In this way, fuel efficiency is merely constraining or putting a price on other desirable characteristics.

The estimation approach in Verboven (1999, 2002) similarly incorporates that improved fuel efficiency is not a goal in itself, but a factor that influences total cost of ownership as well as performance characteristics. No structural relationship is uncovered, but the latter effect is controlled for in the conditional demand estimation.

More recently, Gramlich (2009) has argued that the current fuel efficiency frontier can be taken into account in a reduced form by including both MPG and MP$ together in the demand model. His results suggest that the monetary measure, MP$, is a highly desirable characteristic that significantly boosts average demand – in contrast to the low estimates of the mean effect of MP$ in panel (b) of Table 1. Additionally, including the physical measure, MPG produces a negative coefficient estimate in the demand equation. Once MP$ is controlled for, the MPG variable is capturing the negative impact of higher fuel efficiency on other unmeasured desirable characteristics.

4.2. Innovation to boost the fuel efficiency frontier

The frontier depicted in Figure 4 is naturally not fixed. Through innovation, firms have the potential to shift the entire relationship over time. Technological breakthroughs make it possible to improve fuel efficiency, even holding other characteristics constant. To assess the cost and speed with which this is likely to happen, we need to consider both technological feasibility and firm incentives.

To gauge the potential for such improvements, it is useful to look at past records. Results in Knittel (2009), already mentioned before, highlight that the average fuel efficiency of new vehicles in the US only increased by 15% from 1980 to 2006. However, the average increase, holding weight and power and hence performance constant, amounts to fully 50%. The latter effect is the result of technological improvements, while the former is a combination of firm model positioning and pricing, and consumer choices exploiting the ability to increase performance without a fuel efficiency penalty now afforded by the technology.

Kahn (1996) provides evidence that emissions by the motor vehicle sector of all pollutants but CO_2 have declined tremendously even though total miles driven have increased. CO_2 is still a problem, but it is an outlier.

As the energy provision in the current propulsion by fuel combustion is directly tied to hydrocarbons, it would be a major task to filter CO_2 emissions from the exhausts. Carbon capture technologies are being explored in stationary power plants, but for vehicles the only viable route for many decades will be to simply use less fuel. An alternative solution, being rolled out right now, is to use electric power from batteries and worry about CO_2 emissions in electricity generation separately.

The engineering approach to assessing the scope for and cost of fuel efficiency improvements, amounts to projecting out existing trends in technological improvement. Among many factors that will play a role, one of the most crucial is the different trajectories for incremental versus radical innovations, which lead to different short-term and long-term predictions. Mature technologies tend to require increasing R&D expenditures to realise incremental fuel efficiency gains. It leads to sharply convex costs per unit of improvement increase.

Eventually, existing technologies reach a saturation level or even a bottleneck and only radical innovations can provide further gains. As new technologies are introduced, they tend to have a much higher marginal return to R&D expenditures, at least for a while. As a result, the convexity of costs is diminished if a longer time-frame is considered.

Predictions on the long-run effect of tightening CAFE standards will need, in addition to a demand model for fuel efficiency, a model of costs associated with fuel efficiency improvements. A report by the National Research Council, NRC (2002), provides estimates on how expensive it would be to boost the fuel efficiency average in different vehicle segments. For example, in 2000 the average MPG of a midsize car in the US was 27.1. Using the formula:

$$\Delta p = a_1\left(\frac{\Delta E}{E_0}\right) + a_2\left(\frac{\Delta E}{E_0}\right)^2$$

with a_1=2799 and a_2=2152 (for medium-sized cars), it is estimated that the price of a medium-sized car would increase by $1 074 if its fuel efficiency were raised to the new CAFE standard for 2016, proposed by the Obama Administration, of 35.5 mpg.

Greene and DeCicco (2000) review the sources of heterogeneity in different engineering estimates of the likely cost increases to boost fuel efficiency.

One difficulty of using estimates like this is that there is no explicit time frame. The discussion surrounding adjustments to deal with climate change have brought to the fore that it would be a lot more costly to effect change more rapidly. In that context, the main mechanism is the early retirement of capital goods that have not physically depreciated. In the current context, the trade-off is to push existing technologies further up their cost curves, rather than wait for new breakthroughs.

The study by Fowlie, Knittel and Wolfram (2009) of different treatments of NOx pollution by stationary and mobile sources is another example using an engineering approach. Rather than estimating a marginal cost function associated with NOx abatement *ex post*, using observations on firms' expenditures and observed NOx emissions, they use *ex ante* engineering estimates for cost abatement technologies. For their analysis, they need marginal abatement cost curves for (stationary) power plants and vehicles, both for technologies that were adopted and for those that were not.

They used detailed analyses and field testing of available pollution control technologies, as carried out by industry trade groups, emissions control equipment manufacturers and other stakeholders. For the motor vehicle sector, they use estimates by the US EPA. All estimates fail to capture unanticipated changes in costs, optimization errors or behavioural responses and idiosyncrasies that caused decisionmakers to deviate from the engineering ideal. However, this is exactly what is needed to study co-ordination of adoption decisions, given the available information to policymakers.

In spite of shortcomings, some estimates are needed to do counterfactual analysis of policies right now. We can trust that better estimates will be forthcoming if there is a demonstrable demand for them. Greene, Patterson and Singh (2005) use the above estimates to evaluate the likely effects of fee bates based on fuel efficiency. They find that most of the changes would come about through technological spending to improve average fuel efficiency – with increases in vehicle prices along the lines of the calculations above. The sales reduction would be limited.

Austin and Dinan (2005) use an approach similar to Greene, Patterson and Singh (2005), also relying on the NRC cost estimates associated with fuel efficiency improvements, but their objective is to compare the effect of CAFE standards with taxes on fuel. They thus revisit the often-studied question surveyed in subsection 3.4 in a dynamic context.

Firms receive two sets of incentives to invest in fuel efficiency. Higher fuel prices, because of higher taxes, will boost sales of more efficient vehicles in proportion with the consumers' demand elasticity. The results in Figure 3 suggest the elasticity might even be increasing in the fuel price boosting this effect. At the same time, under the CAFE standard system, firms are charged a penalty if the average efficiency of their fleet does not meet a minimum standard. Certainly, under the newly increased standard, in force from 2016, all firms will be constrained and have an additional incentive to make their vehicles more efficient. The estimates in Austin and Dinan (2005) indicate that the first mechanism would be far more cost effective.

A second difficulty in using the above estimates is that effects are expressed as price increases rather than cost increases. In the automotive industry, the estimated price-cost mark-ups tend to be quite large, due to the concentrated market structure and strong product differentiation. Assuming an elasticity for the residual demand of -2, does the estimated USD 1 074 to bring the average medium-sized car up to the new mpg standard mean that costs would only increase by half, or that profit-maximizing manufacturers who implement these technologies would raise prices by double the amount[8]?

Firms' incentives to invest in innovations will influence the cost and speed of moving to greater fuel efficiency in other ways as well. Shiau, Michalek and Hendrickson (2009) demonstrate that, with heterogeneous consumers and firms, the response to higher CAFE standards will not be uniform or monotonic. Some firms will meet the standard using existing technology, perhaps only having to adjust prices to steer sales. Other firms will invest in new technologies to boost efficiency, but there are limits to this. Exceedingly high standards will make some firms rationally choose to simply pay the fines.

When firms decide on their optimal innovation policy, strategic interactions with their competitors and spillovers from technological progress cannot be ignored. Barla and Proost (2008) derive a general equilibrium model, where rational firms under-invest in fuel-saving technology as competitors are able to benefit from their efforts through technology spillovers. To achieve first best in this situation, an additional policy tool is need, e.g. both fuel taxes and emission standards.

Finally, Hashmi & Van Biesebroeck (2010) study the strategic interaction of firms' innovation decisions in a dynamic context. Results suggest that in highly concentrated markets, such as the automotive industry in the last decades, innovation is subdued as strategic motives start to matter.

One channel is that firms invest partially to increase their value in the case of a merger. When taken over, the compensation for the original shareholders will generally increase with the value of the assets of the firm. With fewer independent groups left, future mergers are becoming increasingly unlikely, given competition policy constraints, which provide reduced incentives for innovation.

A second channel is that firms decide on innovation expenditures strategically. Estimates of the dynamic policy in Hashmi and Van Biesebroeck (2010) suggests that innovation incentives are concave in the knowledge stock of other firms in the industry. At least in the area of the state space where knowledge is high, innovations are found to be strategic complements. Given that the direct effect of innovation on consumer demand is also concave, there is an inevitable upper bound on the optimal steady state knowledge stock.

A final channel hampering innovation, given the current state of the automotive industry, is that the model predicts an inverted U relationship between market structure and innovation. Both the leaders and the distant laggards invest less than the firms in the middle that are trying to catch up to the leaders or trying to avoid the absorbing state with a zero knowledge stock. As the large groups in the industry are converging to some stable oligopoly, fewer middle firms remain.

5. CONCLUSIONS

Calculations of the cost and the best way to achieve a decrease in fuel use by the motor vehicle sector will necessarily take the form of counterfactual simulations of the evolution of a market equilibrium. To have confidence in the predictions, we need to have confidence in the primitives of such a model. In these conclusions, the author wishes to highlight two important areas that could greatly benefit from additional research.

First, while there are many demand estimates that characterise consumers' willingness to pay for fuel efficiency improvements in this industry, the point estimates vary widely and their exact values matter in the counterfactuals. A more rigorous understanding of the nature of identification of the parameters and, ideally, a more transparent identification strategy are needed.

To further our understanding, the instability of the demand elasticity with respect to fuel efficiency and across consumers has to be better understood. A higher elasticity at higher fuel prices is not unreasonable – given the low elasticity of fuel use, fuel cost takes up a much greater share of the total cost of car ownership when prices are high – but the exact way this enters the consumers' decision process needs to be understood and modelled for it to be useful in a counterfactual simulation where fuel prices will be modified.

In addition, the current technological frontier forces manufacturers to trade-off fuel efficiency and other desirable characteristics. This imposes a strong correlation on the different vehicle characteristics. Estimation problems with one of the variables will thus immediately spill over to the other. Functional form assumptions are also more important in this context.

More generally, it should be explicitly understood that fuel efficiency has multiple effects in the vehicle choice decision: it is a fraction of the cost; it is a constraint on the other characteristics a vehicle can possess; and it might have an intrinsic value for the environmentally conscious consumer. If alternative policies differ in their impact on fuel prices, it is important to separately identify these effects.

The second area that deserves a lot more attention is the behaviour of firms. They are not passive actors that simply move along a deterministic cost curve as fuel prices shift exogenously with the crude oil price or fuel taxes.

Firms have to choose other characteristics and prices to position their vehicles along a fuel efficiency frontier. If consumer demand for fuel efficiency is one important ingredient in this decision, it is definitely not the only one. Firms will take into account where on this frontier profit margins are highest. As a result, their responses to fuel taxes and mandated emission norms could be very different if product heterogeneity is explicitly accounted for.

In recent years, an additional choice has opened up for firms. Exploiting the possibilities with diesel or hybrid technology, it is now possible to offer models with similar characteristics, e.g. size and driving performance, but with enhanced fuel efficiency. To predict how firms will exploit this possibility, it is important to separately identify the willingness to pay of consumers for fuel efficiency, not only in terms of other characteristics, but also in terms of out-of-pocket spending.

Finally, existing simulations by and large treat the problem of firm innovations to shift the above frontier as a single agent problem. While natural from an engineering point of view, it leaves out strategic considerations. In a concentrated industry like automotive manufacturing, firms will take innovation decisions by competitors into account in their own decisions and technology spillovers will cause underinvestment.

NOTES

1. During the 1990s, Chouinard and Perloff (2007) document that other factors, such as taxes, mergers and regulations, were of minor importance in explaining fuel price changes over time, but they did predict geographic differences rather well.

2. Studies omitted from the discussion for this reason are, in chronological order, Bresnahan (JIE, 1987), Feenstra and Levinsohn (RES, 1995), Verboven (RAND, 1996), Fehrstman and Gandal (Rand, 1998), Verboven (JIE, 1999), Goldberg and Verboven (RES, 2001), Brambilla (NBER WP, 2005) and Esteban and Shum (Rand, 2007).

3. These are semi-elasticities which need to be multiplied with the mean of the explanatory variable to obtain the elasticities.

4. A lot lower than those in Houthakker (*Energy Journal,* 1980) who ignored the first stage and found an elasticity of 1.4 for the electricity price and 0.7 for the gas price for residential electricity demand.

5. The latter two strategies only work if markets are defined geographically. Specifically for the automotive industry, prices in other markets would not work, as the importance of national advertising would make demand shocks spill over to all geographical areas.

6. Borenstein (1993) tackles this issue head-on in the context of the phase-out of leaded fuel. Goldberg (1998) calculates the cost of strengthening CAFE standards using a demand model that incorporates willingness to pay for fuel efficiency.

7. A benefit of their approach is that the same data is used to estimate the elasticity in vehicle demand with respect to fuel efficiency and the price elasticity of fuel demand.

8. Optimal pricing of a monopolist predicts a price cost margin (p-MC)/p equal to $1/|\varepsilon|$ using the elasticity of the residual demand.

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STIMULATING LOW-CARBON VEHICLE TECHNOLOGIES

Governments around the world are increasingly intervening in automobile markets to improve fuel economy and reduce emissions of CO_2 from new vehicles. This report reviews the rationale for such intervention and examines measures for maximum effectiveness and minimum cost.

The Round Table brought together economists, policy makers and auto engineers with the aim of advancing understanding of why car markets currently fail to deliver sufficient fuel economy. It started by questioning whether any additional measures would be necessary once an appropriate price for carbon dioxide is established via fuel taxes. It confirmed that there are indeed market imperfections that merit additional government intervention. Fuel economy and CO_2 regulations are an essential part of the package. The key to maximising the benefits of such regulations is long-term planning. The longer the timeframe, the less industry investment is handicapped by uncertainty.

Subsidies to electric vehicles are more problematic because of the risks of prematurely picking winning technologies and creating subsidy dependence. And electricity production has yet to be decarbonised. However, intervention to steer innovation in this direction is merited so long as the risks of not attaining climate policy targets are seen as higher than the risks of intervention.

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