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**Regulating CO₂ Emissions of Transportation in
Europe:
A CGE-Analysis Using Market-Based Instruments**

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Abstract: This paper analyzes the use of market-based emission regulation instruments to address the carbon dioxide emissions of transportation. Simulations with a static multi region computable general equilibrium model show that including transportation into the European emission trading system is superior to a closed emission trading system for transportation or a tax-based approach. Furthermore, we show that exempting transportation from emission regulation is the most favorable approach in terms of welfare. This counterintuitive result is due to a large tax interaction effect caused by high pre-existing fuel taxes in the transport sector.

Keywords: Transportation; Carbon Regulation; Emission Trading; Computable General Equilibrium

JEL-Codes: D58, L91, Q51

1 Introduction

Around one quarter of the carbon dioxide (CO₂) emissions of the European Union (EU) are caused by the transportation sector (ECMT, 2007). While total greenhouse gas emissions in the EU decreased between 1995 and 2005 by around 1.4%, emissions caused by transportation rose 17.3% during the same period (Eurostat, 2007). This alarming trend of transport emissions, which is mainly caused by private road transport, is expected to continue further (Schäfer and Victor, 1999, 2000). Thus, there is a growing interest in how to regulate transport emissions in the EU.

In contrast to emissions of energy and energy intensive industries, which are regulated under the European Emission Trading System (EU ETS) (EC, 2003), transport emissions are currently regulated at the member state level. One of the main instruments in use is fuel taxation. All European countries are characterized by high gasoline taxes ranging from 0.60 €/l (Luxembourg) to 1.25 €/l (Hungary)

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(Stern, 2007). The EU is planning to address the emissions of private road transport by imposing an emission standard of 130g/km to new passenger cars (EC, 2007). Emission from aviation shall be included in the EU ETS from 2011 onwards (EC, 2006).

In this paper I analyze the welfare implications of using market-based emission regulation to assess the emissions of transportation. Besides the possibility to include transportation into the EU ETS, national or European-wide taxes on transport fuels can be used. Simulations with a static multi-region computable general equilibrium (CGE) model show that the first option is superior to the latter. However, the results show that exempting transportation from emission regulation and increasing the reduction burden of sectors regulated under EU ETS is superior to transportation under emissions trading. This is due to the large pre-existing fuel taxes in the transport sector which cause a welfare reducing tax-interaction effect.

Restricting attention to market-based instruments², emissions in the transport sector can be regulated either by taxes or by emission permits. Taxes can either be imposed on the fuel (Stern, 2007) or can be related to the level of specific emissions of cars. Emission permits can be targeted at the polluters (downstream trading), the producers and importers of the fuel (upstream trading), or at the producers and importers of vehicles (midstream trading). A further concern about the design of the permit trading system is whether it should be open in the sense that it is connected to the existing EU ETS. The implementation of emission trading for transportation and related design issues have been discussed by Ellerman et al. (2006) and Stronzig et al. (2002).

Since there exists a non-negligible degree of uncertainty about price responses in the motor fuel market, taxes hardly implement a given reduction target (Raux, 2004). Furthermore, since the price elasticity of gasoline demand is low (see e.g. Graham and Glaister, 2002; Stern, 2007), high tax rates are needed to implement a specific emission target. However, consumers are sensitive to fuel taxation; hence, high fuel taxes are difficult to implement politically (Raux and Marlot, 2005).

In the case of a downstream emission trading system, polluters are obliged to hold emission permits. The European Commission proposed such a system for aviation which is intended to be included into the EU ETS (EC, 2006). Due to the large number of polluters such a system has to overcome high transaction cost if implemented for road transport. Raux and Marlot (2005) argue that an electronic system for permit sales and purchases can minimize transaction costs if the system is compatible to automatic teller machines, which already exist at gas stations. In order to achieve the maximum gain of emission trading, the system should be open to the EU ETS. In the road transport case this requires market intermediaries which facilitate trade between the EU ETS sector and the car owners. This role could be taken e.g. by banks or gas stations.

Albrecht (2000, 2001) favors an open midstream trading system in which automobile producers have to hold permits for the lifecycle emissions of the sold vehicles. Such a system has the advantage that it directly affects the specific emissions of new cars since cars with lower specific emissions realize a

² See Parry et al. (2007) and ECMT (2007) for a general survey of externalities of transportation and related regulation approaches.

cost advantage compared to vehicles with high specific emissions. Therefore, midstream emission trading is comparable to the current legislative proposal of imposing a 130 g CO₂/km emission standard on the fleet of new cars of automobile producers (EC, 2007). However, midstream emission trading is superior to the latter since permit trading among producers and, in case of an open system, trading with EU ETS sectors is allowed. Therefore, emissions are reduced by sectors and producers at least abatement costs. Like the emission dependent car owner taxes, midstream emission trading has the disadvantage of regulating emissions only in an indirect way. Hence, fuel prices are unaffected and do not have positive influences on driving behavior or mode choice. Moreover, the effect on emissions depends on the vehicle turnover rate. Since the introduction of permits is likely to raise vehicle prices due to new technological improvements, the vehicle renewal rate is expected to decrease. Consequently, the emission reduction effect will be delayed. Moreover, increased fuel efficiency offers an incentive to increase vehicle use which leads to an increase in other road transportation related externalities like congestion and accidents (Fischer et al., 2007). In midstream trading, the necessary quantity of permits per sold car has to be calculated on the basis of a representative driving cycle, which is only a rough presentation of owners' driving behavior. Thus, midstream systems hardly implement a given emission target. In the context of the EU ETS, midstream trading leads to a problem of time consistency. The EU ETS is separated into fulfillment periods of four years. Since the lifetime of cars exceeds the compliance periods rules have to be implemented stating to the budget of which period the sold or purchased permits belong.

In upstream emissions trading, producers and importers or wholesalers of transportation fuels have to hold emission allowances. The allowance quantity needed is determined by the specific carbon content of the fuel. In the context of road transportation such a system has the advantage that the number of participants is smaller than in the downstream case. Therefore, transaction costs are lower and it is easier to connect to an already existing trading scheme. Especially in the case of the EU ETS opening the system is unproblematic since refineries are already part of the EU ETS. In perfect markets, upstream and downstream emission trading lead to the same result since permits increase the marginal costs of fuel suppliers and consequently the fuel price by the same amount. However, in the presence of imperfect competition between fuel suppliers the equivalence breaks down due to the ability to raise prices above marginal costs (Dobes, 1999).

The following analysis is restricted to approaches implementing regulatory measures at level of the transport fuel (versus vehicle level). Furthermore, I present a model with perfectly competitive markets and no transaction costs. Therefore, implemented emissions trading systems for the transport sector can be understood as up- or downstream trading.

To assess the quantitative effects of including transportation into the EU ETS it is crucial to take market interactions and detailed production structures into account. CGE models have become a standard tool for quantitative assessments of environmental policies since these models account for inter-industry and international trade flows as well as price dependent market interaction and taxation issues on the basis of microeconomic theory (e.g. Conrad, 1994; Wing, 2007). Thus, for the

simulations, a static multi-region CGE model is employed. The modeling work most closely related to this paper, is given in Paltsev et al. (2005a). They analyze the effect of exempting transportation from carbon policy in the MIT Emission Prediction and Policy Analysis (EPPA) model. They find that exempting transportation from carbon restrictions results in welfare gains in Europe but losses in the US. In contrast to their work the presented model is developed to analyze the European carbon market. Therefore it has a finer spatial disaggregation for Europe and explicitly deals with separated carbon markets under the EU ETS. Schäfer and Jacoby (2005, 2006) use a hybrid modeling approach combining the MIT EPPA model with the MARKAL bottom-up model (Seebregts et al., 2001) to study the effect of carbon restriction in the transport sector on the design of vehicle technologies. They find that in the short and medium term only moderate changes in vehicle design are likely to take place. Berg (2007) focuses on CO₂ emissions of private sector transportation in Sweden. In an extended version of the EMEC CGE model (Östblom and Berg, 2006) she integrates different transportation modes, trip purposes, time cost of transportation, and different types of households'. Imposing CO₂ restriction on the economy the model version with the extended transport modeling always shows higher welfare costs. Furthermore, she shows that including transport time has a strong impact on the households' labor supply decision.

The remainder of this paper is structured as follows. The next section describes the model employed in this study and the underlying data basis. Section three summarizes simulation runs and results, and Section 4 concludes.

2 Model

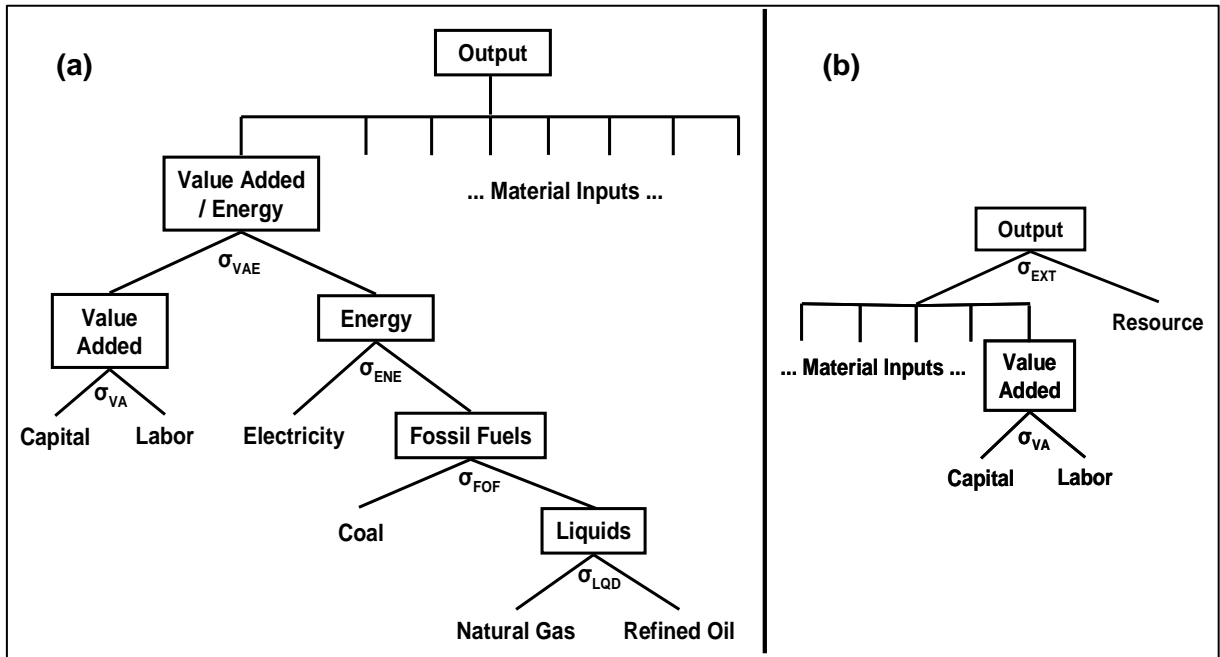
The model includes five energy and four non-energy sectors, two transportation services, and three primary factors (Table 1).

Table 1: Model dimensions

Production sectors	Name	Regions	Name
Non-energy:		EU15:	
Energy-intensive industries	EINT	Benelux	BEN
Macro (industries and services)	MAC	Denmark	DNK
Agriculture	AGR	Finland	FIN
Manufacture of transport equipment	CAR	France	FRA
		Germany	DEU
Energy:		Italy	ITA
Coal	COA	Poland	POL
Crude oil	OIL	Spain	ESP
Natural gas	GAS	Sweden	SWE
Electricity	ELY	United Kingdom	GBR
Refined oil and coke products	P_C	Western EU	WEU
		(Austria, Ireland, Greece, Portugal)	
Transport:		Remaining Eastern EU	EEU
Industrial transport	TRN		
Household transport	HTRN		
Primary factors:		Other:	
Capital	CAP	Annex I	ANI
Labor	LAB	Rest of the world	ROW

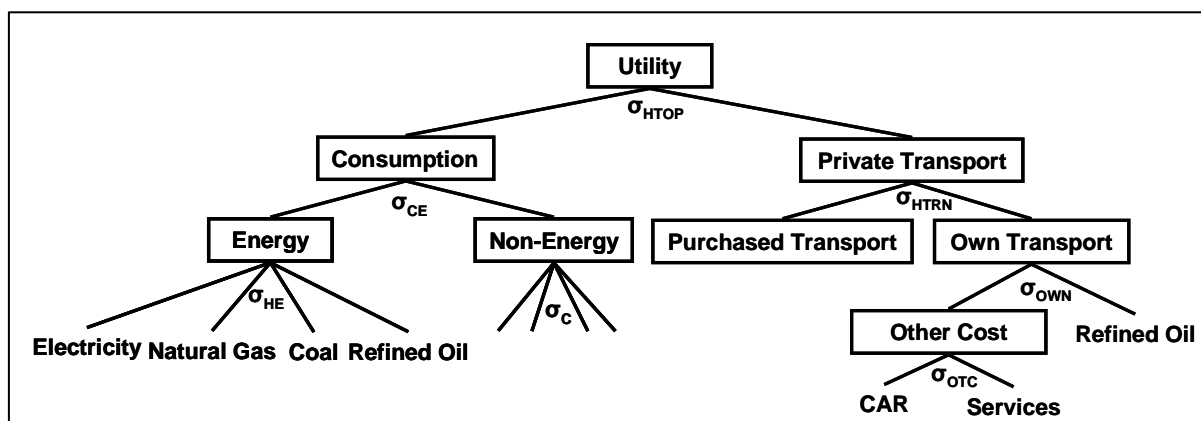
The different sectors' production is modeled using nested Constant Elasticity of Substitution (CES) functions. Except for the extractive industries (coal, natural gas, and crude oil), all sectors have the same production structure (Figure 1). On the top level material inputs and a CES composite of a primary factor value added CES aggregate and an energy aggregate are combined using a Leontief function. The energy aggregate consists of electricity and fossil fuel energy which is a CES composite of coal and liquid fossil fuels (natural and refined oil). For all sectors and consumers fossil fuel inputs are associated with CO₂ emissions. Extractive industries combine the sector specific natural resource and an aggregate of all other inputs at the top level using a CES function. The other inputs are a Leontief composite of materials and the primary factor value added Cobb-Douglas aggregate. All sectors allocate their output to the domestic and export market according to a constant elasticity of transformation curve.

Figure 1: Production functions (a) non-extractive and (b) extractive industries



Consumers' demand is modeled by a representative household, which earns income by supplying primary factors to the domestic market; this supply is inelastic. While capital and labor are fully mobile across sectors, natural resources are sector specific i.e. immobile across sectors. The utility function of the representative household (Figure 2) combines a CES aggregate non-energy and energy commodity consumption with household transportation at the top level. Both, non-energy and energy commodities are also combined using a CES function. Private transportation combines purchased industrial transport services with the household's own supplied transport which consists of refined oils used as transportation fuels put together with cars and other transport input costs (e.g. repair and assurance services).

Figure 2: Utility function



The government finances commodity demands and transfers to the private household by tax revenues. Government demand is modeled using a Leontief function.

Domestic and imported commodities as well as imported commodities from different regions are imperfect substitutes (Armington, 1969). Furthermore, importing commodities are associated with transport margins which are supplied by industrial transport sectors.

Investment demand is modeled using a Keynesian closure, i.e. the marginal propensity to save is held constant at the benchmark level. The investment commodity is a Leontief composite.

For the parameterization of the baseline of the model, the Global Trade Analysis Project (GTAP) database of version 6 is used (Dimaranan, 2006). The GTAP 6 database offers consistent social accounting matrixes for 87 regions including a detailed representation of European countries and 57 commodities based on the year 2001. Furthermore, physical energy flows to the corresponding value flows of fossil fuels are given. The physical energy flows are used to derive CO₂ emissions on the basis of emissions factors as given in IPCC (2006) and historical emission data for the year 2001 (World Resource Institute, 2007). However, the GTAP database does not offer a detailed representation of household transportation. Employing the method developed by Paltsev et al. (2004a), data of the European Budget Survey (Eurostat, 1999) are used to augment the GTAP database to include household transportation.

In order to fully specify the CES function, elasticities of substitutions need to be specified. These elasticities are taken from the MIT EPPA model (Paltsev et al., 2005b) and are listed in the appendix. The elasticity between (refined oil) fuel inputs and other costs of transportation in household transport is calibrated to empirical estimates of the price elasticity of gasoline demand for which a value of 0.3 is used which is assumed to be uniform across regions. This is in line with estimates for the short run elasticity (Graham and Glaister, 2002; Sterner, 2007).³ The model is implemented in GAMS (Brooke et al., 1987) with MPSGE as subsystem (Rutherford, 1999).

³ Simulations with other values of the prices elasticity were also carried out. The presented welfare ranking of the discussed policies is unaffected by varying the elasticity. The magnitude of carbon prices and welfare changes varies, though. Results of the sensitivity analysis are available on request.

3 Policy Scenarios and Results

In all scenarios European regions are obliged to fulfill nominal emission targets as given by the *effort sharing agreement* (EC, 2008). Remaining Annex I countries are assumed to reduce their emissions by 5% (Table 2). No regulation applies for non-Annex I countries. The scenarios differ in the way how the European countries achieve their reduction targets. The Annex I region implements its reduction target by a national emission trading; i.e. all sectors within this region are allowed to trade emission allowances. In all scenarios regions redistribute the income of carbon regulation as lump sum transfer to the representative household by holding government purchases constant.

Table 2: Reduction requirements

Region	Reduction (% vs Benchmark)	Region	Reduction (% vs Benchmark)
Benelux	16	Spain	10
Denmark	20	Sweden	17
Finland	16	United Kingdom	16
France	14	Western EU	10
Germany	14	Remaining Eastern EU	-15
Italy	13		
Poland	-14	Annex I	5

In the calibrated benchmark no carbon policy takes place. In the *Sectoral* scenario, European countries allocate the reduction burden uniformly to all sectors. Emission trading across sectors or across regions is not allowed. In the *National* scenario, allowance trading across sectors is allowed. Additional trading across European countries is permitted in the *Full Trade Europe* scenario. The *EU ETS* scenario implements the European emission trading system in its current state: electricity sectors, refineries, and emission intensive industries trade allowances across Europe while the remaining sectors, including transportation, are regulated by sector carbon restrictions i.e. sector fuel taxes. Regions with negative reduction requirement, i.e. they are allowed to increase emissions, cap emissions of non-EU ETS sectors at the benchmark level and allocate their excess budget to the EU ETS. In the *EU ETS Transport Closed* scenario, industrial and household transport agree to trade emissions across Europe on top of the EU ETS. However, no trade between transport and EU ETS sectors takes place. This is equivalent to a European-wide uniform carbon tax in the transport sector. Trade between transport and EU ETS sectors is permitted in the *EU ETS Transport* scenario, which fully integrates transportation into the EU ETS. Finally, *EU ETS Exempt Transport* implements the European emission trading system and exempts transportation from carbon regulation. The reduction requirement of the transport sector is shifted to the EU ETS. Therefore, electricity, refinery and energy intensive sectors face a higher reduction burden.

For scenarios, which do not differentiate carbon regulation across sectors (*Sectoral*, *National*, *Full Trade Europe*), the welfare ranking (Table 4) is as theory predicts: implementing carbon regulation by

a *Sectoral* approach shows high welfare losses across Europe.⁴ Eastern European countries and Poland only exhibit small welfare changes since they face negative reduction requirements. Consequently, carbon prices in these regions drop to zero. Allowing for *National* carbon trade significantly reduces the cost of regulation since marginal abatement cost (MAC) equalize across sectors. Thus, CO₂ is abated in sectors with the lowest cost. A further decrease results if carbon permits are additionally allowed to be traded across Europe (*Full trade Europe*).

Table 3: Overview of simulations

Scenario	Regulation approach EU27	Regulation approach Annex I
Benchmark	No carbon reduction takes place	No carbon reduction takes place
Sectoral	Carbon taxes differentiated by sectors	Implement reduction target with national carbon tax
National	Permit trade across sectors but not across European regions	
Full Trade Europe	Permit trade across sectors and European regions	
EU ETS	EU ETS sectors (electricity, refineries, energy intensive sectors) trade permits across Europe; other sectors are regulated using carbon taxes differentiated by sectors	
EU ETS Transport Closed	EU ETS system; transport sectors are allowed to trade permits across Europe; no trade between transport and EU ETS sectors	
EU ETS Transport	Transport sectors are included into the EU ETS	
EU ETS Transport exempted	Transport sectors are excluded from carbon regulation; reduction burden of EU ETS sectors is increased to hold overall reduction requirement constant	

Regulating emissions under the *EU ETS* improves welfare compared to the *Sectoral* scenario since the EU ETS sectors electricity, refineries and energy intensive industries equalize MAC across. However, welfare losses in the *EU ETS* approach are much higher than in a *National* trading system. This shows that the gain of allowing permit trade between sectors is higher than of allowing trade across Europe. The European permit price becomes 1.83 \$/t CO₂, while other sectors show high carbon taxes. Especially in the transport sectors taxes are very high (up to 267 \$/t CO₂ for Sweden). The low carbon price in the EU ETS system is explained by the assumption that eastern European countries allocate their excess budget to the EU ETS.

Implementing a closed emission trading system for transportation (*EU ETS Transport Closed*) further lowers the regulation costs. However, European welfare losses are still approximately twice as high as in the *National* trade system. The permit price in the EU ETS sector becomes 1.77 \$/t CO₂. In the trading system for transport sectors the carbon price is still at a high level of 73.42 \$/t CO₂. Even if

⁴ Since the benefit of carbon regulation, the decrease in the global warming process, is not included, welfare result only reflect the cost side of the policy and thus are generally negative.

transport sectors are permitted to trade allowances across Europe, the marginal abatement costs are high compared to the EU ETS sectors.

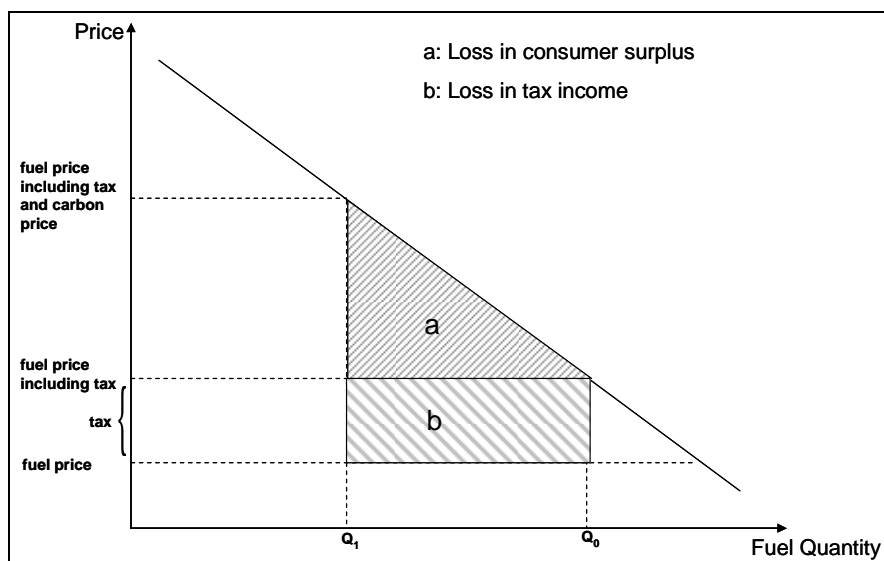
The large difference in the MACs explains the significant welfare improvement of including transportation into the EU ETS (*EU ETS Transport*). Transport sectors buy permits from the electricity and energy intensive sectors and increase emissions. Consequently, the electricity and energy intensive sectors have to decrease emissions. Therefore, MACs are rising in these sectors and falling in transport sectors. As a result, including transport sectors into the EU ETS raises the European emission allowances price to 6.63 \$/t CO₂. The integration of the transport sector leads to welfare costs even below the cost of coexisting *National* emission trading systems.

Table 4: Welfare changes compared to benchmark (% Hicksian equivalent variation)

	Sectoral	National	Full Trade Europe	EU ETS	EU ETS Transport Closed	EU ETS Transport	EU ETS Transport Exempted
Benelux	-1.75	-0.90	-0.34	-1.65	-1.23	-0.51	-0.45
Denmark	-1.73	-0.80	-0.37	-1.53	-0.79	-0.40	-0.38
Finland	-1.70	-0.78	-0.35	-1.59	-1.24	-0.63	-0.58
France	-1.52	-0.68	-0.21	-1.48	-0.98	-0.35	-0.29
Germany	-1.35	-0.47	-0.28	-1.28	-1.01	-0.41	-0.35
Italy	-1.48	-0.63	-0.25	-1.41	-1.05	-0.55	-0.50
Poland	-0.07	-0.07	0.23	-0.01	-0.20	0.14	0.21
Spain	-0.79	-0.26	-0.20	-0.76	-0.79	-0.21	-0.15
Sweden	-1.61	-0.83	-0.25	-1.53	-1.07	-0.39	-0.33
United Kingdom	-1.05	-0.35	-0.18	-1.00	-0.62	-0.20	-0.17
Western EU	-0.82	-0.28	-0.23	-0.78	-0.77	-0.26	-0.20
Eastern EU	-0.08	-0.07	0.22	-0.03	-0.28	0.15	0.24
EU 27	-1.22	-0.49	-0.21	-1.16	-0.87	-0.33	-0.28
Annex I	-0.08	-0.07	-0.06	-0.07	-0.07	-0.06	-0.06
Rest of the World	-0.05	-0.03	-0.02	-0.04	-0.05	-0.02	-0.02

Finally, the implications of exempting transportation from carbon regulation and increasing the reduction burden of EU ETS sectors is examined (*EU ETS exempted*). This scenario leads to a further welfare improvement compared to the extended EU ETS system (*EU ETS Transport*). This result, which also was encountered by Palstev et al. (2005a, 2004b), is explained by high pre-existing fuel taxes in the transport sector. A carbon premium on top of the pre-exist fuel tax raises the price of transportation and, thus, transportation demand is decreased. The loss in consumer surplus of the policy is given as the value of the lost demand net of the production cost. However, in the presence of pre-existing taxes the decline in demand also causes a fall of the tax income from fuel taxation (Figure 3). Since policies are imposed revenue neutral, the loss in tax income has to be balanced by the revenues resulting out of the carbon restriction. Consequently, the lump sum transfer to the household is decreasing. Due to high fuel taxes in Europe, this additional loss in tax income becomes large. Thus, excluding transportation from the emission trading system increases the lump sum transfer and welfare is increasing. Since the abatement burden is shifted to the EU ETS system, the European allowances price increases to 7.73 \$/ t CO₂.

Figure 3: Fuel demand under carbon pricing and pre-existing tax



Source: Following Paltsev et al. (2005a p. 234, 2004b p. 15) and Raux and Marlot (2005 p. 259)

However, the welfare improving result of excluding transportation from environmental regulation should be considered with caution since the presented approach neglects other externalities of transportation mainly congestion, accident, and noise externalities. If a policy instrument addressing carbon emissions reduces the demand for road transport these externalities will decrease as well. Thus, there is a further positive welfare effect. Since excluding transportation leads to an increase in traffic there are negative welfare effects of these externalities which could outweigh the positive effect of decreasing the described tax interaction effect.

4 Conclusions

This paper simulated different market-based approaches for the regulation of the transportation sector CO₂ emissions with a static multi-region CGE model for the EU27. Besides imposing fuels taxes, the possibility of a closed emission trading system for transportation and inclusion into the EU ETS were examined. Measuring welfare changes of regulation using Hicksian equivalent variation, the simulations show a clear-cut ranking of regulation approaches: establishing a European-wide emission trading system for transport sectors, which coexists beside the EU ETS, lowers the cost of carbon regulation compared to fuel tax in the transport sector. Furthermore, integrating transportation into the existing EU ETS further reduces regulation cost. Due to the high pre-existing fuel taxes in transport sectors across Europe the approach with the lowest welfare cost is to exempt transport from carbon regulation and to increase the reduction burden of EU ETS sectors. Furthermore, the results show that if policy makers decide to impose regulation on the level of the transport fuel then a unified European approach by integrating transportation into the EU ETS is the best alternative.

In the presented framework it is not possible to analyze regulation approaches which are imposed at the vehicle level like midstream emissions trading, vehicle performance standards, or CO₂ dependent vehicle taxation. However, the same remark applies to these regulation approaches: every regulation

that decreases demand for transportation fuels exhibits high cost in terms of tax interaction beside abatement cost. Therefore, it is important to analyze transport policies in a consistent general equilibrium framework to account for important second best taxation effects. Nevertheless there is a potential for future research to improve the modeling framework to analyze instruments on the vehicle level by explicitly modeling the vehicle stock and the associated service flow. The clear cut welfare improving result of excluding transportation is partly based on neglecting other externalities. In future research these important effects have to be included.

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Appendix A: Behavioural and Calibration Parameters

If not differently stated, elasticities are taken from the MIT EPPA model (Paltsev et al., 2005).

Table 5: Production and trade substitution elasticities

σ_i	Description	Value
Production elasticities		
ENE	Electricity / fossil fuels	0.2
EXT	Sector specific resource/ other inputs (coal, natural gas, and crude oil)	0.5
FOF	Fossil fuels ⁵	0.5
LQD	Liquid and gaseous fossil fuels	1
VA	Labor / capital	1
VAE	Energy / value-added	0.5
Household elasticities		
C	Non-energy consumption goods	0.5
CE	Energy / non-energy commodities	0.25
HE	Coal / electricity / natural gas / refined oil products	0.4
HTOP	Consumption / transport	1
HTRN	Own supplied / purchased transport	0.2
OTC	Motorized vehicles / other transport costs	0.5
OWN	Gasoline / other transport costs – motorized vehicles ⁶	~ 0.3
Trade elasticities		
DM	Domestic / imported commodities	
		Non-electricity commodities 2.5
		Electricity 0.3
MM	Imports from different regions	
		Non-energy goods 5
		Fossil fuels 4
		Refined oil products 6
		Electricity 0.5

⁵ Taken from the GTAP-E model (Burniaux and Truong, 2002)

⁶ Calibrated to empirical value of price elasticity of gasoline demand of 0.3. For all regions the substitution elasticity is around 0.3.