

Climate policies for road transport revisited (II): Closing the policy gap with cap-and-trade

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ABSTRACT

Current policies in the road transport sector fail to deliver consistent and efficient incentives for greenhouse gas abatement (see companion article by Creutzig et al., 2011). Market-based instruments such as cap-and-trade systems close this policy gap and complement traditional policies which are required where specific market failures arise. Even in presence of strong existing non-market policies, cap-and-trade delivers additional abatement and efficiency by incentivizing demand side abatement options. This paper analyzes generic design options and economic impacts of including the European road transport sector into the EU ETS. Suitable points of regulation are up- and midstream in the fuel chain to ensure effectiveness (cover all emissions and avoid double-counting), efficiency (incentivize all abatement options) and low transaction costs. Based on year 2020 marginal abatement cost curves from different models and current EU climate policy objectives we show that in contrast to conventional wisdom road transport inclusion would not change the EU ETS allowance price. Hence, industrial carbon leakage induced by adding road transport to the EU ETS may be less important than previously estimated.

Keywords: Climate Policy, Road Transport, Cap-and-trade

1. Introduction

Road transport greenhouse gas emissions are rising around the world (IEA, 2008, 2009). Ambitious climate policy objectives such as limiting global warming to 2°C (UNFCCC 2009) require substantial emission reductions in all economic sectors, including road transportation (Luderer et al., 2010; Creutzig and Edenhofer, 2010). Decarbonizing the road transport sector will require new technologies and alternative fuel chains potentially including biofuels, electricity, natural gas or hydrogen.

The companion article by Creutzig et al. (2011) provides an overview of life-cycle emissions of alternative road transport fuel chains. The article explores the consequences of fuel chain diversification for an effective and efficient road transport climate policy portfolio and reviews major current policies. The main finding is that some road transport policies in Europe, the United States and China have proved effective in slowing the growth of emissions but fail to set consistent incentives across all fuels, technologies and other abatement options. Market-based instruments such as a carbon taxation or cap-and-trade system would close the prevailing gap in the climate policy portfolio, while traditional non-market policies will continue to play an important complementary role in addressing market failures beyond the greenhouse gas externality.

Several world regions including the United States, California, Japan, Canada, Australia, or New Zealand are discussing or implementing cap-and-trade systems that would include the road transport sector in an economy-wide trading system (Kossov and Ambrosi, 2010). The EU Emission Trading System (EU ETS) does not include road transport but will cover aviation from 2012 (EC, 2008b). Against this background, this

article reviews the theoretic rationale and practical design of cap-and-trade for the road transport sector and provides an empirical assessment of road transport inclusion to the EU ETS.

Peer-reviewed analyses of road transport inclusion to cap-and-trade are scarce. Raux (2005) focuses on a scheme covering final fuel consumers despite the substantial transaction costs associated with regulating millions of actors. Studies published as gray literature almost consistently omit the diversification of fuel chains (see Creutzig et al., 2010).

The remainder of this paper is structured as follows: Section 2 reviews the merits and demerits of market- and non-market-based policies for regulating road transport emissions. Building on the finding that market-based policies are an essential part of the road transport climate policy portfolio, Section 3 analyzes the relative merits of carbon taxes and cap-and-trade systems. As cap-and-trade is preferable under empirically plausible conditions, section 4 discusses key design issues in cap-and-trade implementation in the road transport sector, in particular the optimal point of regulation. Section 5 compares price and quantity effects of road transport integration into the EU ETS using marginal abatement cost curves from several models. Section 6 concludes.

2. Market-based versus non-market instruments

Implementing market-based instruments such as carbon taxes and cap-and-trade systems to put a price on greenhouse gas emissions is a standard economic prescription in climate policy (Kalkuhl and Edenhofer, 2010; Nordhaus, 2008; Stern, 2007). A properly designed carbon price internalizes the emission externality and, in theory, incentivizes *all* abatement options up to the *same marginal costs of abatement* (MAC). Market-based instruments enable the regulator to directly control emission levels, either via an emission cap or an adjustable carbon tax. From an industry perspective, a carbon price that is harmonized within and across sectors creates a level ‘carbon playing field’ for all firms. Also, market-based instruments enable the regulator to harmonize marginal abatement costs without need for assembling detailed techno-economic information.

Non-market instruments such as technology standards, by contrast, will typically address only specific abatement options and face difficulties in guaranteeing that marginal abatement costs are harmonized within and across sectors (Creutzig et al., 2011). Some options for abatement may be harnessed at suboptimal levels or even not at all, while others can become implemented at disproportionately high cost (Böhringer et al., 2009). Also, efficiency-improving standards suffer from rebound effects as they reduce the marginal cost of transportation (Small and Van Dender, 2007). Finally, to set non-market policies efficiently the regulator needs to draw on reliable techno-economic information.

However, carbon pricing is not a panacea and non-market policies have an important role to play. Where market or government imperfections arise in addition to

the basic climate externality—e.g. knowledge spillovers in research and development of low-carbon fuels and vehicles (Jaffe et al., 2005), or lack of policy credibility (Brunner et al., 2011a)—carbon pricing cannot achieve optimal outcomes and complementary standards may be required (Fischer and Newell, 2008). The basic reason is that the number of policy objectives (e.g. internalization of externalities) needs to be matched by the number of policy instruments (Tinbergen, 1952). In many cases a single policy instrument cannot be specified so as to optimally address each of several market failures. This also implies that introduction of market-based instruments will require checking the configuration of standards to ensure that the portfolio of policy instruments properly addresses the ensemble of market- and government failures (Fischer and Newell, 2008).

Given the presently heavy reliance on non-market road transport policies in the European Union, the United States and other world regions (Creutzig et al., 2011), market-based instruments can be regarded as tools that close the policy space by systematically setting an incentive for harnessing all available abatement options. But there are also less optimistic views of applying market-based instruments in the road transport sector.

2.1 Arguments against market-based regulation

Adverse interaction with existing fuel taxes

Adding carbon prices to high existing fuel taxes has been estimated to be unfavorable for the economy (Paltsev et al., 2004; Abrell, 2009). In Germany, aggregate gasoline taxes (mineral oil tax plus VAT) amounted to 0.85€/liter (2.59\$/gal) on average in 2009 (MWV 2010). This corresponds to 367€ (455\$) per ton of CO₂ contained in gasoline.¹ Existing fuel taxes intend to raise revenue for public goods and to address negative externalities. For uncorrelated externalities the optimal Pigovian fuel tax is equal to the sum of marginal costs of the externalities. Thus, a carbon tax simply adds to the aggregate Pigovian tax (Newbery, 1992). From an economic theory perspective the aggregate optimal transport fuel tax results from combining fiscal and Pigovian elements (Parry and Small, 2005).

In their assessment of optimal fuel tax levels some analysts find that present European Union fuel tax levels are not justified by transport externalities and general taxation requirements (e.g. Paltsev et al., 2004; Parry and Small, 2005) while others consider EU fuel taxes too low (Sterner, 2007; Proost et al., 2009). In the United States, fuel taxes are much lower than in Europe at around 0.16€/liter (0.50\$/gal) (API 2010) and there is agreement that this level is not overly high (Paltsev et al., 2004) and should be raised (Parry and Small, 2005). This paper does not investigate whether pre-existing fuel taxes should be raised or lowered. It adopts the view that the optimal level of current fuel taxation (i.e. not including carbon pricing in most regions) needs to be derived independently of climate policy considerations. A price on carbon would add to this optimal fuel tax level.

Redundancy and lack of impact

With ambitious non-market road transport regulation in place market-based policies may be redundant in achieving emission reduction targets (Kågesson, 2008). Indeed, our analysis of emission reductions from standards in the European Union and United States in Section 5.3 shows that substantial reduction can be expected. However, with incomplete information unanticipated abatement potentials may not be captured by standards and regulations - but would be induced by carbon pricing. Even a combination of standards will likely fail to incentivize *all* available abatement options, in particular demand side reductions. This is illustrated in Figure 1. Based on data from CE Delft (Blom et al., 2007) it displays an aggregate marginal abatement cost curve (MACC) for the EU road transport sector and its decomposition into cost effective technical (vehicle efficiency and fuel switching options) and behavioral responses to carbon pricing.

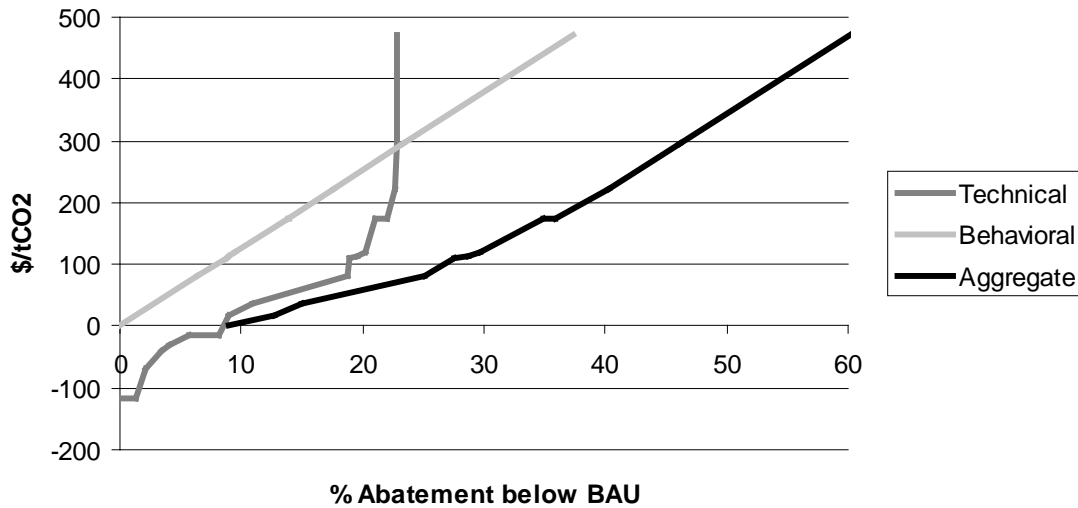


Figure 1: CE Delft year 2020 marginal abatement cost curve for the EU road transport sector and its disaggregation into technical and behavioral cost curves.

It is sometimes argued that the behavioral response to gasoline fuel price increases of 0.035-0.07 €/liter (0.17-0.33\$/gal) resulting from a carbon price of 15-30€ (19-37\$) per ton CO₂e are ‘too small’ to trigger ‘substantial’ quantities of abatement (Ellerman et al., 2010, p.22). But empirical studies of fuel price elasticities show that on aggregate people and companies do indeed respond to fuel price changes (e.g. Goodwin et al., 2004; Small and van Dender 2007). In addition, classifying price increases as ‘small’ requires a benchmark which in case of climate policy is properly provided by the abatement target. With a cap-and-trade system in place the carbon price will adjust automatically to ensure goal attainment (alternatively, a carbon tax can be adjusted to achieve a quantity goal). If ‘low’ carbon prices suffice to meet the environmental objective, this is not a sign of climate policy failure but an indication of sufficient low-cost abatement options in the system.

Dynamic efficiency

Non-marginal technological change will be required to decarbonize the transport sector in the 21st century. Under perfect market assumptions long-term carbon caps or taxes will provide sufficient incentives to foster low-carbon technological change (Edenhofer et al., 2006; Edenhofer et al., 2010; Luderer et al., 2010). But perfect markets and governments are not in place and hence the dynamic efficiency of carbon pricing schedules is compromised. It is crucial to note that such imperfections do not remove the basic rationale for market-based policies in the first place. They rather open the policy space for complementary policies—aiming for dynamic efficiency—such as fuel efficiency standards, R&D subsidies, and infrastructure investments.

3. Taxes versus cap-and-trade

In a simple framework carbon taxes and cap-and-trade are equivalent instruments. The theoretical literature has discussed asymmetries arising under uncertainty (Hepburn, 2006; Weitzman, 1974) or considerations of supply side dynamics (Kalkuhl and Edenhofer, 2010; Sinn, 2008). Section 3.1 reviews arguments that would favor taxes over trading for road transportation climate policy. Section 3.2 then outlines the argument that cap-and-trade has advantages over taxation under specific but plausible conditions.

3.1 Arguments favoring taxes

In the EU context, including the growing transport sector with its relatively steep abatement cost curve into the EU ETS is suspected to prompt EU allowance (EUA)

prices to rise, thereby causing carbon leakage in trade-exposed sectors already covered by the EU ETS (Blom et al., 2007; Holmgren et al., 2006; Kampmann et al., 2008; Kågesson, 2008). A road transport carbon tax would avoid this detrimental general equilibrium effect as it will have no impact on the EUA price. There are a number of conditions to render this a valid concern. First of all, road transport integration needs to actually raise the allowance price. Our analysis in Section 5 indicates that this is not the case for relevant EU climate policy specifications. Thus, leakage concerns would be obsolete. But even if the carbon price would rise due to transport integration to cap-and-trade, each of the following points would have to be met in addition: (i) The carbon price elasticity of leakage is significant, i.e. an increasing allowance price leads to substantial leakage effects. These rates are largely unknown and methodically difficult to determine. (ii) No policy instrument exists which could mitigate carbon leakage risk. (iii) The welfare loss from carbon leakage is large, and indeed larger than the efficiency gain from harmonizing marginal abatement costs, and a transport carbon tax would better balance domestic efficiency and carbon leakage concerns.

Another argument is that transaction costs of road transport inclusion will be very high, in particular when final consumers are the point of regulation (Ecofys, 2006). However, up- or midstream coverage will contain transaction costs and should not exceed those of current EU ETS facilities, where they are not found to be prohibitive (Jaraite et al. 2010; see also Section 4.1). Also, monitoring, reporting and verification (MRV) are required for both carbon taxation and cap-and-trade, and the related transaction costs are identical. An asymmetry arises from the costs of establishing a

well-functioning carbon market which will be lower where such a system is already in place (e.g. the EU ETS).

3.2 Arguments favoring cap-and-trade

Three observations motivate the argument of this subsection: (1) marginal abatement costs are uncertain, (2) policymakers prefer quantitative emission targets and (3) sometimes implement cap-and-trade in other sectors of the economy. To illustrate uncertainty over marginal abatement cost curves (MACCs), Figure 2 displays MACC estimates from several models for the European road transport sector in 2020.

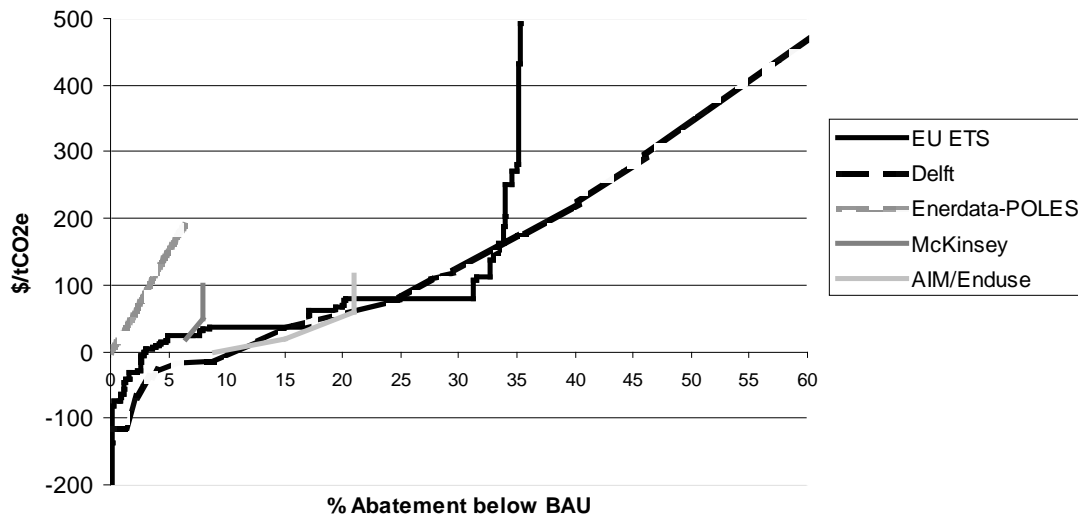


Figure 2: Comparison of marginal abatement cost curves for year 2020 EU road transport sector from CE Delft (Blom et al., 2007), Enerdata-POLES (Enerdata, 2010), McKinsey and AIM/Enduse (Clapp et al., 2009) and an aggregate EU ETS curve (Blom et al., 2007).

On the global level, preference for quantity objectives is documented by the design of the Kyoto Protocol and more recently the 2°C objective enshrined in the Copenhagen Accord (UNFCCC, 2009). Regionally, the European Union has adopted

legislation to reduce emissions by 20% relative to 1990 by 2020. In its submission to the Copenhagen Accord, the United States envisage 17% emission reductions below 2005 levels by 2020. The announcements by China and India to reduce carbon intensity of GDP by 40-45% and 20-25% below year 2005 levels by 2020 are also based on emission quantities rather than prices.

When a fixed carbon tax is used to manage a carbon budget and MACCs turn out to be higher than expected, there will be a shortfall in abatement and the policy objective is missed. To avoid policy failure of carbon taxation in presence of uncertainty, the regulator can implement international flexibility mechanisms for compliance, as foreseen by EU climate policy legislation (EC, 2009a).² However, if the price of CDM credits or statistical transfers deviates from the carbon tax, this indicates that the policy configuration is inefficient. In an economy-wide cap-and-trade system, by contrast, the cap will ensure compliance with the policy objective, and trading will result in a uniform allowance price across all sectors.

With uncertainty over abatement costs, and simultaneous application of a fixed carbon tax in the road transport sector and cap-and-trade in other sectors will almost certainly lead to inefficiency as the tax and allowance price will diverge. When road transport fuels are generated in diverse fuel chains (e.g. crude oil refining, biofuel refining, power generation) such asymmetric carbon pricing also implies intra-sector distortions, as transport technologies and modes will face different carbon prices (e.g. Bühler et al., 2009). By contrast, an economy-wide cap-and-trade system automatically harmonizes sector carbon prices without need for adjustments by the regulator.

The relevance of this argument clearly depends on the scale of the potential policy failure and inefficiency. If the errors in policy-making turn out to be small, and minor failures in achieving quantity targets can be tolerated or mitigated by using flexible mechanisms, the asymmetry between tax and trading will be weak.

4. Cap-and-trade design

Practical implementation of cap-and-trade for any sector requires specification of a number of design elements (Brunner et al., 2010b). The choice of the point of regulation for road transport cap-and-trade has received the most attention. We revisit and extend this debate beyond the traditional gasoline and diesel fuel chains by also considering electricity, natural gas, hydrogen and biofuels (Section 4.1). Section 4.2 discusses additional design features, in particular the allocation of allowance value and international linking of cap-and-trade systems.

4.1 Point of regulation

The point of regulation specifies where in the transport fuel supply chain emission allowances have to be delivered to the regulator. Fuel supply chains can be characterized by up-, mid- and downstream processes and actors. The production of feedstocks (e.g. crude production, farming) and fuel production (e.g. at refineries, power generation) are both defined as upstream here. In addition, fuel storage and distribution (midstream) and vehicle fuel consumption (downstream) can be distinguished.

In general, three principles govern the choice of the most effective and efficient point of regulation:

1. All fuel chain emissions should be covered and double counting excluded (effectiveness)
2. All emission reduction options in the sector should be incentivized (efficiency)
3. Transaction costs should be minimized by choosing the point in the fuel chain where the number regulated entities is minimal, where costs of monitoring and compliance are lowest, or where proper administrative structures are already in place

With three principles, four potential points of regulation (feedstock production, fuel production, fuel storage and distribution, final consumption), and at least five fuel chains a comprehensive discussion needs to cover 60 facets, not including the possibility of fuel blending. While a detailed treatment is beyond the scope of this paper, we aim to elicit crucial issues.³ Figure 3 provides an overview.

Road transport fuel chain emissions arise at the level of feedstock production (e.g. oil or gas drilling, farming), fuel production (e.g. crude refining or biomass fermentation), and combustion of carbon-based fuels in vehicles. Thus, the point of regulation regime might address several levels to ensure that all emissions are included to the cap. Alternatively, if information regarding upstream emissions associated with feedstock and fuel production can be reported along with each fuel delivery, and taking into account that the emissions from oxidization of carbon-based fuels in vehicles can be calculated from chemical fuel properties, the reporting requirement may be placed upon another level in the fuel chain where these data are collected. Also, it needs to be ensured that intermediate products that do not result in transportation emissions, e.g. fossil-based lubricants or biomass products that are used in food production are

exempted from the allowance delivery obligation. Fuel chain emissions that occur outside the regulating jurisdiction require separate treatment.

In competitive markets the costs of surrendering an allowance up- or midstream (e.g. at the fuel production, or storage site) will be factored into the fuel price and shifted downstream. In Germany, for example, fuel taxes are collected at the midstream level but their burden is shifted to consumers. This means that an up- or midstream emission price will be devolved to final consumers, thus incentivizing demand side abatement. As an analogy, in the EU Emission Trading System (EU ETS), emissions from power production are regulated at the power plant level but power producers forward the allowance price to final consumers by including it in the price of electricity (Sijm et al. 2006).

In the conventional gasoline and diesel fuel chain, the amount of CO₂ emissions that will ultimately be released from burning gasoline or diesel produced from one barrel of crude oil or a liter of conventional gasoline can be readily calculated. Thus, the point of regulation accounting for emissions from combusting the fuels in vehicles may principally be anywhere along the fuel chain (Bergmann et al. 2005). As millions of vehicles and car owners would need to adapt to the regulation, high transaction costs prohibit downstream regulation. Additional process emissions, e.g. at domestic coal-to-liquid, tar sand or oil shale facilities, and at fuel refineries need to be addressed separately. The EU ETS, for example, already covers emissions from conventional fuel refineries.

Fuels that are equivalent in end-of-pipe GHG emissions may have vastly varying life-cycle emissions, due to variations in e.g. feedstock recovery, refining, farming

methods, and indirect land-use effects (Creutzig et al., 2011). Also, blending allows for combination of various fuels. Emissions associated with biomass production will differ across crops, regions, and farms. Accurate monitoring of emissions at the farm level is the generally favorable approach, but high transaction costs for accurate monitoring at this level may rather suggest aggregate accounting (DeCicco, 2009). Emissions arising from biofuel refining can be readily monitored and regulated at the biofuel production level, and the carbon content and emissions from burning biofuels in vehicles are well-known at the biorefinery gate. Hence, one approach to include biofuels would be to include both domestic farms and biorefineries, while ensuring that products that do not enter the transportation sector (e.g. food) are exempted.

As an alternative to such an upstream approach, DeCicco (2009) suggests to integrate biofuels midstream at the level of fuel distribution. Fuel distributors would bear the requirement to deliver allowances according to the carbon content of any liquid fuel, and thus the emissions resulting from its combustion in vehicles. In addition, DeCicco proposes a voluntary option for tracing upstream emissions of individual biofuel deliveries (including blended biofuels) that would reduce the allowance delivery requirement in proportion to the overall GHG balance of the biofuel. If the negative GHG effect from plant CO₂ absorption is larger than the emissions from farming (e.g. use of fertilizer, tilling) and refining (CO₂ emissions from fermentation), there will be an incentive to trace emissions back and make use of crops and processes that minimize life-cycle emissions. An advantage of this approach is that transaction cost considerations are internalized to the market, as emission monitoring will only be implemented if the value of carbon credits is expected to exceed transaction costs.

The most significant challenge regarding biofuel integration to cap-and-trade relates to the epistemic uncertainties of indirect land use emissions. Increased domestic production as well as imports of biofuel feedstocks raise world market prices of agricultural goods and increases pressures on global land-use, especially tropical deforestation, while precise life-cycle assessment of these effects raises serious challenges (Plevin et al., 2010; Creutzig and Kammen, 2009; Creutzig et al., 2011). Also, even if indirect land-use emissions could be specified, in absence of a global cap (or an equivalent carbon regime) the question arises how to account for emissions that are induced by behavior of a region adopting climate policy, but that occur outside its borders. One, albeit imperfect, option is to use life-cycle analysis as a proxy to account for indirect land-use emissions and to put a fee on domestic and imported biomass entering the transport sector to adjust incentives for biomass use. Revenues may be used to fund future REDD (Reduced Emissions from Deforestation and Forest Degradation) programs to offset the detrimental effects on emissions (DeCicco, 2009).

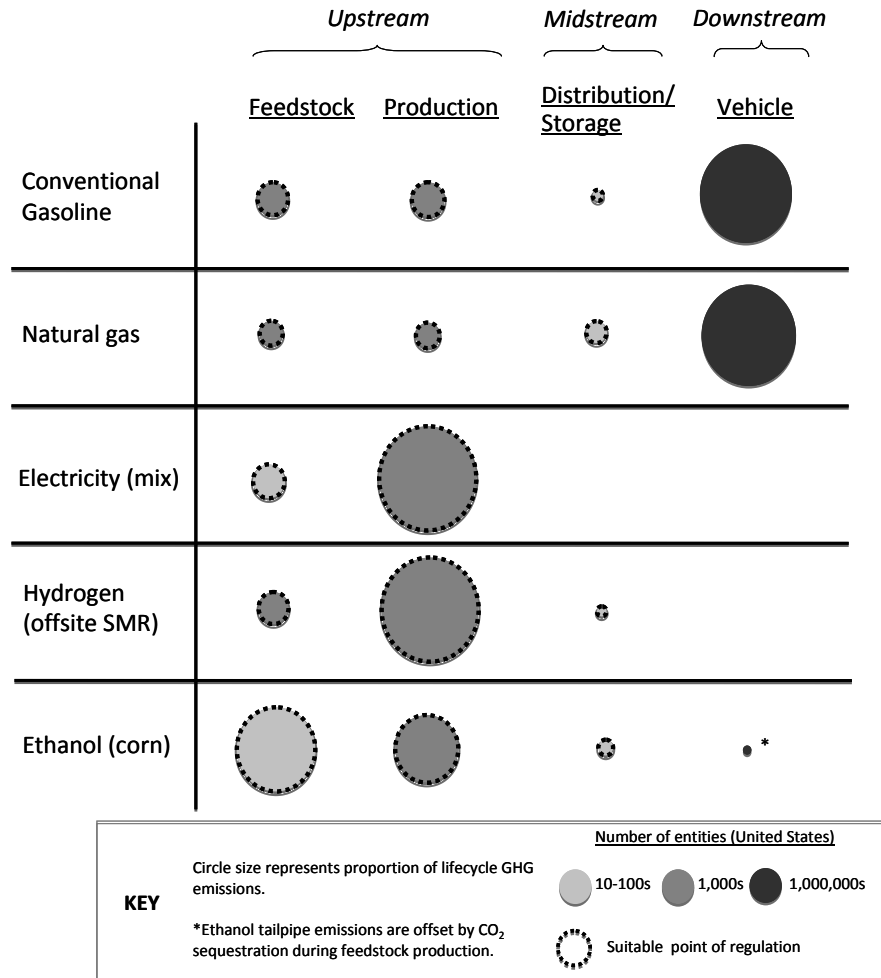


Figure 3: Overview of emissions at different levels in several fuel chains, and suitable points of regulation. Sources (data refer to the United States): CARB (2009), Hargrave (2000), NREL (2010), Stavins (2007).

In both the hydrogen and electricity fuel chain the vehicle-propelling fuel features zero molecular carbon content but can be produced from a range of feedstocks with different GHG emission factors (e.g. coal, gas, oil, renewables). A difference is that hydrogen may be regulated midstream (and, omitting transaction cost considerations, downstream) if the upstream emissions of specific hydrogen deliveries

are traced for each hydrogen delivery, analogous to the biofuel approach discussed above. By contrast, efficient mid- or downstream coverage of electricity is not feasible, as it is impossible to associate a certain flow of electricity with a specific power production site and the emissions that resulted in its production. Only average grid emission factors could be used in mid- or downstream regulation, which would fail setting incentives for fuel switching in power production.

The suitable point of regulation for fuel imports from regions that lack comparable carbon pricing systems depends on the point of regulation regime. In an upstream approach, the facility or company managing the import of the fuel would be suitable. In a midstream approach, fuel distributors may be required to deliver allowances to ensure consistency. In any case, an allowance delivery requirement regarding the molecular carbon content of the fuel should be implemented for imported fuels to account for the resulting domestic emissions and avoid substitution of domestic fuels by imports. Accounting for upstream process emissions (possibly including e.g. tar sand and oil-shale processes, or crops from high-emission farming practices) in foreign countries that lack comparable carbon pricing mechanisms is difficult. But if these emissions are ignored, imported fuels from emission-intensive production processes will feature a lower GHG price than fuels from comparable domestic processes, and may substitute domestic production, i.e. perverse effects may occur. The only perfect remedy is adoption of comparable approaches in other regions and ultimately world-wide. More realistically, fee charges for imported fuels based on average emission factors for foreign fuel production systems might serve as a proxy, e.g. by relying on life-cycle accounting methods. The issue is basically the same as for any other imported product

that embodies upstream emissions (DeCicco, 2009), and thus the essential question is whether border-adjustments shall be applied. If border-adjustments occur via delivery of emission allowances rather than the payment of fees, it needs to be taken into account that this changes the nature of the cap-and-trade accounting system from a production-based approach – as it is commonly applied e.g. in the EU ETS and Kyoto Protocol – to a consumption-based approach.

Another approach to a point of regulation regime that we do not investigate here would include vehicle manufacturers into the cap-and-trade system by attributing their vehicle sales with expected lifetime emissions and requiring delivery of allowances from the manufacturer at the time of vehicle sales - effectively frontloading allowance expenditures for fuels on behalf of the consumer (e.g. Winkelmann et al., 2000). This approach suffers from two fundamental problems. First, it is inefficient because it sets no incentive to adjust driving behavior and fuel production. Second, attributing lifetime emissions to vehicles requires cumbersome definition of uniform emission factors for fuels and cars. Policy design is further complicated by the need of multi-year trading periods to enable car manufacturers surrendering allowances for vehicle emissions several years ahead.

In summary, there is some flexibility in choosing the appropriate point of regulation without compromising effectiveness and efficiency if (1) coverage of the regime is comprehensive and avoids double counting, (2) all mitigation options are incentivized, and (3) transaction costs remain low. The feedstock and fuel production levels can be suitable upstream points of regulation for all of the considered fuel chains. Midstream coverage is another suitable option to account for the direct carbon content

of the fuel, and if upstream emissions are either accounted for separately or an emission tracing system is put in place that reports upstream emissions of fuel deliveries to the midstream level. Downstream regulation is rejected due to the significant transaction costs of regulating millions of vehicles and consumers. Further research is required to develop detailed proposals for the suitable options identified here, including an assessment of transaction costs in particular of biofuel approaches. Also, research is required on how to deal with extraterritorial emissions from upstream fuel processing and indirect land-use change effects. While it is possible to choose between different point of regulation regimes (Hargrave, 2000), consistency is vital to avoid loopholes and double-pricing.

4.2 Other design features

When including road transport into EU ETS, the cap must be designed to be in agreement with regional and/or global mitigation targets, and to ensure an efficient effort-sharing between ETS and non-ETS sectors (Böhringer et al., 2009). In presence of perfectly efficient pre-integration policy adding a non-ETS sector to an ETS should actually not impact allowance prices.

The allocation of allowance value has both efficiency and distributional dimensions. Perverse incentives from free allocation need to be avoided, e.g. when future free allocation is based upon current emission levels. Auctioning is widely preferred by economists as this method does not suffer from such shortcomings (Hepburn et al. 2006). Free allocation is sometimes used as a subsidy to protect trade- and carbon-price exposed sectors (such as steel and aluminum) from international

competitors not facing comparable constraints (EC, 2010). This aspect is not relevant for road transportation as the final economic activity is not subject to international trade. If transport fuel refineries and importers receive allowances for free, they increase their revenue by increasing product prices without having to pay for allowances, realizing so-called windfalls profits. Fuel prices would rise and generate additional revenues for these actors. Auctioning of allowances eliminates windfall profits, and the revenue can be used for a variety of purposes, including ensuring a progressive distribution of the policy burden by compensating consumers accordingly (Burtraw et al., 2009).

If imported fuels have to acquire allowances covering their carbon content, and if the indirect GHG emissions from upstream processes can be included using some proxy to avoid perverse effects (see previous section), no competitive distortion will arise with regard to imported fuels.

Regional flexibility is provided by linking regional cap-and-trade systems or by enabling access to credits e.g. from the Clean Development Mechanism (CDM) (Tuerk et al., 2009). Linking promises efficiency gains if permit prices differ across regions, and harmonization of allowance prices across cap-and-trade systems eliminates industrial competitiveness concerns by ‘levelling the carbon playing field’ (Flachsland et al., 2009). When linking to crediting schemes it is paramount to ensure additionality. This means that emissions need to be reduced below business-as-usual levels, i.e. credits shall not be issued to reward emission reductions that would occur anyway (Schneider, 2007). Linking cap-and-trade systems of major automobile markets such as the United States and Europe would ensure harmonized carbon prices across these

markets, facilitating research, development and deployment planning of international firms.

5. Economic impacts: the European case

5.1 Abatement costs in Europe

Marginal abatement cost curves are a standard tool for analyzing price and quantity effects in carbon markets and are widely used e.g. to analyze the integration of regional trading systems (Anger, 2008; Criqui et al., 1999; Ellerman and Decaux, 1998; Stankeviciute et al., 2008). The basic concepts for analyzing regional links or integration of sectors are identical. Figure 2 above displays four marginal abatement cost curves for the European road transport sector and one aggregate MACC for the EU ETS sectors.

Marginal abatement cost curves can be derived in several ways which is reflected in the differences across models (Clapp et al., 2010). Important choices concern the model structure (e.g. top-down versus bottom-up, scope of considered technologies and behavioral reactions), parameter assumptions (e.g. regarding costs and potentials of biofuels, where little empirical evidence is available), baseline assumptions (e.g. energy prices, economic growth, technological innovation) and policy assumptions regarding the baseline. Also, marginal abatement cost curves are static estimates that possibly underestimate effects of technological learning curves as for example induced by carbon pricing.

Among the MACCs applied in the analysis below, only the CE Delft road transport curve explicitly includes demand side responses while McKinsey and

AIM/Enduse do not include this option. Including behavioral responses into the other curves would flatten all of them (see Figure 1). Also, none of the transport MACCs takes the 2009 EU climate package into account, which would unambiguously shift curves downwards (see Figure 9 and the discussion in Section 5.3). Finally, none of the models takes the recent world economic crisis into account. This would also shift marginal cost curves downwards, as year 2020 baseline emission levels are reduced and a lower price incentive is required to yield a given level of emissions.

When modeling road transport inclusion to the EU ETS, the MACCs from Figure 2 need to be modified to reflect the EU ETS link to the CDM (EC, 2004). This regional flexibility can be modeled by adding the permitted volumes at expected prices of credits to the schedule of available abatement options (Figure 4).

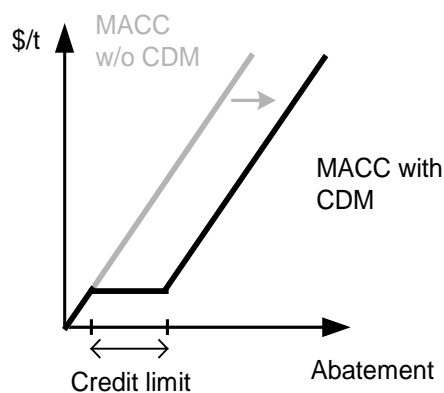


Figure 4: Including limited international credit supply to a marginal abatement cost curve. Credits enable access to additional abatement options in other countries, and the price of this abatement option is set by the world market.

The EU has specified a complicated set of rules determining the quantity of credits available in the EU ETS in the 2013-2020 trading period (EC, 2009b). Our estimate for credit use is the mean of the average annual estimates summarized in Capoor and Ambrosi (2009, p.8), which amounts to 150Mt per year. A CDM world

market price of 30\$/t in 2020 is assumed. As a new sector, road transport would increase the total amount of credits available in the EU ETS. The reformed EU ETS Directive suggests that road transport would increase the amount of available credits in the EU ETS by 4.5% of year 2020 road emissions (EC, 2009b, Article 11a). In the scenario where EU emission reductions are enhanced from 20% to 30% relative to 1990, we assume that 50% of the additional abatement effort can be covered by credits.

Figure 5 illustrates how MACCs enable the analysis of price and quantity effects of adding sectors to an existing cap-and-trade system. The horizontal axis depicts the total abatement required by both sectors. In our example, the section left of Q_{set} represents the abatement target for the ETS already in place, and the section to the right of Q_{set} denotes the abatement target for the road transport sector to be included. The ETS pre-link allowance price P_{ETS} is determined by the intersection of the EU ETS curve and the policy target (Q_{set}), while the transport sector pre-integration MAC is given by P_{trans} . The optimal allocation of abatement Q^* and the corresponding optimal allowance price level P^* result at the intersection of the MACCs as indicated in the right hand panel. The aggregate efficiency gain is indicated by the shaded area.

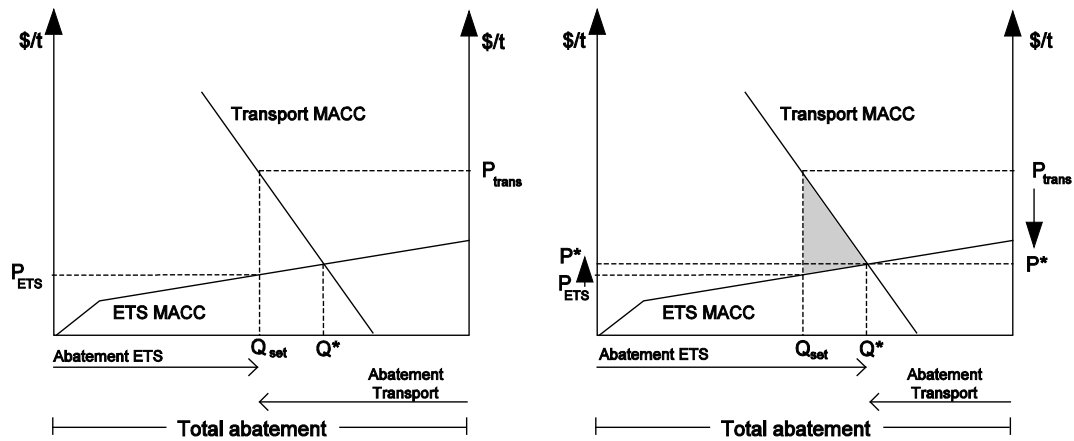


Figure 5: Pre- and post-integration carbon market equilibrium and efficiency gains from including road transport. The left figure indicates asymmetric marginal abatement costs prior to road transport inclusion. The right figure shows marginal abatement cost adjustment due to integration, with the shaded area denoting the efficiency gain from integration.

The assumptions on abatement targets in the default policy scenario are based on the EU-wide GHG reduction target of 20% below 1990 levels by 2020 (EC, 2009a, b). EU policymakers adopted a sector burden-sharing where the EU ETS sectors need to reduce their year 2020 emissions by 21% below 2005 levels (EC, 2008). The transport sector is supposed to reduce emissions 7% below its 2005 level by 2020. It is claimed that these are the efficient burden-sharing levels as determined in modeling exercises, i.e. marginal abatement costs in these calculations are supposed to be harmonized across sectors. Table 1 summarizes historic emissions, future projections, sector caps and abatement targets for the EU ETS and the considered road transport MACCs.

Unit: Mt CO ₂ e	EU ETS (Delft)	Road Transport			
		Delft	Enerdata- POLES	McKinsey	AIM/ Enduse
2005 emissions	2014	895	895	895	895
2020 BAU emissions	2363	1116	893	1000	1100
2020 cap in 20% scenario	1591	832	832	832	832
2020 abatement below BAU, absolute	771	284	61	168	268
2020 abatement below BAU	33%	25%	7%	17%	24%

Table 1: 2005 emissions from EU ETS and road transport sectors, baseline emission projections from different models, sector policy targets under the 20% EU-wide reduction target, and corresponding abatement targets for the EU ETS and transport sectors (in MtCO₂e). Sources: Historical year 2005 emissions EEA (2010); year 2020 BAU projections for the different models same as Figure 2.

A scenario with 30% reduction below year 1990 emission is investigated in addition to the 20% default policy case (EC, 2010). For this enhanced EU effort we assume that EU ETS and road transport uniformly increase their abatement by 50% above the effort of the default scenario. Thus, modified ETS and road transport reduction targets are 31.5% and 10.5% below year 2005 emission levels, respectively. In a third policy scenario, we investigate the impact of the 20% default policy scenario while excluding the link to crediting schemes.

5.2 Results

Figure 6 displays the CE Delft and Enerdata-POLES results for the 20% policy default case (see Creutzig et al. 2010 for all scenarios and models). Figure 7 summarizes the price changes in the EU ETS and the road transport sector, and Figure 8 shows how abatement quantities shift between sectors.

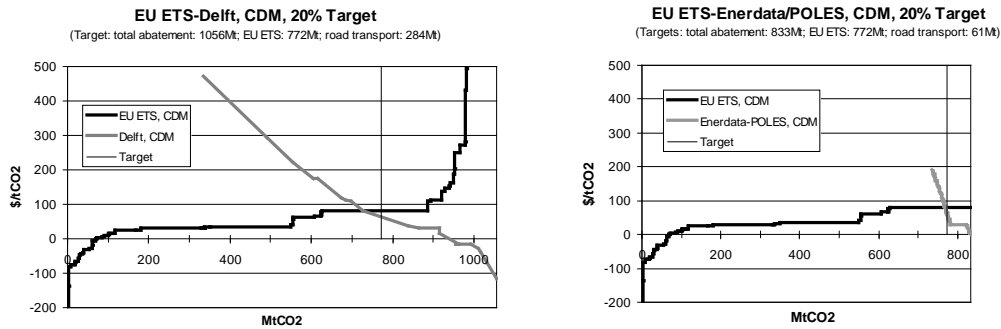


Figure 6: Economic impacts of integrating EU road transport into the EU ETS by 2020 using CE Delft (left) and Enerdata-POLES (right) road transport MACCs. Pre-integration prices and quantities are determined by the intersection of the MACCs with the vertical line which indicates sector abatement targets. Post-integration price and quantity equilibrium results where the MACCs intersect.

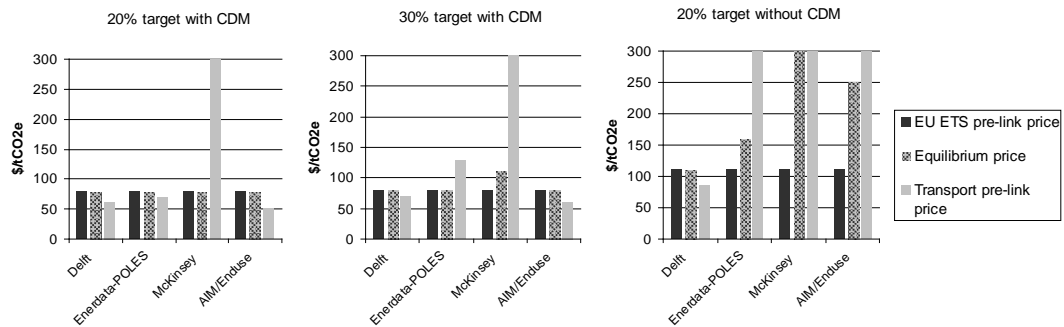


Figure 7: Price effects of EU road transport integration into the EU ETS in 2020 for three policy scenarios and four models. The figure displays pre- and post-integration marginal abatement costs in the EU ETS and transport sector. Bars exceeding the scale indicate that the abatement target cannot be achieved because the model lacks sufficient abatement options.

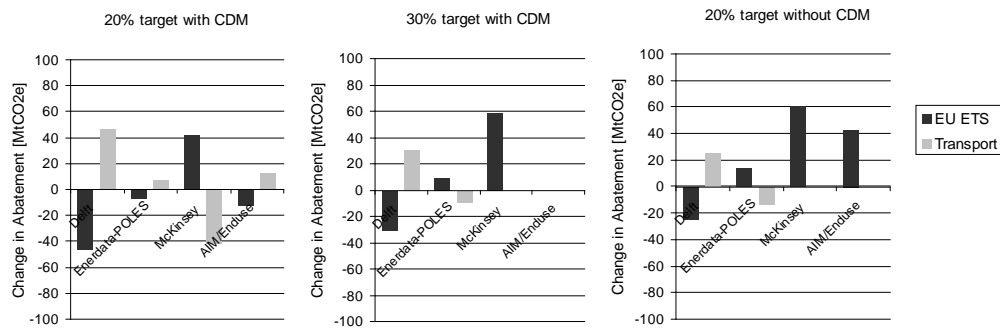


Figure 8: Change in abatement quantities across sectors when including EU road transport into the EU ETS in 2020 for three policy scenarios. Positive values mark increased abatement activity in a sector and vice versa. Where the changes for EU ETS and transport sectors do not cancel out, the quantity objective is not achieved prior to transport integration because models lack sufficient abatement options.

As the perhaps most striking result, in the default 20% policy scenario the EU ETS allowance price remains unchanged for all models (Figure 7). This is in contradiction to previous MACC-based assessments usually concluding that road transport integration to the EU ETS would raise the EUA price (Blom et al., 2007; COWI, 2007; Hartwig et al., 2008; Holmgren et al., 2006). Integration of road transport would actually reduce the amount of abatement required from EU ETS sectors for all but the McKinsey model (Figure 8).

This result can be explained by the combination of (i) the volume of abatement potentials in road transport as represented by the MACCs, (ii) regional flexibility in meeting part of the abatement target with CDM credits, and (iii) the 7 % road transport reduction target below 2005 levels not representing a very large challenge for EU road transportation, given the scope for domestic and foreign abatement.

The pre-integration EUA price of 80\$/t for the year 2020 is quite high compared to the 37\$/t reported by EC (2008) modeling, or private sector estimates of 37-50\$/t

reported by Capoor and Ambrosi (2009, p.8). This reflects the rather conservative EU ETS cost curve estimate by CE Delft (see Blom et al., 2007).

In the 30% reduction scenario, the same picture emerges except for the McKinsey cost curve. In this model the constraint becomes so tight that the EUA price needs to rise to incentivize more expensive abatement options in the EU ETS. It is worth noting that the McKinsey model does not take demand side reductions into account. Including this abatement option into the model would flatten and extend the road transport MACC and would dampen the EUA price increase (see Figure 1). Furthermore, the economic crisis has eased the conditions for meeting a 30% reduction target (EC, 2010). The MACCs in this analysis would reflect the economic crisis by shifting downwards, thereby dampening impacts on allowance prices.

The third policy scenario (20% reduction target without access to CDM) leads to substantially different outcomes. Except for the CE Delft curve, EU ETS prices rise and the EU ETS sectors need to deliver additional abatement. Even for the CE Delft case the pre-link EUA price level is higher than in the default scenario because more expensive domestic abatement options need to be harnessed as international emission trading is not available. For the McKinsey model the aggregate target is not feasible because it features insufficient domestic abatement potentials. This scenario illustrates the importance of regional flexibility for containing EUA prices.

Several conclusions can be drawn from this analysis. First, with the EUA price remaining constant in case of road transport inclusion to the EU ETS in the 20% default policy scenario in all models, concerns over carbon leakage from transport inclusion appear less well-founded than is often suggested in the literature.

Second, the relatively moderate sector differences in pre-integration MACs and the correspondingly modest changes in sectoral abatement in case of transport integration indicate that EU policymakers perform well in terms of sector burden-sharing. However, existing instruments for the road transport sector are not market-based and hence the abatement options in this sector do not consistently face the same shadow price of emissions. Therefore, it can be expected that road transport inclusion would deliver efficiency gains.

Third, the McKinsey and AIM/Enduse models ignore demand side responses and only represent technical abatement options. Taking behavioral responses into account would unambiguously lower the transport MAC curves. Therefore EUA price increases for these curves would be lower than indicated here. In a similar vein, taking into account the world economic recession would work towards reducing EUA price levels and changes in all scenarios.

Finally, this analysis does not include non-price policies as embodied by the recent EU climate policy package (e.g. EC, 2009c). A detailed analysis is beyond the scope of this study. However, estimates of the impact of non-price road transport policies on abatement in the European Union and the United States are discussed in the next section.

5.3 Interaction with non-market policies

Non-market policies will induce abatement even in absence of market-based policies. In the MACC framework this can be represented as a shift in the marginal abatement cost curve as shown in Figure 9. In a cap-and-trade system, standards that trigger abatement options that either cost more than the equilibrium allowance price P^* (in Figure 9 the marginal cost of the standard is indicated by the point where the original and modified MACC intersect) or that do not respond to an allowance price due to some market failure will have the effect of reducing the equilibrium allowance price to P^s .

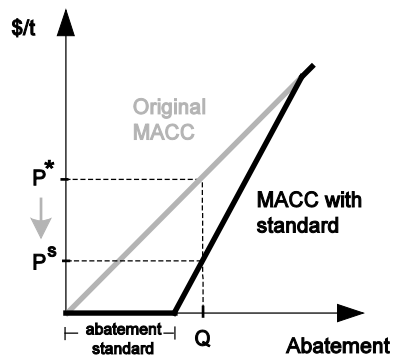


Figure 9: Standards shift the marginal abatement cost curve downwards and can reduce the allowance price in cap-and-trade systems.

Creutzig et al. (2010) calculate that EU non-market policies such as vehicle emission intensity standards, the Fuel Quality Directive and measures including improved air conditioning and tires will reduce EU road transport emissions in 2020 to around 11% below the 2005 level, despite moderate growth of transport volumes (EC 2009c). This would not only exceed the 7% year 2020 reduction target below 2005 emissions in the default policy scenario above, but also the 10.5% target assumed for the enhanced 30% EU-wide effort. In the United States—assuming the revised US CAFÉ

standards will remain constant from 2016 to 2020—vehicle efficiency standards will induce road transport emissions to drop by 3% relative to 2005 levels in 2020.

What does this mean for the EU ETS integration of the European road transport and the results derived above? As standards have the effect of shifting the road transport MACCs downwards, this unambiguously works towards reducing allowance prices in the integrated trading system. In the same vein, it will work towards reducing the level of abatement required in the EU ETS sectors. Therefore, the analyses in the previous section tend to overestimate the increase of the EUA price when adding road transport to the EU ETS. The price impact of road transport inclusion to the EU ETS can be expected to be even more moderate than found above.

6. Conclusions

Well-designed market-based instruments such as carbon taxes and cap-and-trade systems have several advantages over non-market climate policies for the road transport sector. Their merits include the provision of abatement incentives across all available emission reduction options (within and across sectors) at harmonized marginal costs of abatement, the elimination of rebound effects, a level playing field for competing technologies, and lower informational requirements. Therefore, market-based climate policies fill an important policy gap in the current road transport policy portfolio that is dominated by non-market instruments in many regions including the European Union and the United States. Where carbon price signals are ineffective due to market failures, non-market policies continue to play an important complementary role.

Cap-and-trade and carbon taxes are equivalent instruments in a simple analytic framework. However, cap-and-trade is the favorable instrument if marginal abatement costs are uncertain and policymakers prefer quantitative emission targets, or if a cap-and-trade system has already been implemented in other sectors of the economy. If errors in setting a carbon tax turn out to be small or flexibility mechanisms are implemented to contain the magnitude of error, the asymmetry between tax and trading will be weak.

Both the up- and midstream levels are suitable to implement a point of regulation regime that is effective, efficient and features low transaction costs in presence of diversifying fuel chains. Further research is required how to efficiently measure biofuel-associated emissions, and how to deal with extraterritorial emissions from upstream fuel processing and indirect land-use change effects. Auctioning of allowances is preferable to free allocation to ensure efficiency and avoid windfall profits. Well-designed links to other cap-and-trade systems will 'level the carbon playing field' across the linked regions and enhance efficiency. Gains from trade also motivate links to emission crediting schemes.

A comparative analysis of integrating the road transport sector into the EU ETS in 2020 reveals that in the present EU climate policy configuration (20% economy-wide reductions below 1990 levels by 2020) no allowance price changes would result from adding the sector to the EU ETS. This can be explained by the interplay of the volumes of abatement that are available in the road transport sector, regional flexibility exhibited by the access to CDM credits, and the relatively modest emission reduction target for the road transport sector that is envisaged by EU policymakers. Therefore, the

widespread concern over carbon leakage from trade-exposed EU ETS sectors in case of rising allowance prices due to road transport inclusion is not confirmed by our results.

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References

Abrell, J. (2009): Regulating CO₂ Emissions of Transportation in Europe: A CGE-Analysis Using Market-Based Instruments. Economics of Global Warming Working Paper WP-EGW-06, June 2009.

ACESA (2009): American Clean Energy and Security Act of 2009. US House of Representatives, H.R. 2454.

American Power Act (APA) (2010): Discussion Draft, 111th Congress, 2nd Session.

Anger, N. (2008): Emissions trading beyond Europe: linking schemes in a post-Kyoto world. *Energy Economics* 30: 2028-2049.

API – American Petroleum Institute: State Gasoline Tax Report July 2010. Available at: http://www.api.org/statistics/fueltaxes/upload/July_2010_Gasoline_and_Diesel_Summary.pdf

Australian Government, 2008, *Carbon Pollution Reduction Scheme: Australia's Low Pollution Future*, White Paper, 15 December

Bergmann, H., Bertenrath, R., Betz, R., Dünnebeil, F., Lambrecht, U., Liebig, L., Rogge, K., Schade, W., Ewringmann, D. (2005): Emissionshandel im Verkehr. Ansätze für einen möglichen Up-Stream Handel im Verkehr. FiFo Köln, Ifeu, Fraunhofer Isi. Im Auftrag des Umweltbundesamtes.

Blom, MJ., Kampmann, B.E., Nelissen, D. (2007): Price effects of incorporation of transportation into EU ETS. CE Delft Report.

Böhringer, C., Rutherford, T.F., Tol, R.S.J. (2009): The EU 20/20/2020 Targets: An Overview of the EMF22 Assessment. *Energy Economics* 31: 268-273.

Brunner, S., Flachsland, C., Marschinski, R. (2011a): Credibility in Carbon Policy. Submitted to Climate Policy.

Brunner, S., C. Flachsland, O. Edenhofer (2011b): Domestic Emissions Trading Systems. In: Fan Gang, Nicholas Stern, Ottmar Edenhofer, Xu Shanda, Klas Eklund, Frank Ackerman, Lailai Li and Karl Hallding (eds.): *The Economics of Climate Change in China. Towards a Low Carbon Economy*. Earthscan. In print.

Bühler, G., Hoffmann, T., Wölfing, N., Schmidt, M. (2009): Wettbewerb und Umweltregulierung im Verkehr. Eine Analyse zur unterschiedlichen Einbindung der Verkehrsarten in den Emissionshandel. ZEW Mannheim.

Burtraw, D., Sweeney, R., Walls, M. (2009): The Incidence of U.S Climate Policy. Alternative Uses of Revenues from a Cap-and-Trade Auction. RFF Discussion Paper 09-17.

California (2009): Cap-and-Trade Preliminary Draft Regulation. Available online: <http://www.arb.ca.gov/cc/capandtrade/meetings/121409/pdr.pdf> Accessed 8 March 2010.

CARB – California Air Resources Board (2009): Detailed California-Modified GREET Pathway for Transportation Fuels. Available at: <http://www.arb.ca.gov/fuels/lcfs/lcfs.htm>.

Carbon Trust (2008): Energy and carbon conversions. 2008 update. Fact sheet CTL018.

Capoor, K., Ambrosi, P. (2008): State and Trends of the Carbon Market 2009. The World Bank, Washington D.C., May 2009.

Clapp, C., Karousakis, K., Buchner, B., Chateau, J. (2009): National and sectoral GHG mitigation potential: a comparison across models. OECD/IEA COM/ENV/EPOC/IEA/SLT(2009)7.

COWI (2007): Road Transport Emissions in the EU Emission Trading System. Report prepared for Nordic Council of Ministers, Copenhagen 2007.

Creutzig, F., Kammen, D. (2009): Getting the carbon out of transportation fuels. In: H. J. Schellnhuber, Molina, M., Stern, N., Huber, V., Kadner, S. (Eds.): Global Sustainability - A Nobel Cause. Cambridge, UK: Cambridge University Press.

Creutzig, F., Edenhofer, O. (2010): Mobilität im Wandel - Wie der Klimaschutz den Transportsektor vor neue Herausforderungen stellt. *Internationales Verkehrswesen* 62(3):1-6.

Creutzig, F., McGlynn, E., Minx, J., Edenhofer, O. (2011): Climate policies for road transport revisited (I): Evaluation of the current framework. Submitted to *Energy Policy*.

Creutzig, F., C. Flachsland, Brunner, S., Minx, J., McGlynn, E., O. Edenhofer (2010): CITIES: Car Industry, Road Transport and an International Emission Trading Scheme – Policy Options. Report, forthcoming.

Criqui, P., Mima, S., Viguier, L., 1999. Marginal abatement costs of CO₂ emission reductions, geographical flexibility and concrete ceilings: an assessment using the POLES model. *Energy Policy* 27 (10), 585–601.

DeCicco, J.M. (2009): Addressing Biofuel GHG Emissions in the Context of a Fossil Based Carbon Cap. Discussion Paper. Ann Arbor: University of Michigan, School of

Natural Resources and Environment, October. Available at: <http://hdl.handle.net/2027.42/76029>

EC (2003): Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC.

EC (2004): Directive 2004/101/EC of the European Parliament and of the Council of 27 October 2004 amending Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the Community, in respect of the Kyoto Protocol's project mechanisms.

EC (2008a): Impact Assessment Commission Staff Working Document. Accompanying the Package of Implementation measures for the EU's objectives on climate change and renewable energy for 2020. Brussels, 23 Janvier 2008 SEC(2008) 85/3.

EC (2008b): Directive 2008/101/EC of the European Parliament and of the Council of 19 November 2008 amending Directive 2003/87/EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community.

EC (2009a): Decision No406/2009/EC of the European Parliament and of the Council of 23 April 2009 on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020.

EC (2009b): Directive 2009/29/EC of the European Parliament and of the Council of 23 April 2009 so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community.

EC (2009c): Regulation (EC) No 443/2009 of the European Parliament and of the Council of 23 April 2009 setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO₂ emissions from light-duty vehicles.

EC (2010): Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the regions. Analysis of options to move beyond 20% greenhouse gas emission reductions and assessing the risk of carbon leakage. Brussels, 26.5.2010. COM(2010) 265 final {SEC(2010) 650}.

Ecofys (2006): Inclusion of additional activities and gases into the EU-Emissions Trading Scheme. Report under the project "Review of EU Emissions Trading Scheme". October 2006.

Edenhofer, O., Carraro, C., Koehler, J., Grubb, M. (Eds.) (2006): Endogenous Technological Change and the Economics of Atmospheric Stabilisation. A Special Issue of *The Energy Journal*, Vol. 27. International Association of Energy Economics, USA.

Edenhofer, O., Knopf, B., Barker, T., Baumstark, L., Bellevrat, E., Chateau, B., Criqui, P., Isaac, M., Kitous, A., Kypreos, S., Leimbach, M., Lessmann, K., Magné, B., Scricciu, S., Turton, H., van Vuuren, D.P. (2010): The Economics of Low Stabilisation: Model Comparison of Mitigation Strategies and Costs. *The Energy Journal* (31), Special Issue 'The Economics of Low Stabilization': 11-48.

EEA – European Energy Agency (2010): EEA greenhouse gas data viewer. Available at: <http://dataservice.eea.europa.eu/PivotApp/pivot.aspx?pivotid=475>

Ellerman, D. A., Decaux, A. (1998): Analysis of Post-Kyoto CO₂ emission trading using marginal abatement curves. Report 40, Massachusetts Institute of Technology. Joint Program on the Science and Policy of Global Change.

Ellerman, A.D., Convery, F.J, de Perthuis, C., et al. (2010): Pricing Carbon. The European Union Emissions Trading Scheme. Cambridge University Press: Cambridge, UK.

Enerdata (2010): We kindly thank Enerdata-POLES for providing the MACC for this study.

EPA 2010: What is a farm? <http://www.epa.gov/agriculture/ag101/demographics.html>

Fischer, C., R.G. Newell (2008): Environmental and technology policies for climate mitigation. *Journal of Environmental Economics and Management* 55: 142-162.

Flachsland, C., R. Marschinski, O. Edenhofer (2009): To link or not to link: Benefits and disadvantages of linking cap-and-trade systems. *Climate Policy* 9 (2009) 358–372

Goodwin, P., J. Dargay, M. Hanly (2004): Elasticities of Road Traffic and Fuel Consumption with Respect to Price and Income: A Review. *Transport Reviews* (24): 275–292

Hargrave, T. (2000): An Upstream/Downstream Hybrid Approach to Greenhouse Gas Emissions Trading. Washington, D.C.: Center for Clean Air Policy.

Hartwig, K.H., J. Luttmann, S. Badura (2008): Emissionshandel für PKW — Eine ökologische und ökonomische Alternative zu CO₂-Grenzwerten. In: D. Loerwald, M. Wiesweg, A. Zoerner (Eds.): *Ökonomik und Gesellschaft*. Festschrift für Gerd-Jan Krol. VS Verlag, p.18-34.

Hepburn, C. (2006): Regulating by prices, quantities or both: an update and an overview. *Oxford Review of Economic Policy* 22 (2): 226-247.

Hepburn, C., Grubb, M., Neuhoff, K., Matthes, F., Tse, M. (2006): Auctioning of EU ETS Phase II allowances: how and why? *Climate Policy* 6 (1): 137-160.

Holmgren et al. (2006): Greenhouse gas emissions trading for the transport sector. Report B1703 by Swedish Environmental Research Institute (IVL).

IEA – International Energy Agency (2008): World Energy Outlook. International Energy Agency, Paris.

IEA – International Energy Agency (2009): Transport, energy and CO₂: moving toward sustainability. International Energy Agency, Paris.

Jaffe, A.B., R.G. Newell, R.N. Stavins (2005): A tale of two market failures: Technology and environmental policy. *Ecological Economics* 54: 164-174.

Jaraite, J., F. Convery, C. Di Mariaa (2010) : Transaction costs for firms in the EU ETS : lessons from Ireland. *Climate Policy* 10: 190-215.

Kalkuhl, M. and O. Edenhofer (2010): Prices vs. Quantities and the Intertemporal Dynamics of the Climate Rent. Working Paper.

Kampmann, B., M.D. Davidson, J. Faber (2008): Emissions trading and fuel efficiency in road transport. An analysis of the benefits of combining instruments. Swedish Environmental Protection Agency Report 5896.

Kågesson, P. (2008): Tools for Cutting European Transport Emissions. CO₂ Emissions Trading or Fuel Taxation? SNS Press.

Kosoy, A., P. Ambrosi (2010): State and Trends of the Carbon Market 2010. World Bank, Washington D.C.

Luderer, G., V. Bosetti, M. Jakob, M. Leimbach, J. Steckel, H. Waisman, O. Edenhofer (2010): The Economics of Decarbonizing the Energy System – Results and Insights from the RECIPE Model Intercomparison. Submitted to *Climatic Change*.

Meinhausen, M., Meinshausen, N., Hare, W., Raper, S., Frieler, K., Knutti, R., Frame D., Allen, M. (2009) : Greenhouse-gas emission targets for limiting global warming to 2°C. *Nature* 458:1158 – 1163.

MWV Mineralölwirtschaftsverband Deutschland (2010): Zusammensetzung des Verbraucherpreises für Normalbenzin. Available at http://www.mwv.de/cms/front_content.php?idcat=14&idart=55

Newbery D. (1992): Should Carbon Taxes Be Additional to Other Transport Fuel Taxes? *The Energy Journal*: 47-60

Nordhaus, W.D. (2008): A Question of Balance. Weighing the Options on Global Warming Policies. Yale University Press: New Haven & London.

NREL 2010: TransAtlas. <http://rpm.nrel.gov/transatlas/launch>

Paltsev, S., Jacoby, H.D., Reilly, J., Viguier, L., Babiker M. (2004): Modeling the Transport Sector: The Role of Existing Fuel Taxes in Climate Policy. MIT Joint Program on the Science and Policy of Global Change, Report No.117.

Parry, I., Small, K. (2005): Does Britain or America Have the Right Gasoline Tax? *American Economic Review* 95:1276-1289.

Parry, I., Walls, M., Harrington, W. (2007): Automobile Externalities and Policies. *Journal of Economic Literature* XLV: 373-399.

Plevin, R. J., O'Hare, M., Jones, A. D., Torn, M. S., Gibbs, H.K. (2010): The greenhouse gas emissions from market-mediated land use change are uncertain, but potentially much greater than previously estimated. *Environmental Science & Technology* 44 (21): 8015–8021.

Proost, S., E. Delhaye, N. Wouters, D. van Regemorter (2009): Will a radical transport pricing reform jeopardize the ambitious EU climate change objectives? *Energy Policy* 37 (10): 3863-3871.

Raux, C. (2005): A system of tradable CO₂ permits applied to fuel consumption by motorists. *Transport Policy* 12: 255-265.

Schneider, L. (2007): Is the CDM fulfilling its environmental and sustainable development objectives? An evaluation of the CDM and Options for improvements, Report prepared by Öko-Institut e.V. for WWF, 5 November 2007, Available at: <http://www.oeko.de/oekodoc/622/2007-162-en.pdf>.

Sijm, P. M., Neuhoff, K., Chen, Y. (2006): Cost pass-through and windfall profits in the power sector. *Climate Policy* 6: 49-72.

Sinn, H.-W. (2008): Public policies against global warming: a supply side approach. *International Tax and Public Finance* 15 (4): 360-394.

Small, K.A., Van Dender, K. (2007): Fuel efficiency and motor vehicle travel: The declining rebound effect. *Energy Journal* 28:25-51

Stankeviciute L., Kitous A., Criqui P. (2008): The fundamentals of the future international emissions trading system. *Energy Policy* 36 (11): 4272–4286.

Stavins, R.N. (2007): A U.S. Cap-and-Trade System to Address Global Climate Change. The Hamilton Project, Discussion Paper 2007-13. Washington, D.C.: The Brookings Institution.

Stavins, R.N. (2007): A U.S. Cap-and-Trade System to Address Global Climate Change. The Hamilton Project, Discussion Paper 2007-13. Washington, D.C.: The Brookings Institution.

Stern, N., et al. (2007): The Economics of Climate Change. The Stern Review, Cambridge University Press: New York.

Sterner, T. (2007): Fuel taxes: An important instrument for climate policy. *Energy Policy* 35: 3194–3202.

Tinbergen, J. (1952): On the theory of economic policy. Amsterdam: North Holland

Tuerk, A., Mehling, M., Flachsland, C., Sterk, W. (2009): Linking carbon markets. Concepts, case studies and pathways. *Climate Policy* 9: 341–357.

UNFCCC (2009): Copenhagen Accord. Draft decision CP.15. Document FCCC/CP/2009/L.7, 18 December 2009.

WBGU (German Advisory Council on Global Change) (2009): Solving the climate dilemma: the budget approach. WBGU Special Report, Berlin, September 2009.

Weitzman, M. L. (1974): Prices vs. Quantities. *Review of Economic Studies* 41(4): 477–491.

Winkelman, S., Hargreave, T., Vanderlan, C. (2000): Transportation and Domestic Greenhouse Emissions trading. Washington, D.C.: Center for Clean Air Policy.

Footnotes

¹ Throughout this paper, the exchange rate from Euro to US\$ is 1 to 1.24. Combustion of one liter gasoline results in 2.315 kg CO₂ emissions (Carbon Trust 2008).

² The EU climate package enables governments to use CDM credits for compliance with up to 3% of their year 2020 EU-emission objectives in non-ETS sectors. In addition, EU countries can use statistical transfers of non-ETS sector reductions to comply with their reduction burdens in non-ETS sectors, i.e. government-level emission trading.

³ More detailed analyses covering the optimal point of regulation in road transportation are Bergmann et al. (2005), who focus on the conventional gasoline and diesel fuel chains, and DeCicco (2009), who provides a detailed analysis of road transport biofuel integration into an economy-wide cap-and-trade system.