Steering the European transport greenhouse gas emissions under uncertainty

Svante Mandell
vti – Swedish National Road and Transport Research Institute

ABSTRACT

This paper addresses how to regulate greenhouse gas emissions from the transport sector when abatement costs are uncertain. In an EU context, it is shown that a combination of a cap-and-trade system and emission taxes is preferable as it minimizes the expected efficiency loss. The optimal design will depend on the relative cost structure within and outside the transport sector. It is argued that the optimal regime for the transport sector has similarities, but is not identical to, a pure emissions tax.
1. Introduction

The EU has committed itself, under the Kyoto protocol, to reduce emissions of greenhouse gases (GHG) by 8% for the period 2008-12 compared to the 1990 level. A large share of the EU’s total GHG emissions comes from the transport sector\(^\text{1}\), mostly from road transports. Furthermore, emissions from road transports within the EU are increasing. There are substantial differences between member states, but as a whole, GHG emissions from road transports in the EU-15 increased by 25% between 1990 and 2005. The EU has not established any binding emission targets for the transport sector but has recently communicated an intention of reducing its GHG emissions by 20% by 2020.

All member states in EU-25 use taxes as one, out of several, ways to regulate road transports, see for example Eurostat (2008) and COWI (2002). Since it is up to the individual member states to decide on the tax level, this is not uniform throughout the EU. Even though it is hard to distinguish what share of each member state’s taxes are specifically targeted towards CO\(_2\) emissions, differences in tax levels suggest that the cost of emitting a tonne of CO\(_2\) differs between member states. As the origin of the CO\(_2\) emissions is irrelevant for the impact on climate, this difference yields an allocation of abatement efforts among member states that is not cost effective.

An alternative approach that has been discussed in the debate is to subject road transports to a cap-and-trade regime, see, e.g., TemaNord (2007), OCC (2007) and Kågeson (2008). This could entail an isolated cap-and-trade regime for road transport only. There is a possibility to explicitly link such a regime to the existing European Emissions Trading Scheme (EU ETS) that presently covers CO\(_2\)-emissions from the energy intensive industry. Another alternative is to fully

\(^{1}\)In 2005, the transport sector contributed 24.1 per cent of total GHG emissions (CO\(_2\), CH\(_4\), N\(_2\)O) in the EU-27 (including international aviation and maritime transport and excluding land-use change and forestry activities). Source: European Parliament (2007).
incorporate road transports into EU ETS. Introducing a cap-and-trade regime for road transport does not necessarily imply that the current taxes are abolished.

The present paper aims at adding to the discussion about how to best handle the GHG emissions from the transport sector by analysing different alternatives. The analysis is carried out given the quantitative nature of the EU’s targets under the Kyoto protocol and given that a large share of the emissions is subject to the EU ETS. As will be further discussed below, there are mechanisms that allow for total emissions to vary to some degree. Even so, total emissions both from EU as a whole and from the EU ETS sector are to a large extent fixed. This has important implications; in particular, it results in that regulating the transport sector with taxes has two important drawbacks.

Firstly, if the emitters’ cost structures are not known with certainty, transport and energy intensive industry will most likely face different ‘prices’ for emissions. This means that the abatement efforts will not be distributed between the sectors in a cost effective manner. This may be justified for instance by noting that many firms covered by EU ETS act on markets with competitors that face lower (or no) costs for CO₂ emissions. Subjecting these firms to CO₂ prices far above their competitors may result in that emissions move to countries with less or no regulations, so called carbon leakage. For other sectors, e.g., the transport sector, the possibilities of carbon leakage are much smaller. Thus, it may be argued that such sectors should carry a larger share of the burden, i.e., emitters in such sectors should face a higher CO₂ price. Another line of reasoning stems from the fact that a combination of a capped sector and a taxed sector may result in a level of emissions closer to the efficient one. This reasoning concludes that there might be positive effects that counter or even outweigh the lack of cost effectiveness most likely present when some emitters face a cap-and-trade regulation and others face an emissions tax, see Mandell (2008).
Secondly, again under the presence of uncertainty, subjecting the transport sector to a tax results in emissions being uncertain. In itself, this is not a major problem. However, since the EU is subject to a quantitative regulation and emissions from a large share of the economy also is fixed (due to the EU ETS) uncertainties in emissions levels from the transport sector may result in a situation where the EU would be unable to meet its target due to high emission levels from transportation. Such situations are not unanticipated and there are mechanisms designed to handle them, which will be discussed in more detail in the next section. Using these mechanisms is costly. Therefore, it may be better, from a welfare point of view, to adopt a quantitative regulation also for the transport sector.

Although important, the first set of problems, related to cost effectiveness, will not be in focus in the present paper, which rather aims at studying the second set of problems in more detail. Here, we are interested in comparing situations where the transport sector is (i) covered by a separate cap-and-trade system, (ii) covered by a tax system, or (iii) a combination of these two. Effects of linking a cap-and-trade system covering transports with the EU ETS will also be briefly addressed.

The paper is organized as follows. Section 2 addresses the objectives of the regulator along with a discussion about the nature of costs and benefits of GHG emission abatements in the EU transport sector. In section 3, the model is presented. Section 4 contains an analysis of the outcome of the model, including optimal levels and comparative statics of the policy instruments. Section 5 contains some further discussion as well as concluding remarks.

2. Regulator’s objectives and abatement benefits and costs

As stated in the previous section, the present paper aims at examining policy choice with regard to the transport sector. It is assumed that the policy must be decided upon and declared before the agents in the economy decide on which actions to take, which implies that things may
happen between the point in time where the policy is declared and when the abatement actions are undertaken. As a consequence, the policy choice is made under the presence of uncertainty. Thus, the objective of the regulator is to choose a policy that minimizes the expected efficiency loss.

There is a substantial literature on policy choice under uncertainty on which this paper builds. The first to analytically examine this is Weitzman (1974) in his seminal paper on prices versus quantities. As will become apparent, the outcome of the model in the present paper will have strong similarities to the outcome under a regulation mechanism found in a famous paper by Roberts and Spence (1974). This is the case even though the approach pursued in the present paper is fundamentally different to the mechanism developed by Roberts and Spence, which relies on a system with subsidies. Following these two papers is a series of interesting studies with different applications, e.g., Hoel and Karp (2001, 2002) and Newell and Pizer (2003), which study the case of stock externalities and Pizer (1999, 2002) that specifically addresses climate change, as well as variations of the models, e.g., Stavins (1996) that studies the case of correlated uncertainty, Montero (2002) that allows for imperfect monitoring and enforcement, Malcomson (1978) and Yohe (1978) that both argue against the use of linear approximation. They all have in common that there is a regulator that decides on a policy package with the aim of minimizing the expected efficiency loss.

The efficiency loss depends on the relation between costs and benefits of abatements. For the sake of the present paper we do not need specific information about the costs and benefits associated with decreasing GHG emissions from transportation. Regarding the cost side there has been attempts to assess the GHG abatement costs in the transport sector. An example is found in Särnholm and Gode (2007), which looks at 26 different abatement measures and tries to assess the costs and impacts of these by the means of interviews. That study does not report a marginal abatement cost structure for the transport sector. However, it seems to support a general and realistic assumption that marginal abatement costs increase in abatement. The following model
will, for technical reasons, rely on the somewhat more controversial assumption that marginal abatement costs, at least within an interval, increases linearly in abatements.

The benefit side is perhaps not as straightforward. The first thing to note is that decreasing GHG emissions from road transportation in the EU has no actual impact on climate change. This follows from the EU’s commitment under the Kyoto protocol. This may be achieved through reductions from emitters in the trading EU ETS sector, from emitters not in this sector (the non-trading sector) and/or, to a limited extent, by the use of the, so called, flexible mechanisms provided by the Kyoto Protocol: CDM or JI (at the time of writing, IET does not seem to be a viable alternative presumably due to a reluctance of getting hot-air into the system). That is, if the transport sector emits more than anticipated, other sectors must emit less or the flexible mechanisms must be used more intensively. All these alternatives are costly. Thus, the marginal benefit of reducing emissions in the transport sector consists of not having to engage in costly emission reductions in other sectors and/or costly CDM/JI projects. It also seems plausible that the marginal costs in the alternatives are increasing in abatements and consequently that the marginal abatement benefits in the transport sector increases in emissions.

3. The model

The model presented here is general enough to capture both the pure cap-and-trade case and the pure emissions tax case. As will be seen, the optimal regulation often entails elements of

\[ \text{2 CDM (Clean Development Mechanism) and JI (Joint Implementation) are project based mechanisms. IET (International Emissions Trading) is, as EU ETS, a tradable permit system but between nations with commitments under the Kyoto Protocol.} \]

\[ \text{3 The marginal costs in the alternatives should account for all costs associated with abatements. For instance, if abatements in the heavy industry increase the risk for carbon leakage, this is an indirect cost of the policy which should be included in the abatement costs.} \]
both these extremes. In the following it is assumed that all agents strive to maximize their profits or utility, that the markets are perfectly competitive and that income effects are negligible.

To simplify the presentation, a very basic model is used. For instance, it does not consider uncertainty in the benefit function. As in much of the earlier studies in this strand of literature, the abatement benefit function is assumed to be quadratic so that marginal abatement benefits \( MAB \) may be described by

\[
MAB = f + ge
\]  

where \( e \) denotes total emissions from the transport sector, and \( f \) and \( g \) are parameters. From the discussion in the former section it is concluded that the marginal benefits from abatements made in the transport sector must be non-negative and increasing in emissions. Thus, both \( f \) and \( g \) are non-negative.

As the benefit function, the abatement cost function is assumed to be quadratic, but also uncertain, at least at the point in time when the policy package is decided upon. Here, we follow Weitzman (1974) by using additive uncertainty regarding the marginal abatement cost \( MAC \) function. The \( MAC \) function may then be written as

\[
MAC = K - Le + \varepsilon ,
\]

where, as discussed in the former section, \( K \) and \( L \) are positive parameters \( (K > f) \) and \( \varepsilon \) is a stochastic variable for simplicity assumed to be uniformly distributed over the range \((-a, a)\). When

\[\varepsilon\]

\[Under standard assumptions, taking uncertainty into account will not influence the results. Also see footnote at expression (7).\]
deciding on levels of control variables the regulator only knows the MAC in expectation terms. However, at the point in time when emitters decide on abatement efforts the value of \( \varepsilon \) is known.

Given the realization of \( \varepsilon \), the efficient level of abatement yields a total emissions level, \( e^* \), such that MAC equals MAB. That is

\[
e^* = \frac{K - f + \varepsilon}{L + g}
\]  

(3)

Thus, if the regulator could set an emissions target after the realization of \( \varepsilon \), he would simply set it to the efficient emissions level, \( e^* \).

However, due to the assumption of policy decision being made before the value of \( \varepsilon \) is known, the regulator must decide on a policy package, in this setting, consisting of three policy variables. First, the number of emission permits to allocate to the market, which is the cap, denoted \( q \). For the sake of this paper it is of no concern how this allocation is carried through, e.g., by auctioning or grandfathering, but this has efficiency consequences in real life in particular due to the possible gains from the double dividend effect in the former case\(^5\). Second, the level of the fine an emitter has to pay for each unit of emissions made exceeding the number of permits held. This fine is denoted \( s \). Third, the level of the emissions tax, denoted \( \tau \). It seems plausible that this tax is to be paid for each unit of emissions made. However, in the following the emitter will pay the fine only, i.e., not both the fine and the tax, for emissions that are not covered by permits. The reason is that the expressions derived then are more directly interpretable. If all emissions are to be covered by the tax the relevant fine is simply \( s \), as defined here, minus the tax, \( \tau \). As will be returned to, we

\(^5\) Seminal papers on this include Tullok (1967) and Sandmo (1975). A review is found in Schöb (2005). Recent applications on climate change issues are found in, e.g., Perry et.al. (1999), Cramton and Kerr (2002) and Bohm (2002).
may use the three policy variables to mimic a pure cap-and-trade regime, a pure emissions tax regime and combinations of these.

Two technical restrictions are needed for $s$ and $\tau$. The first requires that $s \geq \tau$, i.e., the tax must not exceed the fine. If this is not fulfilled it is beneficial for emitters not to hold any emissions permits and rather pay the fine for each unit of emissions made. The second is less trivial and follows from that the range of $\varepsilon$ is set to $(-a, a)$. This will, for technical reasons, set a lower bound on the level of the tax of $\tau \geq K-Lq-a$ and upper bound on the fine of $s \leq K-Lq+a$. Note that this does not infer any limitations on the applicability of the model. At $s = K-Lq+a$ the fine will never, i.e., not for any possible realization of $\varepsilon$, bind, so using an even higher fine should have no impact on our results.\(^6\)

As discussed in the previous section, the regulator aims to minimize expected efficiency loss, denoted $E\{DWL\}$. The next step in this presentation is thus to provide an arithmetic expression for $E\{DWL\}$. Let us start by introducing the price that would occur in the absence of the tax, that is if $\tau = 0$. Denote this price $p_{CnT}$. Given a well-functioning market, $p_{CnT}$ reflects the marginal willingness to pay for emitting one additional unit of emission at $q$. However, when $\tau > 0$ this will not be the equilibrium price for emissions permit as the emitter also pays the tax. Thus, the price on the emissions permits market, denoted $p$, will be $p_{CnT} - \tau$ as long as this is positive and zero otherwise as we do not allow for negative prices.

Depending on the realization of $\varepsilon$ one of three situations will occur. First, the tax may bind. This will be the case when the realization of $\varepsilon$ is low. The threshold value of $\varepsilon$, i.e., the highest value of $\varepsilon$ for which the tax binds, is denoted $\varepsilon_l$. An $\varepsilon$ realized as lower than $\varepsilon_l$ implies that $p_{CnT} - \tau$...\(^6\) It is possible to design a model that does not require this restriction, but it will become more complicated. Thus, to keep the mathematical presentation simple the subsequent model requires these restrictions.
\( \tau < 0 \) and consequently the emissions permit price \( p \) will be zero, i.e., the emissions permits have no value. To find an arithmetic expression for \( \varepsilon_L \) we only need to find the value of \( \varepsilon \) such that \( p = 0 \), or equivalently \( p_{CT} = \tau \), under a given cap, \( q \). This amounts to setting (2), accounting for that total emissions should amount to \( q \) units, equal to \( \tau \) and solving for \( \varepsilon \), which yields

\[
\varepsilon_L = \tau - (K - Lq) \tag{4}
\]

Second, the fine may bind, which will be the case for high values of \( \varepsilon \). The threshold value over which the fine is binding is denoted \( \varepsilon_H \). If \( \varepsilon \) would turn out as larger than \( \varepsilon_H \) the price of emissions permits plus the tax, i.e., \( p_{CT} \), would exceed the fine and, hence, no agent would choose to buy additional permits (and pay the tax) rather than paying the fine. In a similar manner as in the tax case, an arithmetic expression for \( \varepsilon_H \) is given by

\[
\varepsilon_H = s - (K - Lq) \tag{5}
\]

Third, for values of \( \varepsilon \) between \( \varepsilon_L \) and \( \varepsilon_H \), total emissions will be \( q \) and the price of an emissions permit will be determined on the market according to an ordinary cap-and-trade regime taking into account that the emitter will also have to pay the tax for each unit of emissions made.

Total emissions when the tax binds, denoted \( e_T \), will be such that the \( MAC \) equals the tax. This yields \( e_T = (K - \tau + \varepsilon)/L \). Since \( \varepsilon \) must be lower than \( \varepsilon_L \) for the tax to bind, \( e_T \) will be lower than the cap, \( q \). Similarly, total emissions when the fine binds, denoted \( e_s \), amount to \( e_s = (K - s + \varepsilon)/L \), which will exceed the cap, \( q \), since then \( \varepsilon \) must be greater than \( \varepsilon_H \). See Figure 1 for a graphical presentation of the concepts.

< FIGURE 1 IN ABOUT HERE >

We have now got all ingredients needed to specify the expected efficiency loss as
\[
E\{DWL\} = \frac{1}{2a} \left[ \int_{\hat{s}}^{s_a} \int_{\hat{\epsilon}}^{\epsilon_a} (MAC - MAB) d\epsilon d\hat{\epsilon} + \int_{\hat{s}}^{s_a} \int_{\hat{\epsilon}}^{\epsilon_a} (MAC - MAB) d\epsilon d\hat{\epsilon} + \int_{\hat{s}}^{s_a} \int_{\hat{\epsilon}}^{\epsilon_a} (MAC - MAB) d\epsilon d\hat{\epsilon} \right] 
\]

where the first row covers the efficiency loss when the tax binds, the second row when the regime works as a standard cap-and-trade regime and the third row when the fine binds.

4. Optimal control levels and comparative statics

This section focuses on the optimal levels on the control variables. It will begin by examining each policy variable in isolation in order to determine its optimal level without assuming that the other variables are at their optimal levels. This allows us to address how to optimally set, say, the tax in response to a cap that, for some reason, is not set at its optimal level. Following this discussion, the attention is turned to the optimal policy package in which all three policy variables are optimal.

Substituting expressions (1) through (5) into (6) and solving the integrals yields a cumbersome expression for \(E\{DWL\}\) from which first order conditions for each control variable may be derived. This yields the following expressions for the optimal control levels\(^7\),\(^8\):

\[^7\] Note the symmetry between (8) and (9). If we had defined the tax such that it should be paid for all emissions, not only those covered by emissions permits, the relevant fine would be \(\hat{s} - \hat{\tau} = 2ag/(2L+g)\). Such an approach is equivalent to the one above but the symmetry in the two control levels is not as obviously visible.

\[^8\] Introducing uncertainty also for the \(MAB\) function (additive, symmetric and uncorrelated with \(\epsilon\)) will increase the expected efficiency loss but nevertheless yields the exact same expressions for the optimal control variables as the ones in (7) to (9).
\[
\hat{q} = \frac{s + \tau - 2f}{2g}
\]  
(7)

\[
\hat{t} = \frac{2fL + g(K + Lq - a)}{2L + g}
\]  
(8)

\[
\hat{s} = \frac{2fL + g(K + Lq + a)}{2L + g}
\]  
(9)

Let us examine and provide some intuition for how the three control variables interact. Starting with the optimal cap, \(\hat{q}\), it is seen from (7) that it increases in the level of both the tax and the fine. To see why this is the case, consider a situation where the tax is low enough, such that for all possible realizations of \(\epsilon\) the price of emissions permits, \(p\), is positive, together with a fine that for all possible realizations is larger than \(p + \tau\). This is thus a ‘pure’ cap-and-trade situation under which neither the tax nor the fine is ever binding. For such situation it is well known, see, e.g., Weitzman (1974), that the optimal cap equals the expected efficient emissions level, \(i.e., (3)\) with \(\epsilon\) set to zero, given that both the \(MAB\)-function and the \(MAC\)-function are linear. It is then the case that the efficiency loss that follows from any given positive value of \(\epsilon\) is exactly as large as the efficiency loss for the same, but negative, \(\epsilon\). Under the symmetric assumptions used, increasing the cap would decrease the expected efficiency loss for high realizations of \(\epsilon\) but increase it for low realizations – and the latter effect would outweigh the former. Now, consider what happens when the tax is increased (still keeping the fine at a high level, such that it never binds). For some low realizations of \(\epsilon\) the permit price will be zero and total emissions will be less than the cap. As the efficient emissions level is low when \(\epsilon\) is low, see (3), the resulting efficiency loss for these realizations is less than when total emissions equal \(q\). However, the tax has no influence on the resulting efficiency loss for high realizations of \(\epsilon\). By increasing \(q\) it is possible to reduce efficiency loss for high realization without sacrificing efficiency for low realizations, as these are
now handled by the binding tax. It should be noted that this will result in increased efficiency losses for $\epsilon$ realized close to zero (its expected value), but only by a relatively small amount. As a whole, expected efficiency loss will decrease. Hence, the optimal cap must increase in the tax level.

The exact same line of argumentation may be used to illustrate that a lower fine should optimally lead to a decrease in the cap. The efficiency loss following from high realizations of $\epsilon$ will then be lower as the fine allows for total emissions to exceed $q$ and thereby be closer to the efficient emissions level under such realizations. One might then decrease the efficiency loss under low realizations of $\epsilon$ by decreasing $q$. Again, the resulting efficiency loss for realization of $\epsilon$ around zero will increase, but this effect is relatively small. By using both a tax (that binds at low realizations) and a fine (that binds for high realizations) the optimal $q$ may very well be at the expected efficient level.

The same intuition applies for why both the tax and the fine increase in the cap, as seen from (8) and (9). Consider again the ‘pure’ cap-and-trade starting point as outlined above. If the cap is above the expected efficient emissions level, low realizations will result in greater efficiency losses than the corresponding high realizations. Increasing the tax, such that it binds for some low realizations, counters this asymmetry and decreases expected efficiency loss.

Furthermore, note that the expression for $\hat{\tau}$, (8), does not include $\hat{s}$ and neither does $\hat{s}$ depend on the tax. That is, there is no direct link between the level of the tax and the level of the fine. As shown above however, there is an indirect link as the tax influences the optimal cap, which in turn influences the optimal fine and vice versa. This implies that if a tax is introduced into an existing regulation, where the cap and fine are optimally set to begin with, there is nothing to gain from calibrating the fine as long as the cap is kept unchanged at the now suboptimal level.
Let us now turn to finding the optimal policy, where all three control variables are set to their optimal values. Substituting (8) and (9) into (7) yields an expression for the optimal cap. Substituting this into (8) and (9) yields expressions for the optimal tax and the optimal fine respectively. These operations result in the following expressions:

\[ q^* = \frac{K - f}{L + g} \]  \hspace{1cm} (10)

\[ \tau^* = f + \frac{K - f}{L + g} g - \frac{g}{2L + g} a \]  \hspace{1cm} (11)

\[ s^* = f + \frac{K - f}{L + g} g + \frac{g}{2L + g} a \]  \hspace{1cm} (12)

Note that \( q^* \), from (10), is the expected efficient emissions level, \( i.e., (3) \) under \( \varepsilon = 0 \). It has been shown above that the optimal cap increases if the tax is increased and it decreases if the fine is decreased. Thus, it seems as the optimal tax and the optimal fine are symmetrical in the sense that if the fine binds for some positive realized value of \( \varepsilon \) the tax should bind for the same, but negative, \( \varepsilon \). That this indeed is the case is seen from comparing (11) and (12). The first two terms in these expressions are identical and equal to the expected (‘pure cap-and-trade’) permits price, \( i.e., E\{p_{CT}\} \), under a cap of \( q^* \). The third term is negative for the tax and positive, but otherwise identical, for the fine. This term thus denotes the difference between the expected price and the optimal values of these control variables.

First note that a pure cap-and-trade regime, \( i.e., \) a regime where neither the tax nor the fine will bind for any realization of \( \varepsilon \), is the optimal policy only in two specific situations. Namely, when the marginal abatement costs in the transport sector do not increase in abatement or when further abatements outside the transport sector is infinitely costly. The former corresponds to \( L = 0 \) and the latter to \( g \to \infty \). Both imply that the third term equals (tends to) \(-a\) in (11) and \( a \) in (12). As
this is the range of $\varepsilon$, neither the tax nor the fine will ever bind in these cases. For all other valid values of $L$ and $g$, the optimal tax and fine are such that they will bind in some situations, \textit{i.e.}, when $\varepsilon$ turns out as low or high respectively. As it seems very unrealistic that marginal abatement costs are not increasing in abatements or that they are increasing at an infinite rate, it is concluded that a pure cap-and-trade regime is highly unlikely to be the optimal policy choice.

The other extreme case would be if the marginal abatement costs outside the transport sector, \textit{e.g.}, the marginal cost of increasing the abatement requirements of the EU ETS sector, are not increasing in abatements or if further abatement in the transport sector is infinitely costly. From the transport sector’s perspective, the former implies that the \textit{MAB} function is horizontal, \textit{i.e.}, $g = 0$. The latter implies that the \textit{MAC} function is vertical, \textit{i.e.}, $L \to \infty$. In both cases, the two last terms in (11) and (12) vanish and the expressions simplify to $f$. That is, the optimal policy regime is then to implement a pure emissions tax amounting to $f^9$. Again, both the situation where $g = 0$ and where $L \to \infty$ seem unrealistic. That is, neither a pure cap-and-trade nor a pure emission tax regime seems to be realistic candidates for being optimal policy instrument. Rather, the attention should be focused on a combination of the two instruments.

In general, the steeper the \textit{MAB} function is the further from the expected price will the optimal tax and fine be, as the absolute value of the last term in (11) and (12) increases in $g$. Similarly, a steeper \textit{MAC} function implies that the optimal tax and fine are closer to the expected price, as the absolute value of the last term in (11) and (12) decreases in $L$. This seems intuitively correct. A steep \textit{MAB} function implies that the activities required outside the transport sector if

\footnote{In the model, this is captured as an unnecessary complicated strategy of allocating $q^*$ permits to the market, knowing that these will never be used since if $\varepsilon$ turns out as negative the price will be zero and the tax will bind and if $\varepsilon$ turns out as positive all emitters will opt for paying the fine. Even though complicated, the outcome is identical to that of applying a uniform emissions tax equal to $f$.}
emissions from transportation increase, e.g., emissions reductions in other sectors and/or intensified efforts in JI or CDM, are very costly. Therefore, a relatively high realization of the marginal cost function is required before it is justifiable to increase emissions above $q^*$, i.e., before the fine becomes binding. A steep $\text{MAC}$ function implies that additional reductions in transport sector emissions are relatively costly. In such a situation, the fine should become binding, such that emissions may be larger than $q^*$, for relatively low (but positive) realizations of $\epsilon$.

5. Further discussion and concluding remarks

In the previous section it was showed that regulating the transport sector by coupling a cap-and-trade regime with an emissions tax and/or a fine indeed may be justifiable from an efficiency perspective. The intuition behind this is straightforward; the system becomes more flexible in the sense that further abatements in the transport sector will be made when such should be carried out, namely when the costs of abatements are relatively low. Similarly, in situations where abatements are relatively costly, the transport sector is allowed to increase its emissions.

It should perhaps be noted that it is possible to fully incorporate the transport sector in the EU ETS and still let it be subject to a CO$_2$ tax. By doing this, the transport sector will always face a carbon price equal to the EU ETS price plus the tax. Such a solution may at first seem identical to the isolated cap-and-trade regime discussed in the previous section. This is not fully correct however. In the isolated case it could be the case that the permit price becomes zero, and only the CO$_2$ tax binds. This will occur when the marginal abatement costs in the transport sector are realized as low, which is also the situation in which, from an efficiency point of view, it is desirable to lower emissions. When the transport sector is
incorporated in (or linked to) the EU ETS, in which non-transport emitters do not face an additional CO$_2$ tax, this situation will probably not occur\textsuperscript{10}.

Given realistic assumptions, the original model showed that the optimal policy entails using a combination of cap-and-trade, an emissions tax and a fine. One important result from the model is that the optimal design of the policy depends on the relation between abatement cost and abatement benefits within the transport sector. It has been argued that the latter depends on the abatement costs outside the transport sector. The marginal benefit function merely mirrors the marginal costs of abatements outside of the transport sector (this includes the EU non-transport sectors, \textit{e.g.}, the EU ETS sector, but also measures taken using the flexible mechanisms).

Some rough policy recommendations may be achieved by confronting the model to a few stylized facts. Much suggest that road transports are rather insensitive to changes in fuel prices, see Kågesson (2008) chapter 7 for a discussion and references. This would suggest that the marginal abatement cost function for this sector is steep. In particular, it seems reasonable to assume that it is steeper than the marginal costs for abatement outside the transport sector\textsuperscript{11}. In such a situation, the model shows a cap-and-trade regime with a relatively high tax and a low fine to be optimal, such that there is only a small difference between the two. As has been discussed, such a regime has similarities – but is not identical – to a pure emissions tax solution.

\begin{flushleft}
\textsuperscript{10} In order for the EU ETS carbon price to become zero the supply of permits (the allocation) must exceed the demand, \textit{i.e.}, the emissions made from the EU ETS sector in a business as usual scenario must be less than the number of emission permits on the market. Such situations may occur, but they seem highly unlikely.

\textsuperscript{11} This is of major concern when discussing implementing transport into EU ETS as it suggests that transport will be a large net buyer of permits, possibly increasing the permits prices to such a degree that it will influence the competitiveness of the EU industry on the international market, see, \textit{e.g.}, Holmgren et.al. (2006).
\end{flushleft}
That is, we know that the current approach of using taxes to regulate transport emissions of greenhouse gases most likely is associated with efficiency losses at least in expectation. The model shows that the current situation can be improved upon, in the sense that the expected efficiency loss may be decreased, by introducing a cap-and-trade regime for the transport sector. However, from the model it may also be concluded that, given the stylized facts about the cost structure within and outside the transport sector discussed above, the gain from switching to an optimal cap-and-trade regime are likely to be relatively small (but clearly positive in all but very specific and unrealistic settings).

If a longer perspective is adopted, the case for regulating transport greenhouse gas emissions by the means of emission taxes may be stronger in the future. The reason is that international climate policy is likely to be more homogenous, either through a more intensive use of the flexible mechanisms (possibly including International Emissions Trading) or through linking different regional trading schemes to each other. As a consequence, the market for emission permits will grow to become a market where the agents, including EU emitters, are best seen as price takers. This will result in that the marginal abatement benefit function for the EU transport sector will become virtually horizontal; and the optimal policy, as suggested by the model, is a pure emissions tax.
References


Figure 1: Illustration of the three policy instruments ($q$, $\tau$ and $s$), the MAB-function and six different possible realizations of the MAC-function; the highest possible ($\varepsilon=a$), the upper threshold ($\varepsilon=\varepsilon_H$), the expected realization ($\varepsilon=E\{\varepsilon\}=0$), the lower threshold ($\varepsilon=\varepsilon_L$) and the lowest possible realization ($\varepsilon=-a$). It also illustrates the price for permits at the expected realization, $E\{P_{CnT}\}$. 