Strategies to reduce carbon dioxide emissions from road traffic

Gunnar A Eriksson, Nordplan (Nordic Institute for Studies in Urban and Regional Planning)/Lawrence Berkeley Laboratory

1. SYNOPSIS

A carbon dioxide fee and a complementary fuel economy tax on new vehicles can lead road traffic to an adjustment at the lowest social costs.

2. ABSTRACT

The debate about instruments to reduce carbon dioxide emissions from road traffic is to a large extent focused on carbon dioxide fees and standards for fuel economy taxes. Some transportation demand management and traffic management measures can decrease emissions to low costs; however, their applicability is limited. A general carbon dioxide fee can theoretically be shown to be the superior instrument to reach emission reductions, given a "perfect market." Market imperfections and political obstacles are the main arguments for vehicle standards or fuel economy taxes. The author's past work as well as a current literature review indicate market imperfections. Vehicle purchasers tend to undervalue fuel costs. In combination a carbon dioxide fee and a fuel economy tax on new vehicles are suggested as the main instruments in a strategy to reduce carbon dioxide emissions from road traffic.

3. INTRODUCTION

Over the last few years, risks to the world's climate have put emissions of carbon dioxide on the agenda for international environmental cooperation. The close relationship between carbon dioxide emissions and the use of fossil fuels has given a new dimension to traditional energy policies and efforts to conserve energy. The European Community (EC) has stated that carbon dioxide emissions in the year 2000 shall not exceed the 1990 level; Japan has a similar objective. Intense discussions are taking place about how to reach these objectives. The EC is considering carbon dioxide standards for automobiles as well as a carbon dioxide fee.

This paper is a contribution to the discussion about strategies to reduce carbon dioxide emissions from road traffic.

As long as fossil fuels are used, three factors can be influenced to limit carbon dioxide emissions from road traffic:

(1) Vehicle energy *intensity*, measured in energy use per vehicle km;
(2) Transport *activity*, measured in number of person-km travelled and ton-km transported; and
(3) *Structure*, or modal distribution.

Many countries favor lowered energy intensities through technological means. Politicians appear to believe either that improving technology is less costly than influencing transportation patterns (activity and structure) or that it is politically less difficult to do so. However, society can no longer afford to focus exclusively on technological improvements in vehicles.

While emission-control technologies have been able to reduce carbon monoxide, hydrocarbons, and nitrogen oxides, that possibility is still not feasible for carbon dioxide. The only current avenues for reducing carbon dioxide emissions from vehicles are to reduce energy intensity and to use renewable resources or nuclear energy. While renewables have been proven technically possible for transportation purposes, they are expensive. Costs of 0,05 to 0,15 ECU (0,5 to 1,4 SEK) and above per kg carbon dioxide reduction seem probable. Efficiency improvements, on the other hand, have been offset in most countries--the U.S.

excepted--by increases in vehicle weight, engine size, and acceleration. The effects on average intensity have been modest.

Furthermore, historical international trends show that decreased overall energy intensity has been counter-balanced by growth in transport activity and change in structure. Let us take the U.S. as an example. Between 1973 and 1988, intensity decreased by 18 percent, but total travel increased by 38 percent. The modal share of air travel increased, while the share of car travel decreased and the mass transit share remained almost constant. The result was a 13 percent increase in energy use and a corresponding increase in carbon dioxide emissions. In Germany and Italy, intensity increased substantially (17 and 15 percent, respectively) during the same period. In combination with changes in activity and structure, energy use increased 56 and 85 percent, respectively (Schipper et al. 1992, p. 111 ff.) To summarize, the past does not prove that a decrease in intensity is sufficient to reduce energy use and carbon dioxide emissions.

There are also general reasons to suspect that a focus on a single group of measures is unfortunate and will lead to a more costly change than necessary. The rational way to search for a solution is to look for the least costly means independent of category. Even changes in activity and structure must be taken into account. For instance, Charles River Associates point out that some transportation demand management (TDM) measures to reduce carbon dioxide emissions, such as congestion pricing, building high occupancy vehicle lanes and employer-based car and van pooling programs, have no net social cost (Charles River Associates Inc. 1991). Similarly, Transek AB has identified some investments in transit and transport infrastructure that may reduce emissions with a negative societal cost (Transek AB 1992). Even though these possibilities have limited applicability, they indicate that other low-cost measures besides decreased intensity really exist.

Another reason for a broad perspective is that the potential for low-cost options to decrease intensity is being questioned. Studies financed by the U.S. Department of Energy and other American authorities indicate a substantial potential to reduce carbon dioxide emissions from automobiles at negative costs. They claim that some existing technologies are socially profitable but have not achieved optimal penetration in the market (Difiglio, Duleep, and Greene 1990; Ledbetter and Ross 1990). These studies have been criticized by American automobile manufacturers. The latter financed a separate study carried out by SRI International that concluded that low-cost technologies for decreased fuel intensity are very limited (SRI International 1991).

This background description shows that we cannot rely solely on technical means to limit carbon dioxide emissions. Obviously, we also need to influence transportation patterns, and this conclusion has policy implications. The purpose of this paper is not to analyze how to partition changes among technology, activity, and structure, but to discuss how to develop incentives and regulations that lead in the real world to the reduction of carbon dioxide emissions at the lowest cost to society. Hypotheses from the author's prior work are examined in the light of a literature review. Policy consequences are discussed.

4. INSTRUMENTS FOR IMPLEMENTATION OF CARBON DIOXIDE EMISSIONS REDUCTION

There are three policy instruments or groups of instruments that can cause a reduction of carbon dioxide emissions from road traffic:

(1) A carbon dioxide fee on fuel;
(2) Instruments directly affecting vehicle technology and purchasers' choice of vehicles, like fuel economy taxes, fee-bates, and standards; and
(3) Transportation demand management (TDM) policies.

These possibilities are all known from the international debate.

One can, theoretically, show that a carbon dioxide fee is *the* cost-effective instrument, presuming a "perfect market." As illustrated in Table 1, it will change intensity as well as activity and structure in desirable

Table 1. ***The influence of different measures on the transportation market, energy intensity, emissions of carbon dioxide***

	Technology	Transportation patterns Activity	Structure
Carbon dioxide fee	+	+	+
Standards, etc.	+	-	-
Transportation demand management policies	+	+	+

+ = > Change in desired direction
\- = > Change in undesired direction

directions. A broad-based fee will also stimulate similar changes in other sectors in a favorable way. Standards--like the U.S. CAFE standards or the EC proposed standards related to vehicle weight--would initiate an intensity change in the desired direction. Other things being equal, activity as well as structure will be influenced in a somewhat offsetting manner. Increased fuel economy reduces the cost of driving. The effect on the margin will be an increase in automobile travel and an increase in market share for solo driving--a rebound effect. On the other hand, transportation demand management policies can influence activity and structure in desired directions and can also decrease intensity. Less driving in congested roads and highways decreases intensity.

Consequently, standards and fuel economy taxes should not be used as a single instrument to reduce carbon dioxide emissions. Desired changes in transportation patterns would not occur. TDM policies can contribute to desired changes but their applicability is limited. There is a need for a carbon dioxide fee.

4.1. A carbon dioxide fee in a perfect market

The effects of a carbon dioxide fee on gasoline use, given a perfect market, are illustrated in Figures 1a-d.

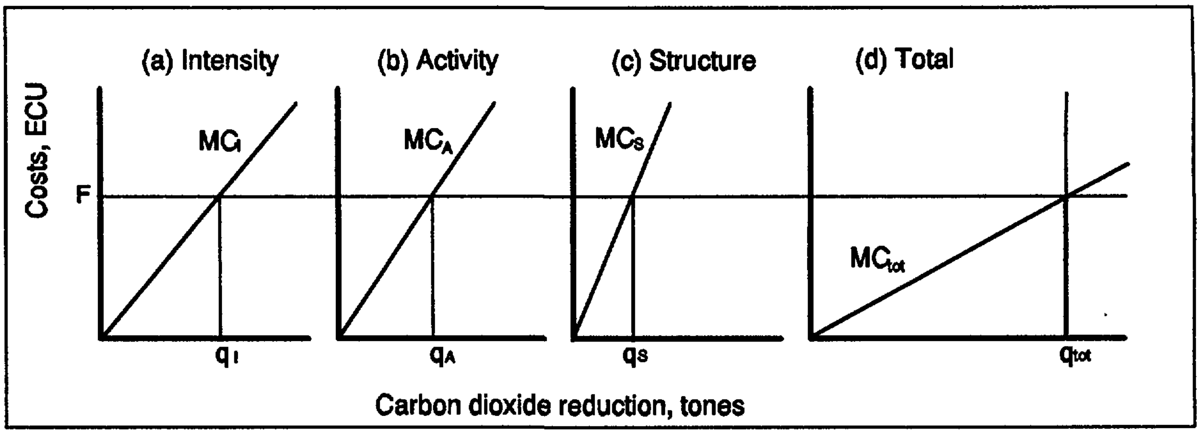

Figure 1a-d. ***Market response to a carbon dioxide fee (F) in a perfect market***

The figures show the marginal costs (MC) to reduce carbon dioxide emissions, with reduction of carbon dioxide at the X-axis and costs at the Y-axis. The diagrams show costs connected to intensity (Figure 1a), activity (1b), and structure (1c), respectively. The MC curves are all assumed to be linear. A carbon dioxide fee (F) is introduced. The fee is set such that the market will respond by reducing the emissions at the targeted level, illustrated by the vertical line in Figure 1d. Figure 1d also summarizes marginal costs for the whole market. In a perfect market, the fee will generate all changes with lower costs than the fee. In other words, all measures described by the continuous parts of the MC-curves would be implemented. Total reduction q_{tot} equals $q_I + q_A + q_C$. Observe that marginal costs for different changes are the same for Figure 1a-c, which is necessary for economic efficiency. This description is somewhat simplified; interactions between measures may in fact result in a MC_{tot}-curve not equal to $MC_I + MC_A + MC_S$.

Analyses often stop at this point, and consequently suggest a carbon dioxide fee as the only measure, but there are reasons for further concern.

4.2. A carbon dioxide fee in the real world

The efficacy of a carbon dioxide fee in the real world has been questioned largely from a political perspective. People object that a sufficient reduction of energy use and carbon dioxide emissions requires a substantial long-term fee that would lead to far-reaching undesirable results, affecting personal mobility as well as other sectors of society. However, once decided that emissions should be limited to the lowest social cost, this kind of argument has little relevance. Then some changes in transportation patterns and a somewhat decreased mobility also have to be accepted.

The necessary level of the fee can be illustrated by a recent study of Swedish conditions. In light of official traffic forecasts, forecasts of vehicle emissions, the estimated price elasticity of gasoline demand, and the national carbon dioxide objectives, the necessary price increase has been estimated. The study finds that the price of gasoline must be kept at about 0,85 ECU per liter (real price) until the year 2000 to force Swedish automobile traffic to meet the objective (Hesselborn 1992). Due to tax increases in January 1993, and a depreciation of the Swedish krona, the gasoline price is already at the required level. The policy then must keep prices at this level. However, past experience shows that high tax increases are generally followed by tax decreases in proportion to inflation.

As a single instrument, a carbon dioxide fee can be called into question from an efficiency point of view. Complementary policy measures may also be needed. A key question is how consumers really value fuel costs. Is the commonly used assumption about rational consumers and a perfect market relevant? This assumption is linked to the consumer's ability to value fuel costs in a rational and consequential way. The consumer is supposed to value fuel costs in the same way when deciding what car to buy (choice of intensity) as when deciding how to use the car (choice of activity and structure). As viewed from the society's perspective, people have to value fuel costs consistently when deciding how to make trade-offs among changes in intensity, activity, and structure. No one would argue that those valuations are carried out absolutely correctly, but some would argue that consumers do rough estimations, which fits reasonably well within the definition of rational behavior. Complementary policy would then be unnecessary.

The valuations connected to choice of intensity, activity, and structure have considerably different characters. It is indeed a complex task to value fuel costs rationally when buying a car. Consumers have to form an opinion about different cars' on-the-road fuel intensity, how much the vehicle will be driven during the time it is owned, how and if prices in the second-hand market are related to fuel economy, future fuel prices, and the alternative value of money--the discount rate.

To value fuel costs connected to an imminent trip is comparatively simple. Normally, based on experience with the automobile, a driver estimates the car's fuel intensity and takes into account the length and expected driving conditions for the trip as well as current fuel prices.

There seems to be little doubt about consumers' ability to make a reasonable valuation of the latter. (Although it has been questioned whether an average driver does a proper valuation of total marginal costs including wear and tear, maintenance, etc.) On the other hand, there is reason to doubt consumers' abilities or willingness to value fuel costs in a "rational" way when purchasing vehicles.

The efficiency of market valuations of energy costs also has generated a lot of interest. There is a broad academic literature on the subject mainly concerned with markets for appliances and housing. There are also general descriptions of the issue--the state of the efficiency gap (see for instance Grubb 1990; Howarth and Andersson 1992). Many studies, some of them quoted below, have indicated such conditions. Technologies proven to be efficient have not reached an economically motivated market penetration. Lack of information and high transaction costs are often mentioned explanations. Some consumers' limited access to capital and difficulties in borrowing money--leading to high implicit discount rates--are other explanations as well as rapid payback requirements and "lack of interest." Fuel costs alone are a small share of total costs for car use. The vehicle purchaser simply might focus on other characteristics.

Separating expenditures and benefits are thought to be of major importance, especially for the housing sector. It might also be significant for the automotive sector in countries where a large share of new cars are bought as company cars used as fringe benefits. In these cases the employees choose the automobile, but the employer pays the fuel bill.

An undervaluation of fuel costs in the vehicle market will also make it unprofitable for vehicle manufacturers to invest in research and development for efficient fuel economy. No one can be expected to produce vehicles that generally are not demanded by the market.

4.3. Buyers' valuation of fuel costs

During 1992 the author conducted informal interviews with vehicle manufacturers and some representatives for larger purchasers in the Swedish market (some results have been reported in Eriksson 1992). The basic assumption was that professionals in the vehicle market could be expected to have special knowledge about evaluating fuel costs.

Representatives for manufacturers expressed their opinions in different ways. One argued that the market demands that extra capital costs for decreased fuel consumption must pay off for the first owner. Another referred to companies' general principles for writing off investments; like all investments, an investment in fuel economy must be profitable during the period it is written off. In a third case the representative claimed that investments in fuel economy have to pay off in two to three years.

However, there are also examples to the contrary. There are some purchasers who practice so-called life-cycle-cost analysis to compare alternatives.

Altogether the interviews indicated an undervaluation of fuel costs. Perhaps surprisingly, the pattern seems to be valid not only for autos but also for buses and trucks. The differences might be greater between types of purchasers than between vehicle categories, for example, between town-owned bus companies and independent tour bus owners. A buyer who intends to use the vehicle during its entire economic life time and a major part of its technical life time, and operates under less uncertainty concerning future market conditions, can be expected to focus more on life-cycle-costs than other buyers do.

The study identified two hypotheses:

(1) Purchasers value fuel costs only during the three first years; and
(2) Manufacturers make a similar estimation of their customers' behavior.

According to these hypotheses, purchasers will take 40 percent of the fuel costs into account, assuming a discount rate of 10 percent. With a 20 percent discount rate the purchasers will consider 50 percent of the fuel costs. Do these hypotheses agree with other research concerning purchaser' valuation of fuel costs?

It is apparent that this question generated much interest during the 1970s and the first years of the 1980s. A search in literature databases gives just a few more recent references. Some results are quoted below.

In the beginning of the 1980s, similar interviews were conducted with automobile manufacturers selling in the American market, but that study was focused on macro-estimations of average fleet fuel use (Energy and Environmental Analysis Inc. 1982). Only one concrete but rough estimation of valuation of fuel efficiency improvements was reported:

> "A $ 200 improvement in the engine is acceptable for an improvement of 3 mpg but it is not acceptable for a 0,5 mpg improvement..."

A rough calculation shows that the given cost-effective estimate included poor as well as profitable solutions. A 0,5 mpg increase should hardly have paid off, but at the given cost ($ 200) a 3 mpg increase would have paid off in about 3 years. Expressed in another way, it was profitable even with a discount rate at 40 percent. The statement gives little information about real fuel valuation.

During the end of the 1970s and the beginning of the 1980s, a number of American econometric studies were carried out to estimate automobile purchasers' discount rate. What discount rate does a buyer in fact use if he or she values fuel costs in a rational way? Methods and results have been summarized and compared in a few articles. The studies give far from a consistent picture of consumers' implicit discount rates. Discount rates vary from a low of 0 to a high of 60 percent (Greene 1983. Tardiff 1980. Train 1985). The lower rate *can* indicate a very high valuation of fuel and the higher rate *can* indicate a low valuation of fuel. Nevertheless, even if there had been consistent results it is difficult to draw conclusions about consumers' valuation of fuel cost. The implicit discount rate can be a result of factors other than valuation of fuel costs, such as expectations about future fuel prices, maintenance costs, etc. A few results of interest are discussed in the following section.

Manski and Sherman found widely varying sensitivity to operation costs for different household types. Some households are even identified as preferring cars with high operating costs, other things being equal (Manski and Sherman 1980).

Boyd and Mellman suggest that fuel savings from gasoline price increases will come primarily from the supply side. Higher fuel prices will lead to improvements in the fuel economy of cars in all size classes, rather than market shifts among size classes (Boyd and Mellman 1980).

In a more recent article, Greene focused on the choice between gasoline- and diesel-fueled cars. He analyzed purchasers of new cars in the U.S. from 1979 to 1983. The results of his calculations with two logit-type models suggest discount rates of 30 percent and higher. According to the author, this indicates that only technologies with payback periods of two to three years or less can be expected to succeed voluntarily in the market (Greene 1986).

As a basis for an analysis of the social costs for CAFE-standards--compared to fuel taxes--Crandall brings up the question about an auto purchaser's valuation of fuel costs (Crandall 1992). He refers to some arguments often raised by advocates of energy-efficiency standards: empirical studies of consumer behavior, which suggest that households employ high discount rates; imperfect information to the purchaser; and principal-agent problems for leased vehicles and market power in the industries. However, he states that high implicit discount rates can have bases other than an irrational valuation of fuel costs, and even if this is not the case--according to Crandall, there are better ways for dealing with that problem than designing standards for one single durable. He claims that mandatory fuel-economy labeling of autos provides substantial information to the consumer, and that leased vehicles are often in large fleets that use sophisticated cost-minimization strategies. The competition in the motor vehicle industry is claimed to have increased remarkably during the 1980s. The discussion is kept at a general level. No empirical studies are quoted.

Crandall concludes that "the existing empirical literature suggests that CAFE costs about 7 to 10 times as much as a petroleum tax that would induce a comparable reduction in oil consumption, because CAFE fails to equate the marginal costs." Crandall quotes results from Charles River Associates and Leone &

Parkinson. However, both those studies assume a perfect market. CRA discuss the question but states that their study is not broad enough to resolve this issue. Leone & Parkinson do not discuss it at all. Consequently, quoted literature is not "empirical" in the sense that they treat the key question--consumer behavior--in an empirical way. The only conclusion that actually can be drawn is that, given a perfect market, fuel taxes are superior to CAFE as a tool to decrease fuel use. However, that is really not an issue. Hardly anyone would disagree.

Crandall's article emphasizes the lack of empirical evidence of a "perfect" vehicle market. The article presents no empirical studies that suggest that the market is perfect. It presents general theoretical comments and personal beliefs.

The inescapable conclusion from this literature review is that current research yields few answers about vehicle purchasers' real valuation of fuel costs. The literature definitely does not contradict the mentioned hypotheses. There are reasons to believe that vehicle purchasers undervalue future fuel costs. The final part of this paper is dedicated to a discussion of its importance in terms of the effects of a carbon dioxide tax.

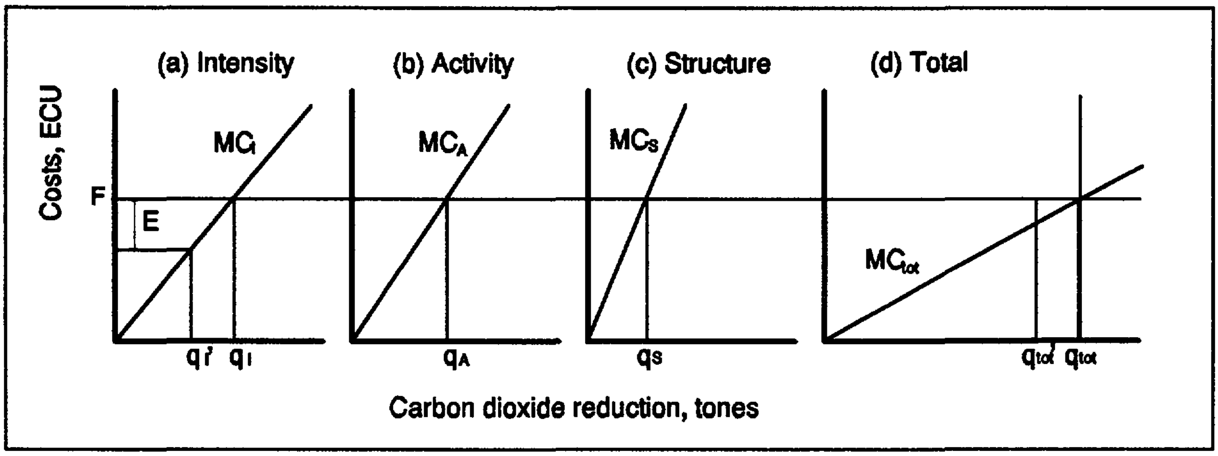

Figure 2a-d. ***Market response to a carbon dioxide fee on fuel (F) whenn fuel costs are undervaluated***

How should this be taken into consideration when establishing policy instruments?

4.4. Combination of a carbon dioxide fee and a fuel economy tax

Figure 2 describes a situation where consumers manage to rationally value fuel costs (including a carbon dioxide fee) linked to imminent trips but undervalue fuel costs in connection with vehicle purchases. The reductions related to changes in activity (q_A) and structure (q_S) are identical to those in Figure 1, but the reduction related to intensity is lower. If purchasers undervalue fuel costs, they will also underestimate their economic gain from investments in fuel economy and carbon dioxide-reducing technology. Reduction of carbon dioxide emissions linked to changes in intensity will be only q_I', compared to q_I. In other words, certain improvements in technology will not occur even though marginal cost falls below the fee (F). This situation, with differing marginal costs for carbon dioxide reduction among the charts or "sectors," is not consistent with social efficiency.

Compared to the situation in a perfect market and to the objective level, the total reduction will be lower. The decrease in reduced quantity will equal the change in q_I--(q_I-q_I'). One possibility to compensate for this is to increase the carbon dioxide fee. However, this would lead to an over-optimal change of transportation patterns (activity and structure). The marginal cost would still differ between changes in intensity and transportation pattern--economic efficiency would not be reached. Combining a carbon dioxide fee with another incentive would be a better solution.

With the picture of market imperfections as described above--and formalized in hypotheses (1) and (2)--it is natural to look for instruments exclusively affecting purchase decisions, but not affecting activity and structure.

From an efficiency point of view, the best solution seems to be to add a fuel economy-related sales tax on vehicles. The tax must be designed to compensate for the typical purchaser's undervaluation of fuel costs (including the carbon dioxide fee). Total distance driven by a typical vehicle belonging to a certain vehicle category must also be taken into account. Distance has to be multiplied by the discounted value of fuel costs and the share of total (discounted) fuel costs that the typical consumer does not consider as a part of the purchase decision. The result is the "effective" sales tax on new vehicles belonging to a certain category. It could, for instance, be measured in ECU per estimated centiliter (cl.) of fuel consumption per 100 km. An example of the calculation is presented in Table 2.

An additional tax of this kind can be questioned from an equity perspective. It would add a burden on vehicle purchasers, a burden that is not motivated by any real social cost. Even though the buyer does not take into account full fuel costs (including carbon dioxide fees, taxes, etc.) when purchasing the car, he or she still has to pay full costs when using the car. The purpose of the tax is exclusively to strengthen the incentives and to influence the choice of vehicle. If the total taxation of road traffic initially is at a desired level, there are reasons to develop a revenue-neutral tax.

First, there is no need to tax every centiliter. An alternative is to have a limit under which no tax is charged. However, it is important that such a limit be lower than fuel use for the vehicles with the best fuel economy in the market (of those sold in amounts of importance). If not, the desired effect will be limited. This alternative would decrease the amount of income transfers, but still not eliminate them. A combination with decreasing or abolishing fiscal taxes on road traffic could render tax neutrality.

Another possibility is to develop a so-called fee-bate system--a solution, almost equally good from an efficiency point of view. An average fuel consumption over a certain level is charged when vehicles are purchased, while vehicles with better fuel economy would be given a rebate. The drawback with a fee-bate system, compared to a fuel economy tax, is that it has an income effect. The rebate given to purchasers of vehicles with low intensity gives, everything else being equal, an extra income to save or to consume,

Table 2. ***Calculation of tax level for a certain vehicle type, given estimations of market valuations. The figures do not represent any specific vehicle category.***

Typical distance per year	15 000 km
Typical life-time	10 years
Typical total distance driven	150 000 km
Estimated average real fuel price	1 ECU/l
Estimate total fuel costs, discounted at a real rate of 10%	9 200 ECU
Estimate average undervaluation of fuel costs, discounted	60 percent
Total undervaluation per vehicle	55 200 ECU/l*100 km
Tax level	552 ECU/cl.*100 km

among others to consume on increased vehicle performance. However, my guess is that this drawback is of minor importance.

Even if the suggestion of a fuel economy tax meets political obstacles, the analysis can still be important. It suggests a combination of a carbon dioxide fee and a complementary measure. If a fee-bate system cannot be introduced, standards can be an alternative. The EC's suggestion about carbon dioxide standards related to vehicle weight is such a possibility. The above calculation of a tax level can be used to determine levels of proposed fees for violations of standards.

5. CONCLUSIONS AND PROPOSALS

This paper suggests the introduction of a carbon dioxide fee in combination with a fuel economy tax on new vehicles.

The carbon dioxide fee should not only be charged exclusively for road traffic, but also for all transport modes and all sectors. This fee is of fundamental importance in reducing the carbon dioxide emissions and controlling climate risks. It would influence not only intensity but also activity and structure. International cooperation creates possibilities for also charging air traffic and shipping. A promising method for estimating the level for a carbon dioxide tax on fuel has been mentioned.

There are reasons to believe that a carbon dioxide fee should be combined with a fuel economy tax to compensate for purchasers' undervaluation of fuel cost and to force decreased intensity. Principles for the calculation of the tax level have been proposed.

These proposals are not based on absolute scientific evidence on how the market works. They are based on available research and general judgments. A broad discussion among researchers and politicians can surely contribute to the development and implementation of the proposals.

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ENDNOTES

1. The author's calculations are described in enclosure to TFB-report 1992:29. The calculations are based on Ecotraffic AB, Alternativa drivsystem och drivmedel för vägtrafik, Enclosure to TFB-report 1992:7, Swedish Transportation Research Board, 1992.

2. Assuming 24 mpg as a base level (average for new car in 1980), stable gasoline prices at 1980 year level (1980 $1,20 per gallon), a real discount rate at 10 percent and, annual driving distances decreasing from 13 800 miles in year 1 to 8 700 miles in year 10.

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