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Carbon Emissions and Cost Benefit Analyses

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Carbon Emissions and Cost Benefit Analyses

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ABSTRACT

New infrastructure projects may affect CO_2 emissions and, thus, cost benefit analyses for these projects require a value to apply for CO_2. This may be based on the marginal social cost of emissions or on the carbon price resulting from present and future policies. This paper argues that both approaches are necessary, but for cost benefit analysis of infrastructure projects the latter should be the primary tool. A series of complications arise when applying this principle in practice. These are discussed in the paper. Even if the complications make the implementation of the approach difficult, we argue that it is still preferable to a social cost approach.

JEL classifications; *H54, Q51, R42*
Keywords; *Climate change, policy, cost-benefit analysis, carbon value*

1. INTRODUCTION[1]

The issue of climate change has been high on the agenda for several years, and seems likely to remain so for some time. Transportation is responsible for a large share of the greenhouse gas emissions. In the EU almost 20% of the CO_2 emissions stem from transportation. The same is true for global emissions. In North America almost 30% of the CO_2 emissions originate from transportation, while the share is around 10% for Asia (European Parliament, 2008). Investments in infrastructure projects, for example new highways, high-speed railways, or airports, will potentially have an impact on the transportation sector's CO_2 emissions. Investments like these are often preceded by cost-benefit analyses (CBA). The present paper aims at discussing how expected changes in CO_2 emissions due to the investment in question are to be handled in the CBA. In particular, the paper addresses principles behind what value to attach to a change in CO_2 emissions in a CBA framework. The discussion is primarily focused on CBAs in the transportation sector but to a large extent it also applies to other sectors, e.g. energy or health.

In a guide on CBA prepared for the European commission, Florio *et al.* (2002, page 125) defines CBA as a "conceptual framework applied to any systematic, quantitative appraisal of a public or private project to determine whether, or to what extent, that project is worthwhile from a public or social perspective. Cost-benefit analysis differs from a straightforward financial appraisal in that it considers all gains (benefits) and losses (costs) regardless of to whom they accrue." Thus, CBAs need to consider factors that are not dealt with – at all or in an incorrect way – by the market. CO_2 emissions may serve as a typical example to the extent that there, without any governmental intervention, will not emerge a market for them. Such externalities are typically not addressed in a financial appraisal, but should be addressed in a CBA as they constitute a loss (or a gain) to people in the society.

The rest of the paper starts with a discussion of potential approaches to derive a CO_2 value applicable in a CBA. The two major options considered are a direct approach under which one tries to establish the social cost of emitting an extra tonne of CO_2 and an indirect approach where one derives the value through the (shadow) price necessary to reach the target underlying the CO_2 policies. This discussion is brief as both approaches have been addressed earlier, see for example Watkiss and Downing (2008), Pearce (2003) or Clarkson and Deyes (2002). Following the introduction of the approaches we will argue that, given a set of assumptions, the latter is more suited for the purposes addressed here, that is, to estimate a CO_2 value for CBAs on infrastructure projects. Having established this principle, and under which circumstances it is relevant, we turn in section 3 to a discussion about practical applicability, limitations and problems. Section 4 concludes.

2. POTENTIAL APPROACHES TO DERIVE THE CO_2-VALUE

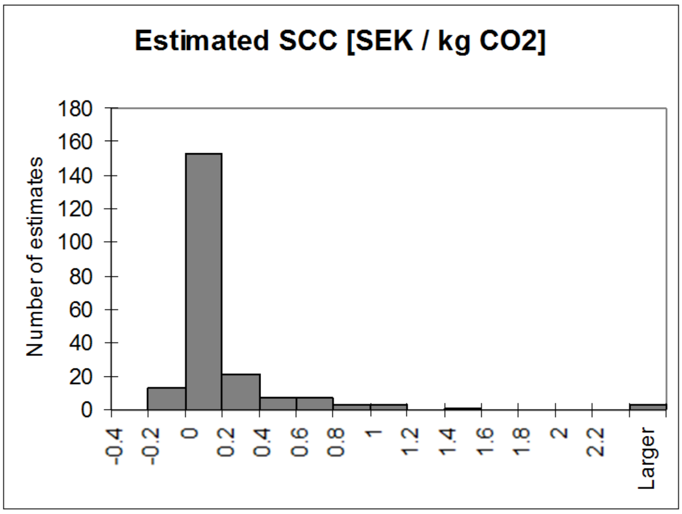
One can think of several ways to establish a CO_2-value suited for use in a CBA. We focus our attention on two distinctly different, though highly related, approaches; the social cost of carbon and the induced price of carbon policy. These two approaches seem to be the most widely discussed. The former may be viewed as a 'direct approach' and the latter as an 'indirect approach'. In this section, the background of these two approaches will be given a brief presentation followed by a discussion on their applicability in a CBA setting.

2.1 Direct approaches

The marginal social cost of carbon (SCC) is the cost one additional unit of carbon, in the form of CO_2, into the atmosphere will cause the society as a whole. There are in particular two complicating matters: First, it is not the flow, but the concentration of CO_2 in the atmosphere that affects the climate. Second, CO_2 remains in the atmosphere for long periods. To calculate the damage for each future period, one needs an assumption regarding the path of future emissions, a baseline, to compare to. The SCC is the present value of the monetized damage caused each period of emitting one extra tonne CO_2 today as compared to the baseline. Calculating the SCC typically requires, so-called, Integrated Assessment Models (IAMs). These models aim at combining the understanding we have about the natural mechanisms behind climate change with monetized benefits and costs and thereby arrive at guidelines for optimal policy now and in the future.

In recent years, several studies reporting SCC estimates using different IAM:s and various settings have been published. Figure 1 exhibits a histogram constructed using data from Tol (2008) which looks at 211 SCC estimates from 47 studies[2]. The mean value is \$104.80 per tonne C (≈ €19.70 per tonne CO_2)[3], but the distribution is skewed so the median is considerably lower; \$29 / tC (≈ €5.45 per tonne CO_2). The estimates range from -\$6.60 per tonne C[4] (≈ €-1.24 per tonne CO_2) to \$2400 per tonne C (≈ €451 per tonne CO_2). The middle 50 per cent of the estimates are found within the range of \$10 to \$90 / tC (≈ €1.88 to €16.92 per tonne CO_2).

Figure 1. **Histogram of 211 SCC estimates from 47 studies**



Source: Based on data in Tol (2008).

The fact that the SCC is hard to estimate is in itself not a reason to dismiss these direct approaches. Even less is it a reason to ignore the problem by applying a zero value. As noted by Pearce (2003, p.3); "*If there is uncertainty about a social cost estimate, that uncertainty does not magically disappear by not adopting the social cost estimate*". Even so, the large spread in estimates serves as an illustration of the difficulties in finding *the* CO_2 value to apply in a CBA.

2.2 Indirect approach

The indirect approach takes its starting point in that existing policies create a cost per unit of emission for the regulated agents. This cost may be more or less difficult to observe. In some cases it is a rather straightforward exercise to at least arrive at a reasonably precise (marginal) cost estimate. In particular this is the case when the regulation is either by the means of an emissions tax or a by a tradable permits scheme that establishes a market clearing price for the permits. Both in the case with an (homogeneous) emissions tax and a well-designed emissions trading scheme[5], the tax or the resulting permit price will be a good measure of the marginal abatement cost in the economy. This follows from the fact that the agents have incentives to reduce their emissions up to a point where additional reductions would cost more than paying the tax or covering the emissions with permits.

As noted, for instance, by Clarkson and Deyes (2002) and Pearce (2003), to use the permit price as a proxy for the social cost of an additional unit of CO_2 emissions is not without problems. In particular, this is due to the circularity in that the approach relies on political decisions which put a price on emissions, but information regarding the expected social costs is required for the policy maker to make the decisions.

To some extent, the circularity may be avoided by studying marginal abatement costs associated with reaching a given target. This approach is, for instance, used by the UK Department for Energy and Climate Change, DECC (2009). It takes its starting point in ranking potential measures according to their (marginal) costs and then derives the CO_2-value from the last measure required to reach a given target. For our purposes, there is no need to make a strong distinction between these two approaches. In the former, the policy will induce a price that is high enough to reach the given target. In the latter, the given target requires a certain series of measures to be taken – the cost of the last of these establishes the induced price. These two prices would, under standard assumption, be the same.

The indirect approach is also associated with large uncertainties, even though these arguably are substantially smaller than those surrounding the direct approach; see Dietz and Frankhauser (2010).

2.3 Which approach to use?

That it is not obvious which approach to use is illustrated by the diversity of ways in which different countries handle the problem. Oddgard *et al.* (2005) provide an overview of practices in the EU's Member States. Since 2005 a series of important policy changes has been implemented, most notably the EU ETS is now up and running, which presumably has led to some Member States changing their approach[6]. In 2005, only a third of the EU's Member States stated that they included greenhouse gas emissions in the CBA. Finland, The Netherlands and Italy used a damage cost approach, i.e. some kind of direct approach. Austria, Germany, Sweden and Switzerland used the cost of avoiding emissions, i.e. an indirect approach. Even though the authors note the difficulties in comparing values between nations, it is apparent that the values differ significantly. Germany applied the highest value per tonne CO_2, more than six times higher than the value applied in Denmark, which is the lowest (205 and 32 €/tonne CO_2, respectively).

The UK is an interesting example. According to Oddgard *et al.* (2005) they did not include climate change in their CBAs in 2005. Clarkson and Deyes (2002) argue that the UK should use a direct approach. The UK Department for Energy and Climate Change (DECC) (2009), however, proposes a revised approach which takes it stand in calculating the marginal abatement cost for reaching a given target, i.e. an indirect approach. The latter approach has been adopted in the UK and is now used in practice.

It is worth noting that for countries that do not have a climate policy with quantitative targets as the EU, the indirect approach becomes less useful. The US, for example, adopts a SCC approached based on series of IAM studies, Greenstone *et al.* (2011).

The principle behind CBA is that all resources required for a project should be accounted for in the analysis. This includes resources for which there is no market. This seems to favour the direct approach; the value to be attached to CO_2 reductions (or increases) in a CBA is the social cost of carbon because it would provide a direct estimate of the monetized damage. This is also a conclusion drawn in some other studies, for instance Clarkson and Deyes (2002). There are two major problems with this approach. First, as noted above, there are huge uncertainties in several dimensions involved partly due to a series of scientific issues that are yet to be resolved. Second, the social cost of carbon approach does not take the existence of policy measures into consideration, which we subsequently argue that a valid approach should.

The first is in itself not a reason to discard the social cost of carbon approach. As a CBA of the kind we are interested in here is forward-looking, basically all values in it will be subject to uncertainty. The value attached to CO_2 may be more uncertain than many other values. This does not imply that the social cost of carbon approach is wrong, only that it is harder – from the great range of estimates conducted – to decide on which value(s) to use in the analysis and that the uncertainties must be dealt with in the analysis. There are several ways, from the range of estimates, to derive a single value, or at least a small number of values.

Ultimately, we expect the policymakers, at least partially based on the scientific findings in the field, to weigh different interests towards each other to arrive at a policy, for example an emissions tax system or a tradable permit approach, which incorporates the 'political' social cost of carbon. This includes taking future generations' wellbeing into consideration, weighing the utility of different groups towards each other, forming a judgement on the impact from low probability/high cost events to name but a few of a whole list of highly complex issues calling for attention.

A consequence of this view is that both approaches are necessary. The direct approach – the social cost of carbon estimates – is an input to a policy process which, as an output, will result in a policy and consequently a (shadow) price, i.e. a marginal cost associated with meeting the policy target. This marginal cost may be interpreted as a manifestation about the political cost of carbon. Once the policy maker has established a policy, this must be taken into consideration when deciding on the value for the CBA. Thus, the fact that there currently – and probably also in the future – exists policies geared towards CO_2-emissions will influence the CO_2 value applicable in a CBA. In practice, these policies often contain numerous different and interdependent instruments. We will return to this in the next section.

To frame the discussion, we start by considering two stylized cases. Either a majority of the global CO_2-emissions are covered by a homogenous emissions tax or by a cap-and-trade regime. In the former case, using some other valuation than the tax would lead to efficiency losses due to a lack of cost effectiveness. If the value applied in the CBA is larger than the tax, the resulting reductions in emissions could have been achieved at a lower cost somewhere else in the economy[7]. Even if an internationally harmonized carbon tax has several appealing features, it is associated with a series of problems making it a less likely candidate for future policies, see Pearce (1991), Pizer (2002) and Bohm (1997).[8]

The latter stylized case entails an agreement specifying an upper limit of emissions from the participating parties. To facilitate cost effectiveness, parties may trade in emission permits. What would then be the implications of an investment in infrastructure that, say, results in that people commute by train rather than by cars? The most important thing to note is that total emissions are not affected as these are fixed through the permit trading scheme. The main consequence of the investment lies in that other emitters do not have to reduce their emissions to the same extent as without the project[9]. That is, what in the absence of a trading scheme would have been emission reductions is now rather a reallocation of abatement efforts in the economy. Let us refer to reductions in emissions that are caused by the project, but countered through the trading scheme, as 'quasi-reductions'. As reducing emissions is costly, the quasi-reductions are associated with a value corresponding to the costs other emitters would have had in the absence of the project. That is, if emissions are covered by a tradable permit scheme, any quasi-reductions in CO_2 emissions generated by a project should be valued at the market price for emission permits, since the permit price reflects the marginal cost of abatements which now are avoided. Thus, in order to correctly capture the effects of the project, the CO_2 value used in the CBA should be equal the (shadow) price generated by climate policy.

Implicitly, this assumes a hierarchy in policy decisions in that the CBA, and thus the decision regarding investing in the particular infrastructure project, depends on the climate policy decision. It is important to note that this discussion relates to what CO_2 value to apply for CBAs of measures not directly related to climate policy, but rather measures like investments in new infrastructure. Pearce (2013) makes the point that if one derives the value from a policy measure and then uses that value to evaluate the same measure, this will always justify the policy. Thus, the indirect approach to derive a CO_2-value is clearly not a good approach to evaluate climate policy. However, a crucial circumstance here is that we do not want to evaluate, say, an infrastructure investment as a climate policy measure. What is important, to avoid cost ineffectiveness, is to evaluate the investment given the climate policy already in place.

As an example, Ortega *et al.* (2013) assesses the benefits and costs associated with investments in Spain. They conclude that on-shore wind and small hydro, but not solar technologies, typically generate benefits in excess of the costs. When assessing the monetary benefits associated with reduced CO_2 emissions they use a SCC approach (using values from Tol (2012)). In the light of the discussion above, this may result in incorrect conclusions. The reason is that Spain's electricity sector is a part of the EU ETS, so any reduction in CO_2 emissions from investing in Spanish renewable electricity will reallocate the abatement burdens – i.e. someone else in the system may now abate less. The value of this does not depend on the SCC, but on the costs saved by those other emitters. The value of these costs on the margin is given by the EU ETS-price, i.e. the price induced by the climate policy.[10]

3. PRACTICAL IMPLICATIONS, PROBLEMS AND LIMITATIONS

Given a tradable permit scheme, the discussion above suggests that the problem is rather straight-forward; the permit price should be used in the CBA as it reflects the value of the reallocation of abatement efforts following from the project. Applying this simple principle to a real life situation is not without problems. In the following we will address some of these.

3.1 Several policy goals are present at different levels

It is currently the case that there are several different CO_2 related policies working at different levels of the society. Climate change is a global problem, and the localisation of CO_2 emissions is not important for its impact on the climate. Thus, at the top of the hierarchy would be a global agreement and the targets specified therein. The closest we currently have to a global agreement is the Kyoto protocol. At a level below this there are multinational agreements such as the EU's climate policy. At the time of writing, the future for a global climate policy is uncertain. The EU has declared that their target will remain. Below these there are national policies. Currently, all of the above are based on quantity targets, even though there is room for flexibility, e.g. through trade in emission permits[11].

There are often different goals for different sectors on a given level. For instance, the household and transport sector within a given nation may face different CO_2 targets. For each of these levels and targets we may, at least in theory, derive a shadow price. Most likely these shadow prices will differ between the different levels. So, which value should be used in the CBA? A starting point is to use the 'closest' binding target. That is, if the project affects transportation and there is a specific binding CO_2 target for the transport sector, disregarding what policy instrument is used to reach it, the shadow price following from the target is the relevant one if it binds. However, if the target in the transport sector is not stringent enough to fulfil the national target the latter must be associated with a higher shadow price. We may view the different levels as a chain of targets. If different targets apply at different levels, so will the resulting shadow prices. By choosing a CO_2 value which answers to the highest shadow price of the chain, no target will be violated.

There is currently no tradable permit scheme in operation that directly targets transportation and thus no permit price directly paid by participants in the transportation sector. Rather, CO_2-emissions from the transportation sector are primarily regulated through taxes, if at all. The discussion above implies that what is crucial is that there is a quantitative overarching (binding) target, e.g. the Kyoto protocol or the EU's climate policy. If emissions from transportation are too large, i.e. larger than the sector's target, some other sector must decrease their emissions or additional permits must be purchased in order to meet the overarching target. In either case, this incurs a cost, which should be considered in the CBA.

3.2 Quasi-reductions occur over time

Project such as the ones discussed here are long-lasting. As a consequence, they will have an impact on CO_2 emissions for many years to come. Thus, we need to estimate the CO_2 values valid in the future. That is, the values created by future (quasi-)reductions. For infrastructure projects, the relevant values are future shadow prices in the transportation sector. Even if this sector will not be subject to a trading scheme, we have argued that the overarching target, which probably will remain being expressed in quantity terms, is important. Thus, the future permit prices carry some information about the induced prices in the transportation sector, as these will reflect the then prevailing marginal abatement cost in the overarching economy.

A starting point for estimating these prices would be to look at the futures market for permits. Most likely this will not reveal the prices actually valid in the future – but, as long as the market is functional, it provides information about the market's 'best guess'. The futures market for EU ETS permits shows that prices are rather volatile and that contracts valid further into the future cost more. The latter indicates that the market believes that the European climate policy will remain and perhaps even be more stringent in the future[12]. One needs to keep in mind that many of these markets are currently not very transparent.

Thus, the values used in CBA should change over time in accordance to what the policy induced price is believed to be at different points in the future. A good illustration of how difficult this is may be found in the current situation on the EU ETS-market. The EU commission (2012) noted in their report "The State of the European Carbon Market in 2012" that there is a substantial surplus of allowances on the market. Furthermore, the surplus is growing and is estimated to peak under 2014 at volume of ~2700 Mt CO2, (Neuhoff *et al.*, 2012). The commission has suggested potential measures to tackle the problem, e.g. implementing a stricter target, incorporate additional sectors in the ETS etc. It is however far from clear which measures, if any, will be implemented. Obviously, the future price will depend on what will happen and, thus, so should – according to the discussion above – the CO_2-value used in the CBAs. The market's beliefs about the outcome are already capitalized into the market prices. However, if the EU reaches a decision on how to handle the problem (if at all) this will likely have a strong and rather immediate impact on the EU ETS-price[13]. Even if it is clearly difficult to handle such price shifts in the CBA-process, this is not an argument to adopt the SCC-approach. A practical way forward may be the approach the UK uses which specifies an increasing path over time for the CO_2-value, DECC (2009). The path may be calibrated with some interval if new information becomes available.

3.3 The interconnectivity between future permit prices and future climate policy

A complicating matter from a CO_2 value perspective lies in the interconnectivity between future permit prices and future climate policy. A policy maker concerned with efficiency would allocate a number of emission permits to the market such that the expected marginal abatement costs, which corresponds to the expected price, equals the expected marginal benefit from abatement. If the marginal abatement costs are reduced, the policy maker would typically reduce the number of permits thereby making the (overarching) system more stringent. Thus, even if the emissions are fixed through the trading scheme in the shorter run, in the longer run the scheme will be calibrated and the project may influence this calibration.

Even if a single project has negligible impact on future climate policy, there is an important observation to be made in that future calibrations of the trading scheme probably will dampen the fluctuations in permit prices. If, for instance, a new technology that makes abatement much cheaper is introduced, permit prices will drop *ceteris paribus*. As the optimal response from the policy maker then is to set a more stringent target (than if the new technology had not been introduced) the price drop will at least partly be countered. Note that this applies to innovations in the transport sector as well, even when it is handled through taxes. A decrease in transport sector emissions, given a tax, creates room for further emissions from other sectors without violating the overarching target and, hence, there are incentives to make the target more stringent.

3.4 Several policy systems are present simultaneously

Most of the discussion above relies on a setting in which emissions from any given sector, *e.g.*, transportation, are regulated through one single mechanism. However, in real life there are often multiple instruments in use simultaneously. There may be circumstances under which this is justified, Bennear and Stavins (2007) and Mandell (2008).

The large number of different instruments makes it particularly difficult to achieve an overview of the system. Thus, deriving a CO_2 value for CBAs becomes even more complicated. With respect to the discussion above, there is a particular problem present in the different tradable permits and taxes being in place in that they point towards different values. To an extent this is a similar problem as the vertical levels discussed above, and the guidelines are the same – one needs to consider what the value of a quasireduction is in the particular setting. This value may differ between if the project influences emitters subject to, say, EU-ETS as compared to a non-trading EU sector as transportation[14].

3.5 Striving for transparency in the CBA

The CO_2 value applied in the CBA should capture the value of changes in (quasi-) reductions of CO_2, nothing else. This is of particular importance, because the sole purpose of a CBA is to provide transparent information regarding whether or not to conduct the project in question. As a consequence, it is desirable that CO_2 policies that are partly motivated by, say, increasing the incentives for technological progress, are labelled as such in the CBA and not as general CO_2 policies. Of course, this applies to the policies as such – but given their existence, it may prove useful trying to disentangle the pure CO_2 emissions motivated part from other “hidden” motives, as to protect the competiveness of domestic industry, to induce further technological progress, to influence emissions that covary with CO_2 emissions, or to provide an example for other nations to follow, to name but a few. All such other effects may be important, but hiding them in a CO_2 price fits badly with the primary purpose of conducting a CBA.

4. CONCLUDING REMARKS

This paper contains a discussion about underlying principles of importance when deciding on a value to apply on CO_2 emissions in CBAs. Even though the discussion has been focused on CBAs for infrastructural investment it is applicable on projects in other sectors, but not on CBAs on climate policies. The first question addressed is whether the value should be based on the social cost of carbon, being the discounted social damage caused by a unit of emissions, or on a shadow price created by present and future policies.

The discussion may be summarized in two claims. Firstly, as long as science can only provide a range of estimates of the (marginal) social cost of CO_2 emissions, choosing which value to apply is ultimately a task for politicians/policy makers. This is not an uncontroversial claim as one may argue that, say, a group of scientists are more likely to arrive at a value close to some true – but unobservable – value. Secondly, the choice of value to put into the CBA should not ignore existing and future policies. Given the type of CBA we address, the second claim would seem to be less controversial than the first.

From this we conclude that the question is not which approach, direct or indirect, should be applied. Rather, both approaches are required, but at different stages of the process. The social cost of carbon is necessary to provide input to the political process. This process will, as an output, provide a set of policies and this set is what generates the induced prices, which provides the base for the CO_2 value in the CBA. This conclusion stands in contrast to some earlier studies, for instance Clarkson and Deyes (2002). However, it is in line with HEATCO's (2005)[15] recommendations but, interestingly, for different reasons. In HEATCO it is argued that the induced price is a second best approach as the social cost of carbon – which would be the first best – is not observable.

We argue that the CO_2 value shall be derived from existing and future policies, disregarding whether or not the social cost of carbon is observable. To a large extent our conclusions are also in line with those of the UK's department of energy and climate change, DECC (2009). The main difference is that DECC uses the marginal abatement cost resulting from a given target, *i.e.* not directly the resulting price from a given policy. The advantage with that approach is that it avoids the circularity inherent in using the CO_2 value when evaluating climate policy. For project CBAs this is not a problem. Rather, directly using the prices induced by the policy assures that the evaluation is aligned with the overarching climate policy. However, the two approaches (abatement cost or induced policy price) should result in the same value, at least as long as the standard assumptions for a functional market apply.

We have also argued that under an overarching quantitative target, in contrast to an emissions tax approach, the first, and more controversial, claim is basically not required to arrive at the conclusion above. The reason is that quantitative target keeps the aggregate emission level fixed. Consequently, also the aggregate damage will be fixed and whether or not the regime is designed using the 'correct' social cost of carbon or not has no impact on the CBA's CO_2 value. Transportation emissions (not international air or maritime) are covered by the EU's climate target and, thus, subject to an overarching quantitative constraint, as is the case in other countries with binding Kyoto obligations. However, there is currently no transportation sector directly regulated through a tradable permit scheme and, hence, no permit prices that directly reveals the carbon price in the transportation sector. Thus, the relevant price must be derived from the policies aimed towards the sector's CO_2 emissions.

Having established a principle applicable in a stylized setting, we devote the remaining paper to problems and limitations when applying the principle in practice. We conclude that there is a whole series of complications that may occur, including permit markets that are far from transparent, several different instruments that capture different aspects of a CO_2-value, multiple policies present simultaneously.

One main conclusion from this second part of the paper is that it is difficult to establish a CO_2-value to apply in CBAs for infrastructure projects. However, this should not be taken as a reason to abandon this approach in favour of a social cost of carbon approach. The principles put forward are still relevant, even if they are hard to apply.

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NOTES

1. This discussion paper is an updated version of Mandell (2011).
2. Tol (2005, 2008) examines these studies in more detail, for example by comparing peer-reviewed with non-peer-reviewed studies, and more recent studies with older ones.
3. The conversion uses $1 = €0.69 and that one unit CO2 weighs 3.67 times one unit C.
4. Negative values are due to an initial positive impact on crops etc. For higher concentrations this is reversed.
5. That is, one which keeps transaction costs low, does not result in that any agents receive market power, and provides transparent information to the market *etc*.
6. To the best of my knowledge, there is no more recent review of current practices published.
7. Consider a project with one single effect; to decrease emissions by one unit and that this project just passes a CBA test when evaluated using a CO2 value larger than the CO2 tax. It would then have been less costly to decrease emissions by one unit somewhere else in the economy (the cost for this equals the tax). Thus, using a value for evaluating the project that differs from the marginal cost induced by the policy leads to investments that are not cost effective.
8. Noteworthy, there are recent studies that argue the problems with international and harmonized taxes may be avoided, see Nordhaus (2007) and Cooper (2008).
9. If the project is large enough, permit prices will decrease. In practice, it is hard to think of a project of such a large scale that it has anything but a negligible impact on the permit price.
10. In this particular case, the SCC chosen is close to the EU ETS price, and thus the qualitative results would still hold.
11. For instance, the EU-15 reduced its greenhouse gas emissions by 8%, compared to 1990, in the period 2008-12. Sweden has a national target of reducing emissions by 4%. In both cases, some of the reductions may be achieved by purchasing emission permits or conducting projects outside the EU.
12. The latter observation is not necessarily the case as higher prices in the future may, for instance, be due to the discount rate, cf. Hotelling’s rule.

13. That the market reacts strongly when uncertainties are resolved may be illustrated by the way EU ETS prices dropped from around €4.50 to around €3 when the European Parliament voted against backloading on April 16, 2013.

14. It is worth repeating that this may be an indication of a sub-optimal policy mix, but that there may also be reasons, *e.g.* differences between the sectors' risk for carbon leakage, that may justify price differences. See, e.g. Mandell (2010).

15. HEATCO strived to develop Harmonised European Approaches for Transport Costing and Project Assessment and was financed by the 6th Framework Programme.

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