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Transportation and Emission Trading
A CGE Analysis for the EU 15

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Abstract: Transportation, the second largest contributor of CO_2 emissions, is not part of the European Emission Trading System. Since transportation is subject to national environmental instruments, this causes differences in marginal abatement costs, and hence, results in economic inefficiencies. We analyze the welfare effects of including transportation in the European emission trading system in a static multi-region CGE model of the EU 15. Our results show that the inclusion road transportation provides a high welfare gains for Europe. Including aviation leads to smaller welfare gain. Concerning water transportation, our analysis indicates the importance of carbon regulation of maritime shipping for international trade.

Keywords: Transportation, Emission Trading, Computable General Equilibrium
JEL-Codes: D58, L91, Q51

1 Introduction

The European Emission Trading System (EU ETS) covers the main contributors of CO_2 emissions: energy and energy intensive industries, thus leaving out the second largest contributor of emissions: the transport sector. Environmental regulation of the transport sector takes mainly place at member state level. However, there exists a voluntary agreement of automobile producers to reduce average emissions of new cars to 140 g/km by 2008 at the European level. This coexistence of regulation – so called hybrid regulation – induces welfare losses due to differences in marginal abatement costs of the sectors regulated under the ETS and transportation.

Concerning regulation of emissions from road transportation, the European discussion focuses on introduction CO_2 emission standards for new cars. Currently, there is a value of 120 g/km in fleet of sold new cars in discussion. However, such uniformly imposed standards are not cost efficient since they do not allow of equalization of marginal abatement costs of car producers. Furthermore, even if

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marginal abatement costs equalize between car producers due to tradable or differentiated emission standards, there are difference in the marginal abatement costs compared other economic sector i.e. sectors under EU ETS. Thus, the problem of hybrid regulation still shows up, and emission are not abated at the lowest cost. Another problem of emission standards for automobiles is the induced improvement of fuel efficiency which implies a rebound effect: due to higher fuel efficiency there is an increase in vehicle use. This increased vehicle use leads to an increase in other road transportation related externalities like congestion and accidents (Fischer et al., 2007). Including road transportation in the EU ETS, is a better way to regulated emissions from road transportation since it allows for flexible abatement across the main emitters in Europe. There are two way to include road transportation in the EU ETS: either in a midstream (SRU, 2005) or upstream manner (UBA, 2005). In midstream emission trading, automobile producers have to hold emission allowances for the average emissions of sold cars, whereas in upstream emission trading, the producers and importers of gasoline have to acquire permits for the emission induced by sold units of gasoline. At the end of 2006, the European Commission proposed to include aviation in the EU ETS (European Commission, 2006). It would also be possible to include inland water way and maritime transportation in the EU ETS to address their emissions in a cost-effective way.

We estimate the effects of including different transportation modes in the EU ETS on the European welfare in a static multi-region computable general equilibrium model. Concerning the regional dimension of our model, we explicitly include EU 15 countries and an aggregated rest of the world region. In the sectoral dimension, we include sectors regulated under EU ETS and different transportation modes as well as fossil fuel. We find, that the inclusion of road transportation in the EU ETS provides high welfare gains compared to national fuel taxes in this sector or national emission trading. The inclusion of aviation also provides welfare gains. Concerning maritime shipping, we obtain a welfare loss compared to an situation with road and air transportation under EU ETS and fuel taxes for water transportation. However, this result is due to our aggregated modelling of extra-European trade links and should be taken as illustrative scenario to illustrate the importance of the impact of carbon regulation of international transportation services on international trade.

Böhringer et al. (2006) and Babiker et al. (2000, 2003) analyze the effects of separated carbon markets. Böhringer et al. (2006) implement the European Burden Sharing Agreement[2] (BSA) in a partial equilibrium model of Germany and the rest of the EU. Marginal abatement cost functions are derived from the PACE model (Böhringer, 2001). The results show that deviation from the optimal allocation of emission allowances to the sectors regulated under the ETS causes excess compliance costs. The deviation from the optimal allocation is generated either by lobbying of influential ETS sectors or by information problems since governments need to know future allowances price to determine the optimal carbon tax rate for the non-ETS sectors. Babiker et al. (2003) model the BSA in the European version of the MIT EPPA model (Viguier et al., 2003) which includes private transportation. They compare the welfare losses of implementing the emission reduction requirements on member state level and non-existence of European wide emission trading. The results show that domestic emission trading causes less welfare losses in all member states than a scenario in which each sector is faced with the BSA reduction requirement individually. Babiker et al. (2000) show, that the exemption of different sectors from emission trading for the United States economy causes welfare losses using the MIT EPPA model.

The remainder of the paper is organized in following way. Chapter 2 describes the model and calibration of the relevant parameters. In chapter 3, we show the welfare effects of the current system of hybrid regulation under the European Emission Trading System (EU ETS). Welfare effects of transportation under emission trading are analyzed in chapter 4. Finally, chapter 5 provides a short summary and draws conclusion.

2 Model and Calibration

2.1 Model Description

To asses the quantitative effects of including transportation in the EU ETS it is crucial to take market interactions and detailed production structures into account, Computable general equilibrium models (CGE) have become a standard tool for quantitative assessments of environmental policies, since these models account for inter-industry as well as international trade flows. We implement a static multi-region CGE model representing the (former) EU15 countries and an aggregated rest of world region. We include five energy, four non-energy, three transportation services, and three primary factors. The detailed model dimensions are given in Table 1.

Consumers' demand is modelled by a representative household, which earns income supplying primary factors to the domestic market. While capital and labor are fully mobile across sectors, natural resources are sector specific. Additionally, there exists a government agents which collects taxtes.. Following Armington (1969), import commodities are distinguished by their origin. The model is implemented in GAMS (Brooke et al., 1987) with MPSGE as subsystem (Rutherford, 1999).

Production and household consumption are implemented using nested constant elasticity of substitution functions. Government consumption is modeled using a Leontief function. Figure 1 shows the nesting structure of all production sectors except transportation services (OTP, ATP, WTP) and extraction industries (GAS, OIL, COA). Every sector provides output to the domestic and exports to foreign markets. At the top level, materials, transportation and value-added/energy composite enter the production function in a fixed factor manner. Different transportation modes are combined in the transportation nest. Primary factors are combined in the value-added composite which enters the value-added/ energy nest. In the energy composite electricity is combined with a fossil fuel composite which consists of coal and a sub-nest of liquid fossil fuels. In the liquid fossil fuel nest, natural gas

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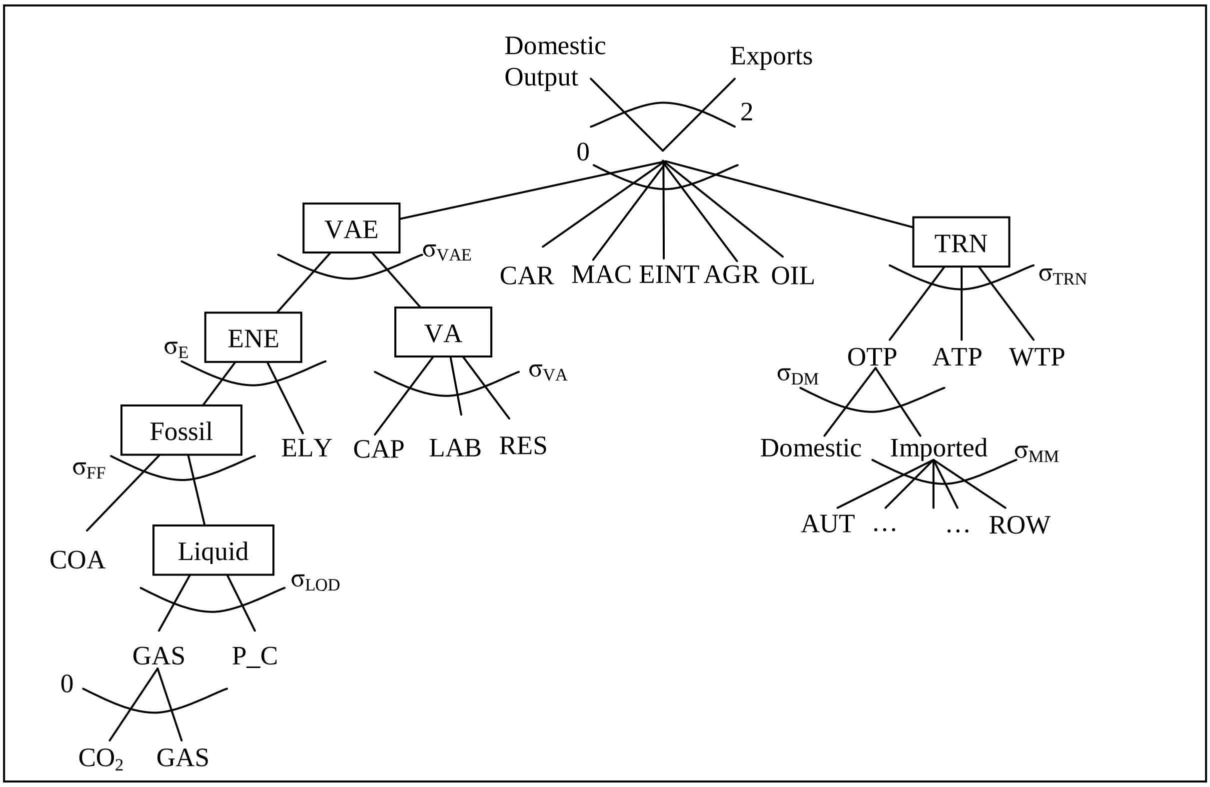
[2] The EU has taken the opportunity to fulfill the obligation of the Kyoto protocol as a *bubble*. The EU bubble has to reduce emission by 8% compared to 1990. Internally the allocation of the EU emission budget is regulated under the EU Burden Sharing Agreement.

trades off against refined oil inputs. As exemplary shown for natural gas, every fossil fuel input is combined with the caused amount of CO_2 emissions. The Armington approach, which is used for all commodities, is shown for the OTP sector: domestic commodities are combined with imported ones which are a composite of imports across regions. Substitution elasticities which are mainly borrowed from the MIT EPPA model (Paltsev et al. 2005) are listed in the appendix.

Table 1: Model Dimensions

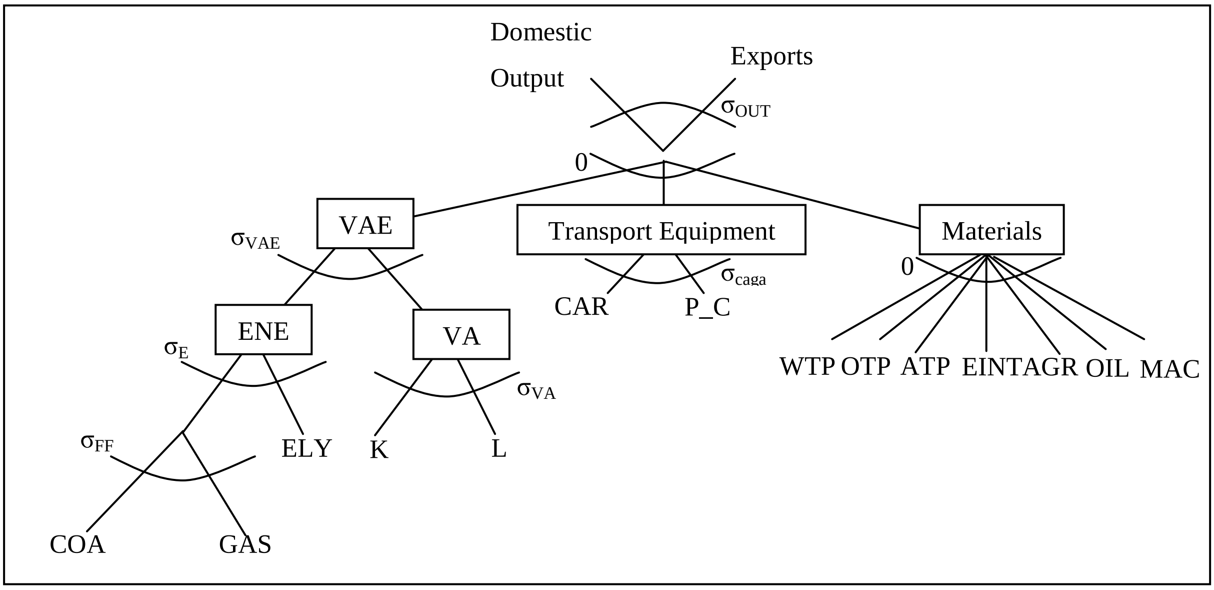
Production Sectors	Name	Regions	Name
Non-Energy:		**EU15:**	
Energy-intensive Industries	EINT	Austria	AUT
Macro (Industries and Services)	MAC	Belgium	BEL
Agriculture	AGR	Denmark	DNK
Manufacture of transport equipment	CAR	Finland	FIN
(motor vehicles, aircrafts, and ships)		France	FRA
		Germany	GER
Energy:		Greece	GRC
Coal	COA	Ireland	IRL
Crude Oil	OIL	Italy	ITA
Natural Gas	GAS	Luxembourg	LUX
Electricity	ELY	Netherlands	NLD
Refined Oil and Coke Products	P_C	Portugal	PRT
		Spain	ESP
Transport:		Sweden	SWE
Air Transport	ATP	United Kingdom	GBR
Other Transport	OTP		
Water Transport	WTP	**Other:**	
		Rest of the World	ROW
Primary Factors:			
Capital	CAP		
Labor	LAB		
Natural Resources	RES		

Figure 1: Nesting structure of production sectors except transportation and extraction industries



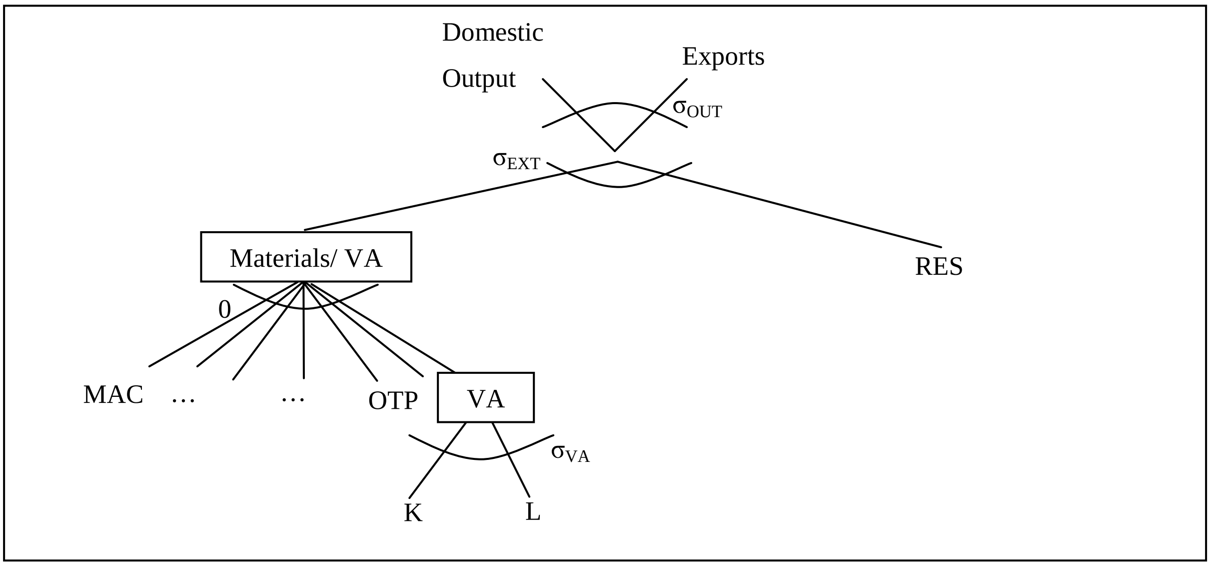
The production structure of transport services is shown in Figure 2. At the top-level transport equipment – a combination of the transport equipment sector and used refined oils/ transportation fuels – value-added composite and material bundle enter the production function.

Figure 2: Production structure of transport services



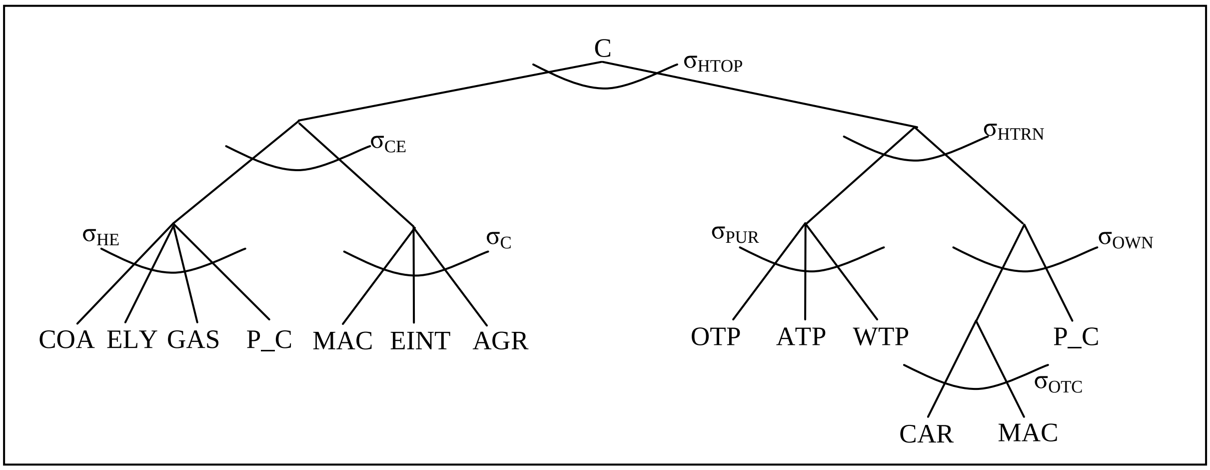
In extraction industries - natural gas, coal, and crude oil – the sector specific resource trades of a material/ value added composite (Figure 3).

Figure 3: Production structure of extraction industries



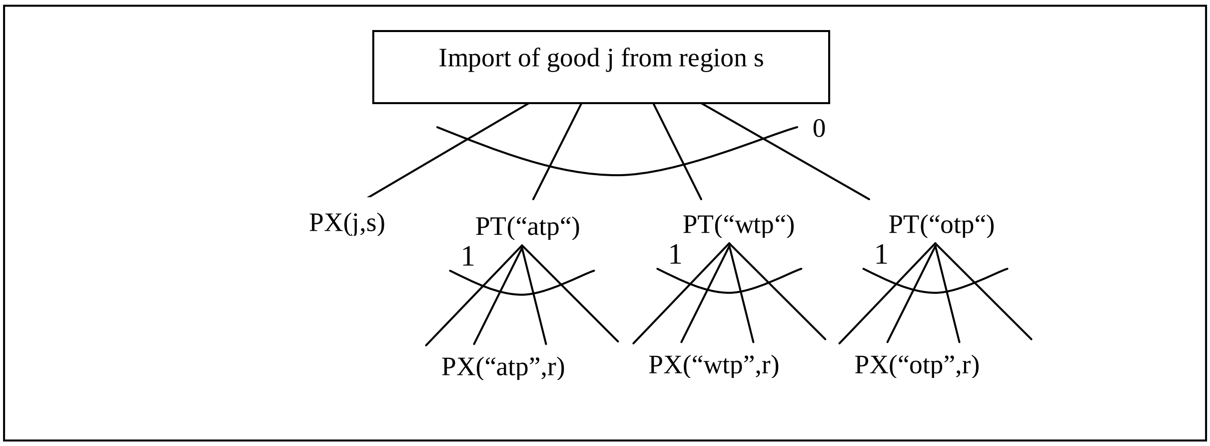
The utility function of the representative household is depicted Figure 4. It combines a consumption/energy with transportation composite at the top level. The transportation composite combines purchased transport services of different modes with household's own supplied transport which consists of refined oils used as transportation fuels put together with cars and other transport inputs costs (e.g. repair and assurance services).

Figure 4: Nesting structure of the household sector



International transport margins are explicitly modeled. Each country export transportation services to an international transportation pool. As shown in the bottom nest of Figure 5, this transportation pool combines transportation modes from different countries according to a Cobb-Douglas function to transportation margins differentiated by modes. Importing commodity i from region s, a country has to pay to the export price for this commodity (PX(i,s)) as well as transportation margins which are combined in a Leontief nest.

Figure 5: International transport margins



2.2 Data and Calibration

Calibration is based on the GTAP6 database (Hertel, 1997). The GTAP6 database provides consistent production and demand data as well as tax rates for 57 sectors in 87 regions with bilateral trade, transportation margins and energy flows based on IEA energy statistics for 2001. Since this database includes only aggregated refined oil production we disaggregated the refined oil sector in order to derive transportation fuels.

To derive households' own supplied transportation we use data from the European Budget Survey (EUROSTAT 1999). Following the methodology described in Paltsev et al. (2004), we derived the share of transport expenditure in total households' expenditure (ES) and the share of gasoline expenditure in the refined oil expenditure (OS) from the Budget Survey. These values are provided in Table 2. Using these shares we can derive total transport and gasoline expenditure out of the GTAP6 data. Car purchases are also directly taken from the GTAP6 database. Defining total transport expenditure as the sum of car purchases, gasoline expenditure and other transport costs, we are then able to derive other transport cost (OTC) as a residual. Since other transport costs contain services and materials associated with private transportation, we assume it to be part of the MAC output.

Given the energy flows from the GTAP database we are able to calibrate CO_2 emissions in a top-down manner using emission factors provided by the *Intergovernmental Panel on Climate Change* (IPCC, 2006) to report emissions using the *Tier 1* method. To account for the use of refined oil as transportation fuel of different modes, we apply differentiated emission factors (see appendix). In order to avoid double counting of emissions, only 7 % of the crude and refined oil input in refineries is associated with carbon emissions. This factor is implied by the *European Oil Statistic* provided by Eurostat (2001). Since we determine emissions by fuel use, we do not account for bunker fuels, i.e. emissions from international air and water transportation are assigned to the countries to which the supplier belongs to. This leads to an overestimation of emissions caused by transportation.

Table 2: Household expenditure shares

	Share of fuels for own supplied transport in total refined oil demand – OS (%)	Share of own supplied transport in total expenditure – ES (%)
Austria	79.9	14.4
Belgium	78.8	12.5
Denmark	79.8	14.1
Finland	89.9	17.0
France	77.4	13.9
Germany	84.8	13.3
Greece	69.0	11.2
Ireland	82.1	13.3
Italy	92.3	13.7
Luxembourg	74.0	15.5
Netherlands	99.7	10.3
Portugal	99.1	15.0
Spain	91.9	12.5
Sweden	99.7	13.4
UK	97.6	13.6
EU15	87.9	13.4

3 Hybrid Regulation under the European Emission Trading System

3.1 Scenario definitions

In this section we analyze the effects of hybrid regulation under EU ETS. Under the EU ETS electricity generation, refineries, and energy intensive industries are part of the emission trading system while the rest of the economy is addressed by regional policies i.e. carbon taxes (European Commission, 2003). To show the effect of hybrid regulation, we compare six different scenarios. First, in the sectoral scenario all countries, except ROW, fulfil their abatement targets by sectoral taxes. Household own transportation and other transport services face the same tax rate which might be seen as a uniform tax on gasoline and diesel consumption. Every sector is obliged to cut its emissions by regions' effective reduction target. This scenario describes approximately the pre-EU ETS situation: European regions impose sectoral actions to regulate emissions. However, we do not take into account the different allocation of the reduction burden across sectors, since we assume that every sector performs the same percentage cut in carbon emissions. In every scenario, the ROW region is engaged in domestic emission trading resulting in a uniform CO_2 tax. The sectoral scenario is the most inflexible method of European carbon reduction. Thus, it theoretically provides an upper bound of the welfare losses from environmental regulation. Second, all regions are engaged in domestic emission trading. This policy is the theoretically best solution if regions take purely domestic actions to fulfil reduction requirements. Third, all sector are allowed to trade emission allowances across Europe. Theoretically, this is the best option for the European Union. Fifth, the in the EU ETS TAX scenario electricity, energy intensive industries, and refineries are allowed to trade emissions across Europe while remaining sectors are subject of sectoral taxes. Again, commercial and private road transportation face the same tax. Finally, in EU ETS DOM electricity, energy intensive industries, and refineries trade emission allowances across Europe while remaining sectors are allowed to domestically trade allowances.

Table 3: Scenarios hybrid regulation

Name	Description
SECTORAL	Sectoral carbon constraints: different CO_2 taxes across sectors and regions. Road transportation has a uniform tax rate. ROW: regional emission trading system
DOMESTIC	All regions implement regional emission trading scheme
EUROPEAN	All sectors in European regions trade allowances across Europe. ROW: regional emission trading system
EU ETS TAX	Electricity, energy intensive industries, and refineries trade allowances across Europe. Remaining sectors are regulated by sectoral taxes; uniform tax for road transportation. ROW: regional emission trading system
EU ETS DOM	Electricity, energy intensive industries, and refineries trade allowances across Europe. Remaining sectors regionally trade allowances. ROW: regional emission trading system

In every scenario, we implement the effective EU Burden Sharing Agreement (BSA) emission reduction target of the year 2001 (Table 4) in each sector. The Rest of the World (ROW) region is assumed to reduce emissions by 5%, which approximately represents the Kyoto reduction requirement. The emission budgets under emission trading systems are derived by summing up the budget of the single sectors subject to emission trading scheme and cutting the sum of emissions by the regional reduction requirement. Sectoral taxes are implemented by cutting sectors' emissions by the effective target. Emissions allowances are auctioned. The revenues from carbon taxes and auctioned permits are recycled as lumpsum transfer to representative household. In every scenario government purchases are constant.

Table 4: Effective emission targets in 2001 after EU Burden Sharing Agreement

	1990 CO_2 (Mt)	**Target BSA (%)**	**Annual Budget after BSA (Mt)**	**2001 CO_2 (Mt)**	**Effective Target 2001 (%)**
Austria	53.22	13.0	46.30	61.19	24.3
Belgium	108.83	7.5	100.67	114.42	12.0
Denmark	51.49	21.0	40.67	52.79	22.9
Finland	57.44	0.0	57.44	64.01	10.2
France	368.39	0.0	368.39	389.89	5.5
Germany	988.86	21.0	781.20	850.62	8.2
Greece	76.47	-25.0	95.59	97.86	2.3
Ireland	29.78	-13.0	33.65	43.48	22.6
Italy	402.72	6.5	376.55	443.16	15.0
Luxembourg	10.54	28.0	7.59	8.57	11.4
Netherlands	158.12	6.0	148.63	175.71	15.4
Portugal	39.99	-27.0	50.79	58.28	12.8
Spain	206.38	-15.0	237.33	286.41	17.1
Sweden	51.51	-4.0	53.57	48.86	-9.7
UK	568.75	12.5	497.66	543.68	8.5

Source: Own calculations based on EEA (2004); only energy related emissions are taken into account

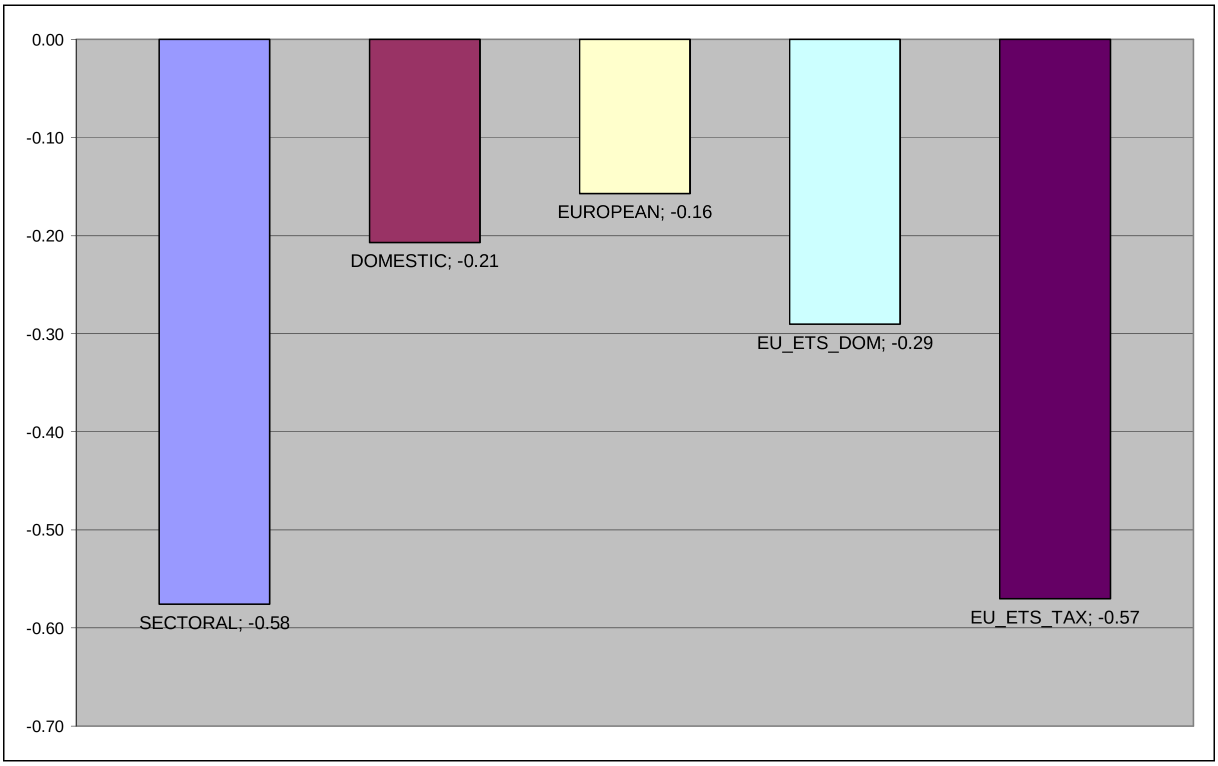
3.2 Welfare effects of hybrid regulation

Figure 6 shows the differences in Hicksian Equivalent Variation compared to the benchmark scenario of no carbon regulation. Comparing column one to column two shows that there exist a welfare gain of using domestic emission trading instead of sectoral regulation[3] since abatement costs equalize across sectors and emissions are abated in industries with the lowest costs. Especially road transportation is charged with a high CO_2 taxes which indicates high marginal abatement cost[4]. Allowing permit trade across Europe, provides and additional welfare gain (column three). The permit price under European trade becomes 12.73 \$/t CO_2. Comparing the introduction of the EU ETS under sectoral policies in member states (first versus last column), show only a very small welfare effect, since the sectors under sectoral regulation, i.e. transportation sectors, are still taxed at a high rate. Thus, intermediate inputs and transportation are very expensive which handicaps the expansion of EU ETS sectors which pay the lower European Allowances (EUA) price (6.57 \$/t CO_2). Introducing the EU ETS while member states implement a national permit trading system (comparing column two and four), shows that European welfare is going down. This shows the effect of hybrid regulation: while the sectors regulated under the EU ETS pay a lower carbon price (7.34 \$/t CO_2) compared the situation under domestic emission trading, sectors not regulated under the EU ETS pay a higher price. The positive welfare effect of flexible regulation of electricity, energy intensive industries and refineries is more than compensated by the increase in the domestic carbon price paid by the remaining industries i.e. transportation services.

[3] All scenarios show negative welfare effects, since we do not include the gain from carbon regulation, i.e. the improvement of environmental quality.

[4] Carbon prices are listed in the appendix. In the Sectoral scenario carbon prices in the road transportation sector range from zero (Sweden has a negative reduction requirement i.e. is allowed to increase emission) to 448.34 \$/t CO_2 for Denmark.

Figure 6: Welfare effect of hybrid regulation



4 Including Transportation in the European Emission Trading System

4.1 Scenario definitions

We analyze the welfare effects of transportation modes under emission trading in two sets of scenarios: under sectoral taxes and national emission trading for non-EU ETS sectors. We start by including the road transportation – commercial and private – in the EU ETS. Afterwards, air and water transport are included. Again, the rest of the world region implements regional emission trading in al scenarios. Scenario settings are given in Table 5.

4.2 Welfare effects of including transportation

Figure 7 shows the welfare effects of different EU ETS regimes compared to SECTORAL scenario. Including road transportation in the EU ETS provides a high welfare gain for Europe. Due to the high marginal abatement costs in the road transportation, the EUA price rises from 6.57 to 11.85 \$/t CO_2. The increased demand for road transportation leads to an increase in car demand. Thus, the sectoral carbon price in the car industry is also increasing. The gain from flexible environmental regulation shows up in the different carbon reduction in the EU ETS sectors: while under the standard EU ETS commercial transport reduces 7.30 % and private transport 14.47 % of its emissions at the European level, under the extended EU ETS these sectors reduce emissions by 1.30 % and 2.61 % respectively. To compensate these differences, additional reduction is mainly carried out by electricity and energy intensive production (10.98 % to 17.17 %, 10.79 % to 14.44 %). In contrast, the refinery sector also slightly reduces emission abatement due to the increased demand for transportation fuels (10.73 % to

13.31 %). Including road transportation, the EU ETS covers about 65 % of the total EU15 emissions while the standard EU ETS only cover about 45 % in the calibrates benchmark dataset.

Table 5: Scenarios transportation under emission trading

Name	Description
EU ETS TAX R	Electricity, energy intensive industries, refineries, and road transportation trade allowances across Europe. Remaining sectors are regulated by sectoral taxes; uniform tax for road transportation. ROW: regional emission trading system
EU ETS TAX RA	Electricity, energy intensive industries, refineries, road, and air transportation trade allowances across Europe. Remaining sectors are regulated by sectoral taxes; uniform tax for road transportation. ROW: regional emission trading system
EU ETS TAX RAW	Electricity, energy intensive industries, refineries, road, air, and water transportation trade allowances across Europe. Remaining sectors are regulated by sectoral taxes; uniform tax for road transportation. ROW: regional emission trading system
EU ETS DOM R	Electricity, energy intensive industries, refineries and road transportation trade allowances across Europe. Remaining sectors regionally trade allowances. ROW: regional emission trading system
EU ETS DOM RA	Electricity, energy intensive industries, refineries, road, and air transportation trade allowances across Europe. Remaining sectors regionally trade allowances. ROW: regional emission trading system
EU ETS DOM RAW	Electricity, energy intensive industries, refineries, road, air, and water transportation trade allowances across Europe. Remaining sectors regionally trade allowances. ROW: regional emission trading system

Further including air transportation (column 3 in Figure 7) leads to an additional welfare gain. The EUA price is slightly rising from 11.85 to 12.55 \$/t CO_2. Again, emission increase in the air transportation sector – reduction reduces from 10.90 % to 3.69 % – is compensated by additional abatement of electricity and energy intensive production. In turn, due to the increased transportation fuel demand, emissions in the refinery sector increase. The EU ETS covers 68.78 % when air transportation is additionally included and 71.93% when water transport is in the scope of the EU ETS. Surprisingly, additional inclusion of water transport leads to a decrease of the European welfare. The EUA price rises up to 13.03 \$/t CO_2; water transport services and refineries increase emissions while electricity and energy intensive increase emission abatement. The welfare loss, occurs due to fact, that European trade with the rest of the world is mainly based on water transportation i.e. water transport margins account for about 58 % of the total transport margins followed by other and air transport with 23.8 % and 18.2 % respectively. In contrast, intra-European trade is mainly based on road transportation (about 58.3 %; water: 36.3 %, air: 5.4 %). The drop of the carbon price for water transport services leads to a decrease of the water transport which facilitates trade with the rest of the world[5]. However, the rest of the world industries face a lower carbon price (3.23 \$/t CO_2) since the abatement target is assumed to be low a regulation is flexible with domestic emission trading.

Therefore, rest of the world industries have a comparative advantage over European industries which comes in place due to the lower water transport margin and leads to an welfare gain for the rest of the world. This effect also occurs for Sweden which is the only European country which experiences positive welfare effect, since Swedish international trade is water intensive and sectoral carbon prices are zero due to the negative abatement burden. However, the positive welfare effect for Sweden is not able to compensate the negative effects of remaining European countries and European welfare is decreasing. The gain from additional carbon regulation flexibility is overlaid by this negative trade effect.

Figure 7: Welfare effects of transportation under emission trading compared to SECTORAL scenario; sectoral policy

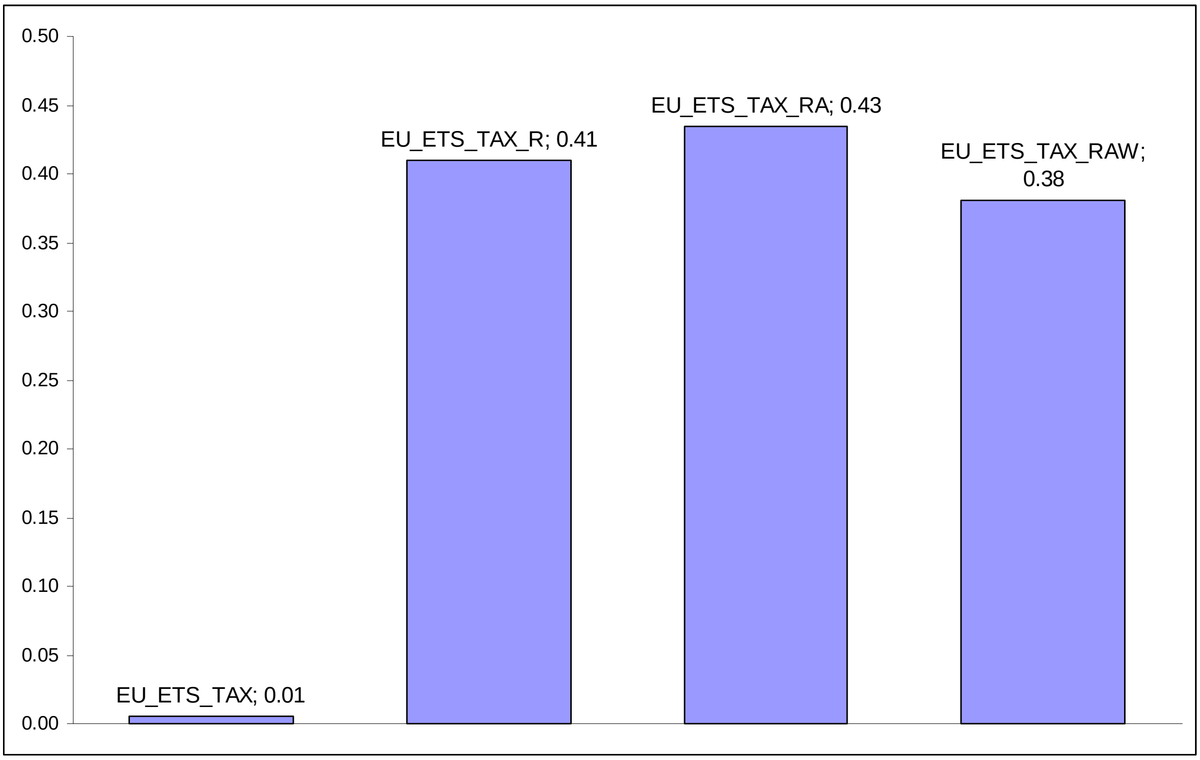
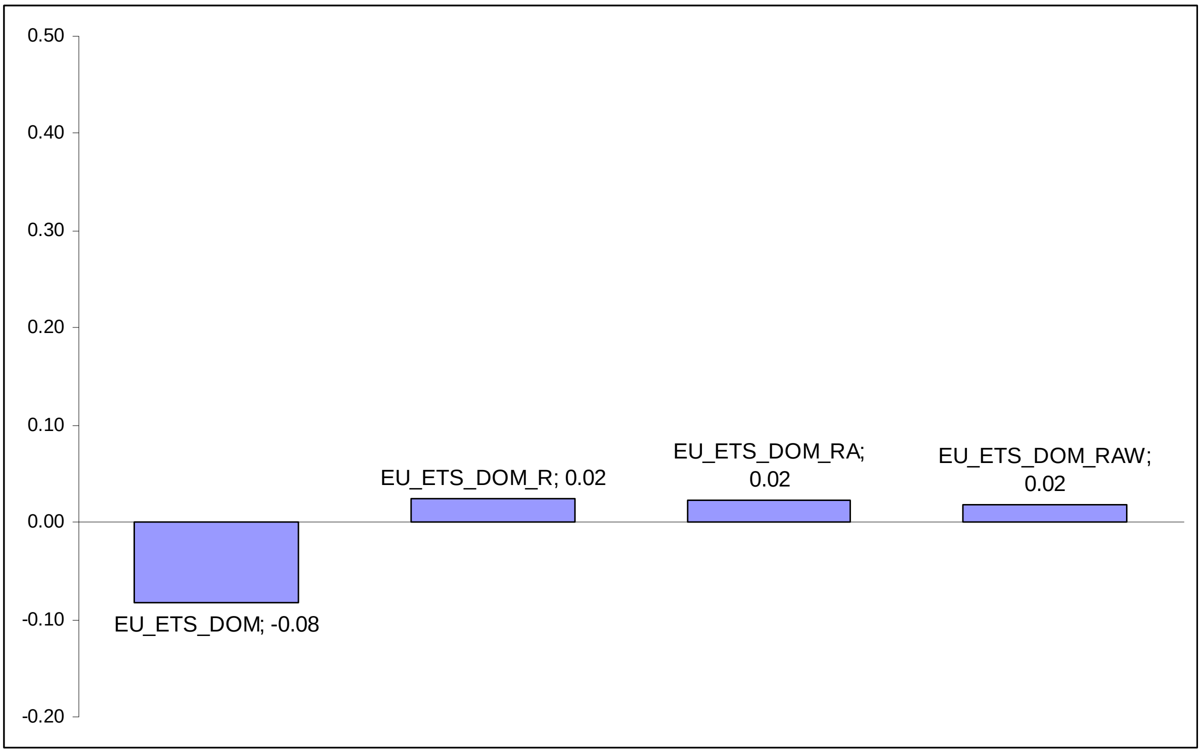


Figure 8 shows the same configuration for the EU ETS under domestic emission trading. Again, the inclusion of road transportation shows welfare gains. However, these gains are smaller than the gains under regional carbon tax regimes. Since road transportation is subject to regional emission trading in the DOMESTIC scenario, the difference in carbon price is lower for the road transportation sector. Put differently, compared to the tax scenario in the domestic trade scenarios in the reference ETS scenario carbon regulation is more flexible. Thus, the gain from additional flexibility induced by European trade becomes smaller. Even if the gains from additional flexibility are small compared to the tax scenarios, Figure 8 demonstrate that the inclusion of road transportation partly offset the problem of hybrid regulation. The imposition of European emission trading leads to an European welfare gain even if member states impose the most flexible type of carbon regulation. However, there is still room for improvement since the full European emission trading scenario performs better in terms of welfare.

[5] Transport margin prices in different scenarios are listed in the appendix.

Like in the tax scenarios, the EUA price is increasing (7.34 to 12.07 \$/t CO2) due to the high marginal abatement costs of road transport. On the other hand, national carbon prices decrease. Again, emission abatement shifts from the sectors with high marginal abetment cost – commercial and private road transport – to sectors with relative low marginal abatement cost – electricity and energy intensive production while the refinery sector increases emission due to increased demand. The further inclusion of air and water transportation provides no additional welfare gain for Europe. The reason for this results with is in contrast with the result of the tax scenarios, is the lower carbon price under domestic emission trading compared to sectoral carbon prices. Thus, the impact of the inclusion of water transportation in the EU ETS on the water transport margin price is smaller which leads to a smaller trade effect.

Figure 8: Welfare effects of transportation under emission trading compared to DOMESTIC scenario; national emission trading



5 Conclusion

We presented a static multi-region CGE model, representing the EU 15, with a detailed modeling of transportation i.e. household transportation. In the first set of scenarios we presented the effects of different approaches to carbon regulation on a regional as well as a European level. On a regional level the best approach is to apply regional emission trading instead of sectoral carbon taxes. On a European level, the first best solution is full emission trading across all European regions and sectors. If European member-states perform regional emission trading, the introduction of the EU ETS causes welfare losses due to the nature of hybrid regulation. Even if sectoral carbon taxes are used to regulate emission on a regional level, the introduction of the EU ETS shows only small positive welfare effects. In a second set of scenarios, we included different transportation modes in the EU ETS. The inclusion of road transportation in the EU ETS provides high welfare gains for Europe and is able to compensate the inefficiency of hybrid regulation. We also have shown that aviation under emission trading, leads to a welfare gain for Europe. Concerning water transportation, our results show that the inclusion of maritime shipping in the EU ETS compared to sectoral differentiated carbon taxes on a member-state level leads to a dead-weight-loss. However, this should not be converted into an argument into an argument against emission trading in the maritime sector due to two reasons. First, we have not address the issue of differentiated reduction requirements for different sectors. However, at the time the CO_2 emission from maritime shipping is exempted from carbon regulation. Thus, the trade barrier build by a high carbon tax is purely theoretical. Second, we modeled extra-European trade links in very rough manner as an aggregated rest of the world region. We assigned this region a low reduction requirement implemented in a first best manner by domestic emission trading. A more detailed modelling of the main European trading partners and their carbon policies is expected to produce qualitatively different results. However, our result is valuable in that is indicates the importance of international trade links when regulating emissions of international transport services. In the current policy debate about regulated emissions of road transportation, our results suggest that the inclusion of this sector in European emission trading would allow cost effective reduction of emissions of road transportation and, additionally, reduce the inefficiencies of the current EU ETS. Thus, we propose this widening of the scope of the EU ETS instead of the inflexible approach of imposing fuel or carbon emission standards.

Subsequent work will apply European policy on an EU 27 level and model other regions in a more disaggregated way. Further, we applied regional emission reduction targets uniformly to every sector. However, national allocations plans of the European member states indicate carbon regulation differentiated by sectors. The allocation of emissions to the EU ETS has a large impact on the allocation of abatement between sectors. A low reduction target for EU ETS sectors implies a high abatement burden for domestic sectors. We plan to address this issue in future work. We only included EU 15 member-states and modelled remaining regions in a rough manner as an aggregated rest of the world region.

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Appendix A: Behavioural and Calibration Parameters

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

Table 6: Production and trade substitution elasticities

σ_i	Description		Value
	Production Elasticities		
CAGA	Gasoline / transport equipment[6]		0.2
E	Electricity / fossil fuels		0.5
EXT	Sector specific resource/ other iputs (coal, natural gas, and crude oil)		0.6
FF	Fossil Fuels[7]		0.5
TRN	Other / air / water transport services[3]		0.2
VA	Labor / Capital		1
VAE	Energy / value-added		0.5
	Armington 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

Table 7: Household substitution elasticities

	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	0.3
PUR	Other / air / water transport services[3]	0.2

Table 8: CO_2 emission factors (Gt/EJ)

	OTP/ Household Transport	ATP	WTP	Other Sectors/ Houehold
Coal	0.0975	0.0975	0.0975	0.0975
Crude Oil	0.0733	0.0733	0.0733	0.0733
Natural Gas	0.0561	0.0561	0.0561	0.0561
Refined Oil Products	0.0693	0.0700	0.0741	0.0733

Source: IPCC (2006)

[6] Own guess
[7] Taken from the GTAP-E model (Burniaux and Truong, 2002)

Appendix B: Welfare Effects

Table 9: Regional welfare effects in Hicksian Equivalen Variaton (%) compared to benchmark of no carbon regulation

	aut	bel	deu	dnk	esp	fin	fra	gbr	grc	irl	ita	lux	nld	prt	swe	row	EU	WORLD
SECTORAL	-0.66	-0.08	-0.45	-0.48	-0.99	-0.70	-0.32	-0.47	0.09	-1.68	-1.11	-0.05	-0.63	-1.04	-0.05	-0.12	-0.58	-0.23
DOMESTIC	-0.34	-0.10	-0.15	-0.22	-0.40	-0.17	-0.12	-0.08	0.06	-0.83	-0.48	-0.24	-0.23	-0.41	0.00	-0.09	-0.21	-0.11
EUROPEAN	-0.18	-0.08	-0.17	-0.22	-0.21	-0.15	-0.14	-0.10	0.03	-0.43	-0.23	-0.18	-0.21	-0.27	0.06	-0.08	-0.16	-0.10
EU_ETS_DOM	-0.57	-0.18	-0.25	-0.17	-0.71	-0.55	-0.13	-0.09	0.06	-1.04	-0.60	-0.09	-0.18	-0.84	-0.02	-0.09	-0.29	-0.14
EU_ETS_DOM_R	-0.20	-0.07	-0.17	-0.19	-0.32	-0.26	-0.12	-0.11	0.04	-0.61	-0.29	-0.23	-0.23	-0.44	0.00	-0.09	-0.18	-0.11
EU_ETS_DOM_RA	-0.19	-0.08	-0.17	-0.22	-0.30	-0.22	-0.13	-0.12	0.05	-0.52	-0.29	-0.25	-0.25	-0.44	0.01	-0.08	-0.18	-0.11
EU_ETS_DOM_RAW	-0.24	-0.12	-0.18	-0.22	-0.32	-0.22	-0.14	-0.12	0.06	-0.51	-0.29	-0.21	-0.25	-0.42	0.07	-0.08	-0.19	-0.11
EU_ETS_TAX	-0.68	-0.09	-0.45	-0.42	-0.99	-0.70	-0.33	-0.46	0.10	-1.67	-1.09	-0.03	-0.60	-1.01	-0.04	-0.12	-0.57	-0.23
EU_ETS_TAX_R	0.03	0.19	-0.16	0.14	-0.33	-0.32	-0.14	-0.15	0.08	-0.59	-0.32	0.15	-0.04	-0.46	-0.04	-0.12	-0.17	-0.13
EU_ETS_TAX_RA	0.04	0.19	-0.13	0.05	-0.31	-0.25	-0.13	-0.11	0.08	-0.53	-0.30	0.11	0.13	-0.47	-0.02	-0.11	-0.14	-0.12
EU_ETS_TAX_RAW	-0.25	-0.13	-0.18	-0.34	-0.33	-0.21	-0.14	-0.12	0.04	-0.51	-0.30	-0.21	-0.29	-0.42	0.07	-0.08	-0.19	-0.11

Appendix C: CO_2 Prices

Table 10: CO_2 prices SECTORAL scenario (\$/t CO_2)

	aut	bel	deu	dnk	esp	fin	fra	gbr	grc	irl	ita	lux	nld	prt	swe	row
agr	71.00	36.70	16.21	0.31	44.64	35.88	10.17	0.01	7.15	51.50	33.20	2.99	1.43	46.51	0.00	3.29
car	51.12	15.22	12.84	74.18	22.59	46.73	6.79	17.18	5.53	71.06	16.37	1.86	0.88	13.63	0.00	3.29
mac	38.55	24.31	15.53	1.14	38.66	31.65	10.40	2.38	2.99	46.90	29.47	4.95	14.09	28.45	0.00	3.29
road	297.18	109.80	78.25	448.34	184.99	144.51	80.47	161.72	26.14	188.40	267.51	71.45	170.07	105.84	0.00	3.29
wtp	230.43	117.66	60.73	339.68	60.10	81.32	32.54	68.25	16.53	61.69	94.99	57.54	257.50	45.88	0.00	3.29
atp	104.68	72.37	51.61	112.30	43.13	52.37	25.87	46.73	60.07	31.03	72.38	34.49	155.59	19.01	0.00	3.29
eint	38.62	16.07	8.89	0.61	28.70	17.66	7.63	0.12	7.02	51.14	23.27	3.79	9.50	36.06	0.00	3.29
ely	23.28	9.59	5.20	15.71	10.63	10.42	4.01	3.96	1.90	24.61	16.52	2.49	17.14	7.32	0.00	3.29
p_c	6.19	4.80	3.48	102.43	5.03	4.17	3.18	4.16	6.68	11.02	5.10	0.00	8.40	17.87	0.00	3.29

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Table 11: CO_2 prices DOMESTIC scenario (\$/t CO_2)

	aut	bel	deu	dnk	esp	fin	fra	gbr	grc	irl	ita	lux	nld	prt	swe	row
Region	50.18	18.80	10.03	23.80	28.14	14.72	11.43	4.43	3.37	40.74	31.83	12.68	14.30	19.37	0.00	3.24

EUA price under full European emission trading: 12.73 \$/t CO_2

Table 12: CO_2prices EU_ETS_TAX scenario (\$/t CO_2)

	aut	bel	deu	dnk	esp	fin	fra	gbr	grc	irl	ita	lux	nld	prt	swe	row
agr	70.76	35.68	15.68	0.65	44.34	34.45	9.78	0.01	6.97	52.45	33.01	2.96	1.30	48.56	0.00	3.27
car	51.22	15.03	12.54	86.05	22.63	44.37	6.61	16.91	5.43	71.94	16.35	1.84	0.78	13.91	0.00	3.27
mac	38.46	23.90	15.08	1.24	38.45	30.39	9.96	2.49	3.38	46.81	29.29	4.92	13.52	29.88	0.00	3.27
road	296.30	108.37	76.09	474.38	184.27	141.34	77.56	159.44	26.57	187.24	267.21	70.81	172.07	109.18	0.00	3.27
wtp	230.49	116.29	58.94	344.08	59.95	79.54	30.64	68.05	16.47	61.77	95.14	57.27	263.67	48.55	0.00	3.27
atp	104.39	70.73	49.93	113.44	42.73	50.18	23.56	45.24	59.02	31.10	71.96	34.02	161.00	20.66	0.00	3.27
EUA	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	6.57	

Table 13: CO_2 prices EU_ETS_TAX_R scenario (\$/t CO_2)

	aut	bel	deu	dnk	esp	fin	fra	gbr	grc	irl	ita	lux	nld	prt	swe	row
agr	62.94	32.25	14.77	0.35	42.72	30.46	8.91	0.01	5.74	49.42	30.57	2.86	1.36	43.19	0.00	3.26
car	56.96	17.14	14.20	79.17	26.85	39.79	7.77	17.03	5.42	72.87	20.89	2.09	0.90	14.94	0.00	3.26
mac	37.60	22.66	14.56	1.20	37.84	27.66	9.59	2.76	3.23	46.57	29.23	4.93	13.70	29.16	0.00	3.26
wtp	228.32	115.87	53.24	344.45	68.95	90.86	30.28	89.77	15.61	71.08	138.04	58.49	249.88	43.43	0.00	3.26
atp	131.68	69.72	53.07	120.70	54.14	54.15	25.30	52.50	70.01	37.08	115.30	33.90	153.16	73.67	0.00	3.26
EUA	11.85	11.85	11.85	11.85	11.85	11.85	11.85	11.85	11.85	11.85	11.85	11.85	11.85	11.85	11.85	

Table 14: CO_2 prices EU_ETS_TAX_RA scenario ($/t CO_2)

	aut	bel	deu	dnk	esp	fin	fra	gbr	grc	irl	ita	lux	nld	prt	swe	row
agr	62.51	32.01	14.81	0.32	42.49	30.41	8.91	0.01	5.71	49.50	30.49	2.86	1.37	42.98	0.00	3.22
car	56.70	17.37	14.17	77.58	26.82	39.13	7.82	16.83	5.28	72.64	20.88	2.12	0.91	14.74	0.00	3.22
mac	37.52	22.62	14.54	1.19	37.85	27.44	9.59	2.79	3.24	46.51	29.24	4.95	13.78	29.17	0.00	3.22
wtp	226.74	114.85	52.55	343.59	68.63	90.63	29.67	88.75	16.32	71.95	136.43	58.11	246.83	44.18	0.00	3.22
EUA	12.55	12.55	12.55	12.55	12.55	12.55	12.55	12.55	12.55	12.55	12.55	12.55	12.55	12.55	12.55	

Table 15: CO_2 prices EU_ETS_TAX_RAW scenario ($/t CO_2)

	aut	bel	deu	dnk	esp	fin	fra	gbr	grc	irl	ita	lux	nld	prt	swe	row
agr	62.51	32.01	14.81	0.32	42.49	30.41	8.91	0.01	5.71	49.50	30.49	2.86	1.37	42.98	0.00	3.22
car	56.70	17.37	14.17	77.58	26.82	39.13	7.82	16.83	5.28	72.64	20.88	2.12	0.91	14.74	0.00	3.22
mac	37.52	22.62	14.54	1.19	37.85	27.44	9.59	2.79	3.24	46.51	29.24	4.95	13.78	29.17	0.00	3.22
EUA	12.55	12.55	12.55	12.55	12.55	12.55	12.55	12.55	12.55	12.55	12.55	12.55	12.55	12.55	12.55	

Table 16: CO_2 prices EU_ETS_DOM scenario ($/t CO_2)

	aut	bel	deu	dnk	esp	fin	fra	gbr	grc	irl	ita	lux	nld	prt	swe	row
Region	132.39	44.23	26.79	68.18	74.08	60.93	19.48	5.35	8.11	64.29	76.65	19.93	14.26	51.21	0.00	3.25
EUA	7.34	7.34	7.34	7.34	7.34	7.34	7.34	7.34	7.34	7.34	7.34	7.34	7.34	7.34	7.34	7.34

Table 17: CO_2 prices EU_ETS_DOM_R scenario ($/t CO_2)

	aut	bel	deu	dnk	esp	fin	fra	gbr	grc	irl	ita	lux	nld	prt	swe	row
Region	63.41	30.84	17.84	19.07	43.24	35.12	12.43	2.51	5.29	43.93	38.37	6.07	8.41	32.64	0.00	3.24
EUA	12.07	12.07	12.07	12.07	12.07	12.07	12.07	12.07	12.07	12.07	12.07	12.07	12.07	12.07	12.07	

Table 18: CO_2 prices EU_ETS_DOM_RA scenario (\$/t CO_2)

	aut	bel	deu	dnk	esp	fin	fra	gbr	grc	irl	ita	lux	nld	prt	swe	row
Region	56.48	29.88	17.16	2.91	42.64	33.02	11.86	2.05	5.10	50.24	37.17	5.08	7.47	31.30	0.00	3.23
EUA	12.60	12.60	12.60	12.60	12.60	12.60	12.60	12.60	12.60	12.60	12.60	12.60	12.60	12.60	12.60	

Table 19: CO_2 prices EU_ETS_DOM_RAW scenario (\$/t CO_2)

	aut	bel	deu	dnk	esp	fin	fra	gbr	grc	irl	ita	lux	nld	prt	swe	row
Region	48.08	26.75	16.27	1.57	41.29	29.30	11.61	1.91	4.43	48.71	36.11	3.00	6.41	30.44	0.00	3.23
EUA	12.94	12.94	12.94	12.94	12.94	12.94	12.94	12.94	12.94	12.94	12.94	12.94	12.94	12.94	12.94	

Appendix D: Prices of transport margins

	atp	otp	wtp
SECTORAL	1.03	1.05	1.05
DOMESTIC	1.01	1.01	1.01
EUROPEAN	1.01	1.01	1.01
EU_ETS_DOM	1.02	1.01	1.02
EU_ETS_DOM_R	1.02	1.01	1.02
EU_ETS_DOM_RA	1.01	1.01	1.02
EU_ETS_DOM_RAW	1.01	1.01	1.01
EU_ETS_TAX	1.03	1.05	1.05
EU_ETS_TAX_R	1.03	1.01	1.05
EU_ETS_TAX_RA	1.01	1.01	1.05
EU_ETS_TAX_RAW	1.01	1.01	1.01