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On the Robustness of Marginal Abatement Cost Curves: The Influence of World Energy Prices

by

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Abstract:
Since the study of Ellerman and Decaux (1998) marginal abatement cost curves (MACCs) have become one of the favorite instruments to analyze the impacts of the implementation of the Kyoto Protocol and emission trading. This paper shows that the MACC in one country depends - via the link of world energy prices - on the level of abatement in the rest of the world. The strength of the dependence is influenced by factors, such as trade elasticities and trade structures. After discussing the mechanism theoretically, the CGE model DART is used to quantify the effects. We show that the MACC of a region does indeed shift with changes in the abatement level in the rest of the world and that especially with low domestic abatement level the MACCs can differ considerably.

Keywords: Marginal abatement costs, energy prices, computable general equilibrium model, DART

JEL classification: C68, D58, F18, Q41

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1 Introduction

In the last years marginal abatement cost curves (MACCs) have become a standard tool to analyze the impacts of the Kyoto Protocol and emission trading. Once such curves are available for the different world regions it is very easy to determine permit prices, total abatement cost and regional emissions for different scenarios of international emission trading. A detailed description of the use of the MACCs is provided in the papers of Ellerman and Decaux (1998) and Criqui, Mima, and Viguir (1999). A number of other authors have followed the approach (Blanchard, Criqui, and Kitous 2002; den Elzen and de Moor 2001; den Elzen and de Moor 2002; Loeschl and Zhang 2002; Lucas, den Elzen, and Vuuren 2002; Steenberghe 2002) analyzing scenarios such as emission trading with and without the participation of the USA, the use of market power by Russia and the Ukraine, multiple gas abatement and banking.

One justification for the approach is the finding of Ellerman and Decaux (1998) that each region/country has its unique marginal abatement cost curve independent of how much other regions reduce their emissions. This is not automatically clear. Ellerman and Decaux note themselves that with international trade the abatement level in one country influences trade flows such that the MACCs may change in other countries. Their simulations with the EPPA model show though that the curves are robust and that the variation in prices is less than 10% between different scenarios for any given level of abatement. In contrast, the result of this paper is that, depending on the level of abatement in other regions, the regional MACCs can shift and that the variation in prices can be explained by the world energy prices. In short, the reason behind this shift is that abatement levels in one country influence its energy demand, which might in turn influence the world energy price. For example, with higher world energy prices regions automatically demand less energy and emit less carbon so that the same emission target becomes less binding. The magnitude of the shift depends on a number of factors such as trade elasticities and trade structures. In this paper, first we explore these effects theoretically and second quantify them using the computable general equilibrium model DART. The main result is that marginal abatement cost curves can indeed shift and that even if the difference is in many cases below the 10% level it can be as high as 25% or in extreme situations even 75% for low regional abatement targets lying still in the range of the Kyoto targets after Bonn and Marrakech.

The paper proceeds as follows. The next sections defines marginal abatement cost curves, explains how they can be constructed and present estimates for different regions. Section 3 shows theoretically how MACCs shift depending on world energy prices and analyzes the influencing factors. Section 4 introduces the computable general equilibrium model DART and defines our scenarios. Section 5 presents the results of the simulations. Section 6 discusses the US withdrawal from the Kyoto Protocol as one example in more detail. Section 7 concludes.

2 Marginal abatement cost curves

The marginal abatement cost (MAC) for emissions (e.g. CO_2 emissions) in a specific region represents the cost of the last ton of emission mitigation undertaken in order to fulfill a certain reduction target. The MACs for different targets taken together form the marginal abatement cost curve (MACC) that shows the MAC for varying amounts of emission reduction. MACCs can vary significantly from one country to another and are influenced by factors such as the initial level of energy prices, the energy supply structure and the potential for developing carbon free energy resources (Criqui, Mima, and Viguir 1999). In practice basically two different types of models are used to analyze climate policies as well as to generate MACCs for the different regions. The first approach is denoted top-down and is based on aggregated microeconomic models. The models are most often computable general equilibrium (CGE) models that may carry a detailed representation of the energy sector. Bottom-up models on the other hand are based on an engineering approach that analyzes the different technical potentials for emission reductions in detail.

In a CGE model, marginal abatement cost is the same as the shadow cost that is produced by a constraint on carbon emissions for a given region and a given time. This shadow cost is equal to the tax that would have to be levied on the emissions to achieve the targeted level or the price of an emission permit in the case of emission trading. The more severe the constraint, the higher the marginal abatement costs are. Marginal abatement costs curves are obtained, when the costs associated with different levels of reductions are generated. Ellerman and Decaux (1998) use the EPPA model and run it with proportional reductions by all OECD countries of 1,5,10,15,20,30 and 40% of reference 2010 emissions. In the next step they fit simple analytical curves of the form

$$MAC(Q) = aQ^2 + bQ$$

to the sets of plots where Q denotes the level of abatement relative to the reference scenario in tons of carbon (tC). Their R^2 is close to one and they find that each region has a unique curve independently of how the other regions behave and independent of how the reductions are implemented (emission trading versus regional constraints).

Besides the EPPA-MACCs many models (Boehringer and Loeschl 2001; Blanchard, Criqui, and Kitous 2002; Criqui, Mima, and Viguir 1999; Loeschl and Zhang 2002) use curves generated from the energy systems model POLES (Criqui, Cattier, Menanteau, and Quidoz 1996) which is mainly a bottom-up model. Here, the MACCs are constructed the other way around (Criqui, Mima, and Viguir 1999). Different levels of a "shadow carbon tax" are levied on all areas of fossil fuel use. Via technological or implicit behavioral changes and the replacements in the energy conversion systems for which the technologies are explicitly defined in POLES, this leads to adjustments in the final energy demand and to the corresponding levels of emission reductions. Boehringer and Loeschl (2001) and Loeschl and Zhang (2002) use the data from POLES to estimate MACCs of the form:

$$MAC(Q) = \alpha Q^{\beta}$$

Another rather ad-hoc approach to estimate MACCs is used by Ghersi (2001). He uses the same analytical form as Boehringer and Loeschl (2001), but estimates the MACCs using the shadow costs reported from twelve different models affiliated to the Energy Modelling Forum (Weyant 1999). Available for each model is the marginal abatement cost C and the abatement in tC Q for the scenario where Kyoto is implemented through unilateral emission reductions and the scenario where it is implemented by international emission trading. With the two points (C_1, Q_1) and (C_2, Q_2) $\beta = \frac{ln(C_1/C_2)}{ln(Q_1/Q_2)}$ and $\alpha = C1/Q_1$. This approach is only valid though, if the MACCs are indeed robust against changes of policy. Otherwise, the two points do not lie on the same MACC.

Taken together, the literature shows that the MACCs vary considerably across different models and depend on the different model types and model assumptions e.g. on baseline growth and baseline emissions.

Nevertheless all models produce approximately the same regional order of the MACCs and the same general upward sloping curves. In the literature there are two ways to visualize MACCs: either with absolute emission reductions on the abscissa or with percentage reductions relative to the benchmark in a certain year (usually 2010). Figure 1 shows the marginal abatement cost curves for the Annex B regions of the DART model, when each country unilaterally undertakes an emission reduction in both graphical visualizations. They show in line with the results from the POLES, EPPA and WorldScan model that the same amount of emission reductions is cheapest in the USA, followed by countries of the former Eastern Block (FEB) and Western Europe (WEU). The reductions are most expensive in Japan (JPN) and the remaining Annex B countries (ANC = Canada, Australia, New Zealand). Regarding relative targets, the same percentage reduction relative to the benchmark is more equal across the regions. Here, abatement is again most expensive in Japan, followed now by Western Europe and the USA, ANC and finally the FEB. The results are discussed in more detail in section 5.

All studies that use MACCs need to rely on the result of (Ellerman and Decaux 1998) that each region has a unique MACC independent of the behavior of the rest of the world. Even though it is sometimes noted (den Elzen and Both 2002) that this might not be true, this issue has not been explored yet. Thus, we will look at this question in the rest of this paper. The following section describes the mechanism through which the marginal abatement cost curves are indeed dependent on the foreign abatement efforts and analyzes the parameter that determine the strength of that dependence.

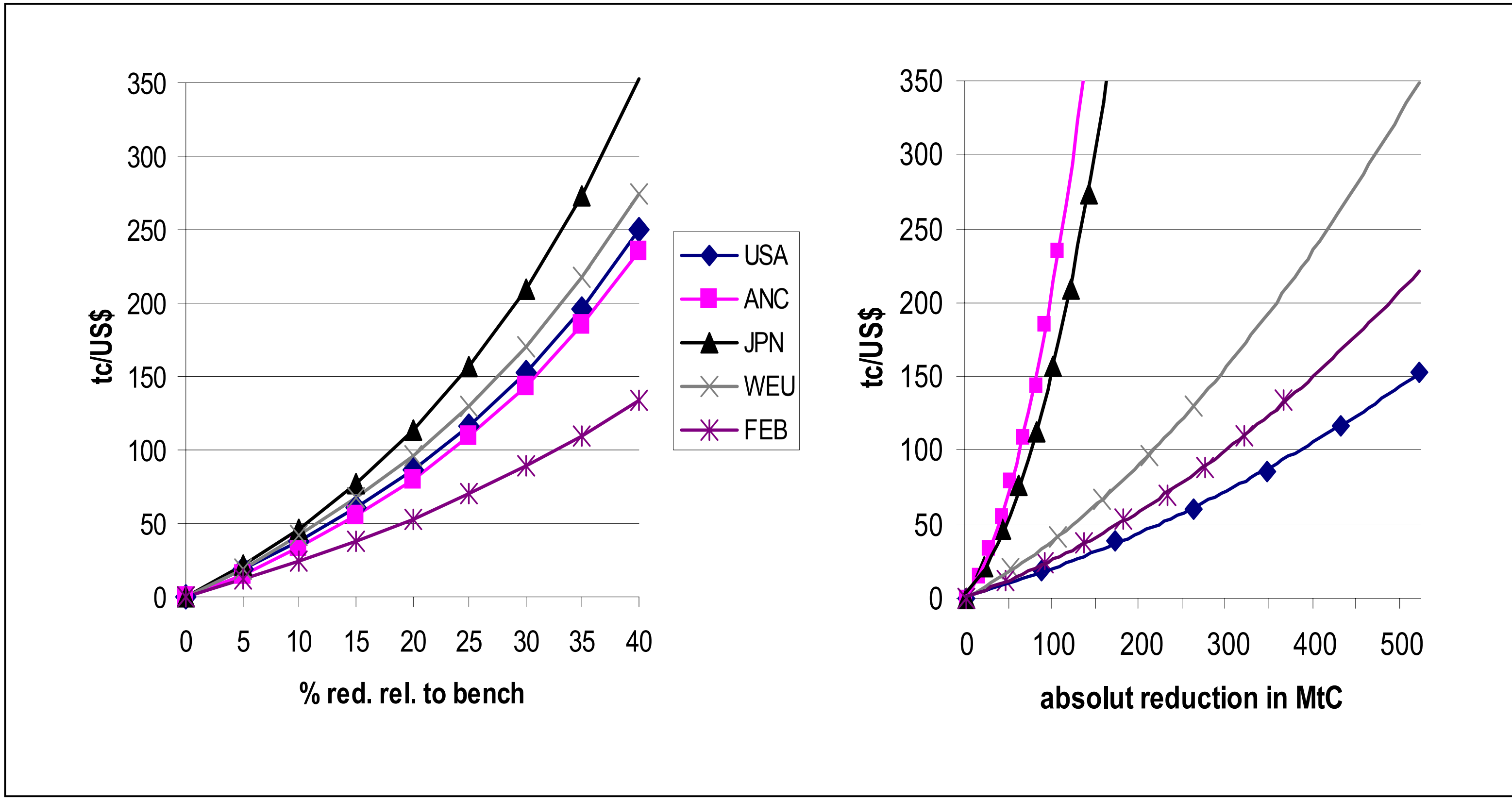

Figure 1: Typical marignal abatement cost curves

3 Why MACCs can shift: the role of energy prices

It is easy to see that the MACC of a country depends amongst others on energy demand and energy prices. Take for example the oil market in the Europe as illustrated in figure 2.

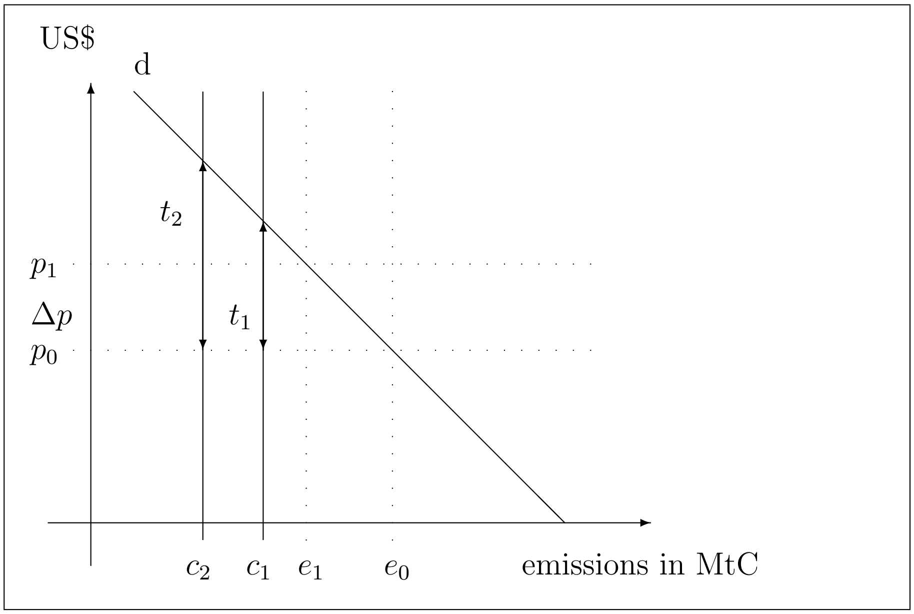

Figure 1: marginal abatement costs and fossil fuel prices

Line d represents the domestic European demand for oil. Since each barrel of oil contains a fixed amount of carbon, we can, without loss of generality, replace the quantity of oil on the abscissa by the associated CO_2 emissions. On the ordinate we keep the price of oil in US$. Assume now that the domestic oil price, that is influenced by the world market, is initially p_0. Without any emission constraints Europe would emit e_0 MtC. If Europe now commits to emit only c_1, the marginal abatement cost is the difference between p_0 and the price that would lead to c_1 MtC. In figure 1 this difference is denoted by t_1. t_1 is also equal to the emission tax that would have to be levied to achieve target c_1 or the permit price that would emerge under domestic permit trading. Under a stricter commitment c_2, the MAC would rise to t_2. The energy price also influences the MAC for a certain emission target. If the price rises to $p_1 = p_0 + \Delta p$, the emissions associated with unrestricted oil demand fall to e_1 MtC and the difference between the energy price on the market and the price that is needed to achieve a certain emission target (the MAC) falls exactly by Δp, independent of the level of the target.

In a globalizing world, where trade plays an increasingly important role, energy prices on the world market influence the domestic energy price. If now some foreign country changes its abatement effort, its energy demand changes as well. For example, if the country lowers its emission target, more energy is demanded. In the case where the foreign country is a large open economy as for example the United States, this increase in energy demand drives up the world market price of energy. If this leads in turn to an increase in the domestic energy price in Europe by Δp as in Figure 1, MACs in Europe decrease by the same amount. The whole MACC is subject to a vertical shift as illustrated in figure 3. Since the absolute difference is the same for all abatement levels, namely Δp, the percentage change of marginal abatement costs between the two situations is higher at low abatement levels. Note that the new MACC does not go through the origin. The reason is, that higher energy prices reduce the demand for oil so that even the original "benchmark" emissions, which were equivalent to a zero reduction at constant energy prices, would not represent a

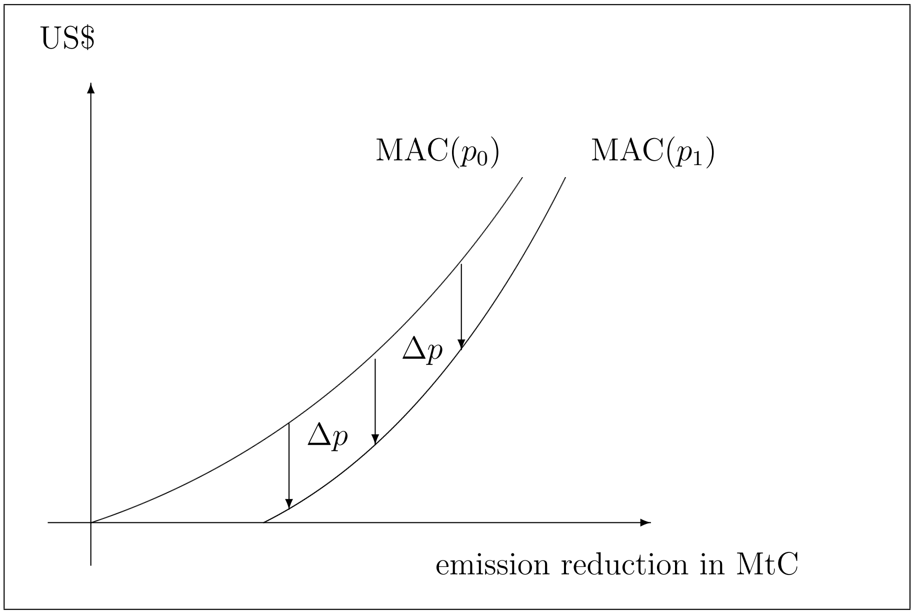

Figure 2: Shift of the MACC induced by a change in energy prices

binding constraint anymore. If, to the contrary, energy prices fall, the MACC is shifted upward so that even keeping benchmark emission levels requires some abatement.

Even though this model is just a crude simplification of reality, it is helpful for exploring the factors that influence the extent of the shift. First, as one can see in figure 2, the level of the MAC associated with a certain abatement level depends on the slope of the domestic demand curve for oil or in other words the domestic elasticity of demand for oil. Even though the vertical difference between the MACs for one emission target under different world oil prices is independent of the parameters of the demand function, the relative difference becomes larger with larger demand elasticities and lower MACs.

Second, the extend of the absolut difference in the MACCs, the level of Δp, depends on how strongly domestic energy prices are correlated with the world market price. Most CGE models work with the Armington assumption where foreign and domestic goods are imperfect substitutes. For the sake of simplicity we assume here, that each country is either only an oil exporter or only an oil importer.

Consider first an oil importing country. Let I denote the amount of imported oil and D the amount of domestically produced and used oil. Define S as the amount of oil imports relative to the domestic oil $S = I/D$. Let further p_I be the price of imported oil and set for simplicity the domestic oil price p_D equal to 1. The actual domestic oil price is then defined as

$$p_a = \frac{D + p_I I}{D + I} = \frac{(1 + p_I * S)}{1 + S}$$

Now we can derive the reaction of p_a to a change in the international energy price:

$$\begin{aligned}
\frac{\delta p_a}{\delta p_I} &= \frac{(1+S)\left(S + p_I \frac{\delta S}{\delta p_I}\right) - \frac{\delta S}{\delta p_I}(1 + p_I S)}{(1+S)^2} \\
&= \frac{S}{1+S} + \left(1 - \frac{1}{p_I}\right) \frac{S}{(1+S)^2} * \epsilon_A \\
&= \frac{I}{I+D} + \left(1 - \frac{1}{p_I}\right) \frac{ID}{(I+D)^2} * \epsilon_A \\
&= m * \left(1 + \left(1 - \frac{1}{p_I}\right) * (1 - m) * \epsilon_A\right) \quad (*)
\end{aligned}$$

Where $\epsilon_A = \frac{\delta S}{\delta p_I} \frac{p_I}{S}$ and $m = \frac{I}{I+D}$. ϵ_A can also be written as

$$\epsilon_A = \frac{\delta(I/D)}{\delta(p_I/p_D)} * \frac{(p_I/p_D)}{(I/D)}$$

and is the elasticity of substitution between imported and domestic oil, which is called trade or Armington elasticity. As imports decrease with rising import prices, ϵ_A is negative. m is the import share.

(*) implies that $\frac{\delta p_a}{\delta p_I}$ increases with decreasing p_I. As we can assume that the import price of oil is lower than the domestic price, we have that $p_I < p_d = 1$. Thus, $\frac{\delta p_a}{\delta p_I}$ increases also with an increase in the trade elasticity. To determine the role of the import share m we differentiate (*) with respect to m:

$$\begin{aligned}\frac{\left(\frac{\delta p_a}{\delta p_I}\right)}{\delta m} &= 1 + \left(1 - \frac{1}{p_I}\right) * (1-m) * \epsilon_A - m * \left(1 - \frac{1}{p_I}\right) * \epsilon_A \\ &= 1 + \left(1 - \frac{1}{p_I}\right) * (1-2m) * \epsilon_A \quad (**)\end{aligned}$$

As $p_I > 1$ (**) is positive if $m < 0.5$. If $m > 0.5$ the sign of (**) depends on whether the whole term $\left(1 - \frac{1}{p_I}\right) * (1-2m) * \epsilon_A$ is smaller than -1.

For oil exporting countries the comparative statics are much more straight forward. If the international oil price increases, the oil exports and thus the demand for domestically produced oil increases as well, which in turn drives up the domestic price of oil. This effect is stronger with a larger increase in the international price of oil, with a larger relative price of exports and with a larger export share. The trade elasticity plays a different role here. If we go back to the scenario that one large country, (for example the USA), lowers its energy target, the effect on an energy exporting country depends on the trade elasticity in the USA. The higher the elasticity in the USA, the more extra energy the USA are demanding from the world market and thus from the exporting county. Hence, the change in domestic prices is also larger.

In reality there is more than one foreign country, more then one source of energy and most countries export and import energy at the same time. A theoretical overall "energy price" in one country would be a weighted composite of many domestic and foreign prices. If now one foreign country changes its abatement level, the strength of the shift of the domestic MACC depends on the relative importance of the imports from that country, the exports to this country, its ability to influence the different world energy prices and the substitutability between the different sources of energy. If a country like the Netherlands decides to impose a stricter reduction regime it will not alter the marginal abatement costs of the rest of the world. It is different though, if the United States refuse to fulfill their Kyoto commitment.

We can summarize the results of this section as follows. If the change in the abatement level in one country is able to effect the world market prices for energy, it also effects the MACs in the remaining countries. This effect on a country's MACC is stronger

- the smaller the relative price of energy imports
- the larger the relative price of energy exports
- the more elastic the Armington elasticity
- the larger the export share for energy and
- the larger the import share for energy provided the share remains below 0.5.

In the next section we quantify the strength of the shifts in different scenarios for different regions, using the CGE model DART.

4 Simulations with the DART model

The DART (**D**ynamic **A**pplied **R**egional **T**rade) Model is a multi-region, multi-sector recursive dynamic CGE model of the world economy developed by the Kiel Institute for World Economics to analyze climate policies. In the version used for this paper it covers 11 sectors and 12 regions that are summarized in Table 1 and the two production factors labor and capital. The regional aggregation for this study include the FEB, the USA and other Annex B parties, that agreed to emission reductions in the Kyoto Protocol. The economic structure of the DART model is fully specified for each region and covers production, final consumption and investment. For a more detailed model description see (Klepper, Peterson, and Springer 2003) .

Table 1: Dimensions of the DART-Model

Countries and regions		Production sectors	
Annex B		Energy	
USA	USA	COL	Coal
WEU	West European Union	CRU	Crude Oil
ANC	Canada, Australia,	GAS	Natural Gas
	New Zealand	OIL	Refined Oil Products
JPN	Japan	EGW	Electricity
FEB	Former Soviet Union,		
	Eastern Europe	Non energy	
		AGR	Agricultural production
Non-Annex B		IMS	Iron Metal Steal
LAM	Latin America	CPP	Chemicals, rubber, paper
IND	India		and plastic products
PAS	Pacific Asia	Y	Other manufactures
CPA	China, Hong Kong		and services
MEA	Middle East, N. Africa	TRN	Transport
AFR	Sub-Saharan Africa	CGD	Investment good
ROW	Rest of the World		

MACCs are generated by setting different levels of emission constraints. Comparable to the study of Ellerman and Decaux (1998) we use abatement levels relative to the benchmark of 5, 10, 15, 20, 30 and 40%. To quantify the change in MACs depending on the abatement level in the remaining countries we assume different reduction schemes:

UNI The country for which the MACC is constructed is the only country that reduces its emissions. All other regions follow the business as usual path.

AXB All Annex B countries, except the region for that the MACC is constructed, fulfill their Kyoto commitment [1]. The reductions are achieved by a unilateral emission taxes. As in our model FEB does not reach its target emissions in 2010 they do not face reductions.

NOUS This scenario is the same as scenario AXB but we assume that the USA do not participate in the Kyoto Protocol and do not undertake any emission reductions.

We do not consider emission trading here, as with emission trading the abatement levels of all countries change in comparison to the unilateral action scenario and are dependent on the participants in the trading scheme. Wee would thus not only see a shift in MACCs, but also a move along one curve. As the focus of this paper is on the shift of the curves, for the moment we restrict ourselves to the non-trading case. Emission trading is treated in the example in section 6 though.

[1] The Kyoto targets applied in this study are the targets induced by the agreements in Bonn and Marrakech and include sinks. We use the percentage reductions cited in Boehringer (2001) and derive the targets for our regions aggregation using emission data from the IEA. The targets are relative to 1990 emission: USA: 96.8%, WEU: 94.8%, ANC: 109%, JPN: 99.2% and FEB 103%.

In addition to these scenarios, we construct the MACCs for lower and higher trade elasticities. Here, we focus on the reduction scenarios UNI and AXB and simulate the same absolute reductions as before[2].

LOWTR In the original DART model the elasticity of domestic versus imported goods δ^{DM} is 4, the elasticity of substitution of imports from different destinations δ^{MM} is 8. There parameters are now set to $\delta^{DM} = 2$ and $\delta^{MM} = 4$.

HIGTR The trade elasticities are set to $\delta^{DM} = 8$ and $\delta^{MM} = 16$.

5 Simulation results

Table 2 shows the marginal abatement costs for the different abatement levels in the different reduction scenarios for the Annex B regions USA, WEU, JPN, ANC and FEB. The first two columns show the relative and the absolute CO_2 reduction in 2010 compared to the benchmark emissions in 2010. The following three columns show for each reduction level the associated MACs in the three different abatement scenarios UNI, NOUS and AXB. The last three columns show the differences in the MACCs between different scenarios: the absolute and the percentage difference between scenario NOUS and AXB and the percentage difference between scenario UNI and AXB.

We can see, that the MACs in one country depend indeed on the level of abatement in the other countries. The difference in the MAC in the case of unilateral reductions compared to the case where all Annex B countries stick to their Kyoto commitment is between 10

[2]Note that these are not entirely the same relative reductions as before, as with different trade elasticities the energy demand in the business as usual scenario changes as well.

Table 2: Marginal abatement cost curves

	Reduct.$_1$ in		MAC in US$/tC			NOUS-AXB		UNI -
	%	GtC	UNI	NOUS	AXB	abs.	in %	AXB in %
WEU	5	0.05	19.53	23.77	30.36	6.58	27.7	55.4
	9.9*	0.10	41.15	45.39	51.88	6.49	14.3	26.1
	10	0.11	41.62	45.86	52.35	6.49	14.1	25.8
	20	0.21	96.24	100.50	106.79	6.29	6.3	11.0
	30	0.32	170.40	174.68	180.69	6.01	3.4	6.0
	40	0.42	274.98	279.28	284.85	5.57	2.0	3.6
JPN	5	0.02	21.08	26.44	33.67	7.22	27.3	59.7
	10	0.04	46.43	51.96	59.28	7.33	14.1	27.7
	20	0.08	112.94	118.82	126.30	7.48	6.3	11.8
	20.4*	0.08	116.10	122.03	129.51	7.48	6.1	11.5
	30	0.12	209.15	215.44	222.91	7.47	3.5	6.6
	40	0.16	352.39	359.17	366.38	7.21	2.0	4.0
ANC	5	0.01	15.37	20.78	26.80	6.02	29.0	74.3
	10	0.03	33.67	39.09	44.99	5.90	15.1	33.6
	13.1*	0.03	46.45	51.87	57.70	5.83	11.2	24.2
	20	0.05	79.66	85.12	90.79	5.67	6.7	14.0
	30	0.08	143.34	148.90	154.29	5.39	3.6	7.6
	40	0.10	234.90	240.55	245.47	4.93	2.0	4.5
USA	5	0.09	18.34	x	22.90	x	x	24.9
	10	0.17	38.32	x	42.97	x	x	12.1
	19.8*	0.34	85.24	x	90.25	x	x	5.9
	20	0.35	86.34	x	91.36	x	x	5.8
	30	0.51	152.58	x	158.28	x	x	3.7
	40	0.69	250.32	x	256.94	x	x	2.6
FEB	5	0.05	11.767	16.24	18.44	2.21	13.6	58.0
	10	0.09	24.34	28.87	30.90	2.03	7.0	26.9
	20	0.18	53.18	57.70	59.44	1.74	3.0	11.8
	30	0.27	88.59	93.26	94.76	1.50	1.6	7.0
	40	0.36	133.90	138.91	140.18	1.28	0.9	4.7

1: Emission reduction in 2010 relative to benchmark

*: Target after Bonn and Marrakech

- 14$/tC in WEU, JPN and ANC. For the USA it is only around 4-7$/tC, as the USA account for about 25% of Annex B energy demand, so the difference between the case with only domestic reductions and reductions of all Annex B countries is the lowest. The FEB is net energy exporter, but the share of net exports is below 0.2. Thus, it is effected less by the world market price. Even though and is not much affected by the world market prices. Even though the difference between the level of abatement in the other countries between scenario UNI and AXB is the highest for FEB, the difference in MACs is just around 7 $/tc.

In order to compare the impact of the same external shock to different regions we compare the original abatement commitment under the Kyoto-Protocol (AXB) with the situation of the USA withdrawing from the Protocol (scenario NOUS), i.e. all Annex B countries but the USA keep their commitments. The withdrawal of the USA lowers the marginal abatement costs in all regions (see column "NOUS-AXB abs." in table 2). As predicted by the equation (∗) of section 3, the regions with high import shares and high domestic energy prices experience the strongest shift in their MACCs. This turns out most strongly in Japan (JPN) followed by Western Europe (WEU). ANC as an energy exporter experiences a smaller shift. The difference between the two scenarios is the lowest in FEB, for the reasons explained above.

Finally the simulations show that the relative difference between MACs is below 10% for high abatement levels above 20% reduction relative to the business as usual scenario. For low abatement levels though, the difference can reach almost 75% comparing UNI and AXB and still 25% comparing AXB and NOUS. For the Kyoto targets it is still above 20% in WEU and ANC (UNI compared to AXB) resp. above 10% (NOUS compared to AXB).

As the cause for the shift in the MACs is the change in the energy prices, table 3 shows the net and gross prices for the different fossil fuel and electricity for WEU, which is representative for all other regions as well.

Table 3: WEU Energy Prices

	Gross price COL*			Gross price GAS*			Gross price OIL*		
	UNI	NOUS	AXB	UNI	NOUS	AXB	UNI	NOUS	AXB
10	2.04	2.04	2.06	1.44	1.45	1.46	1.91	1.90	1.87
20	2.72	2.74	2.76	1.66	1.67	1.68	2.18	2.17	2.14
30	3.69	3.71	3.74	1.97	1.98	1.99	2.55	2.54	2.51
40	5.11	5.14	5.18	2.41	2.42	2.43	3.09	3.0	3.05
	Net price COL*			Net price GAS*			Net price OIL*		
	UNI	NOUS	AXB	UNI	NOUS	AXB	UNI	NOUS	AXB
10	1.42	1.37	1.29	1.25	1.24	1.23	1.79	1.75	1.68
20	1.30	1.25	1.18	1.23	1.22	1.20	1.75	1.71	1.63
30	1.18	1.14	1.08	1.20	1.20	1.18	1.71	1.66	1.58
40	1.06	1.03	0.98	1.18	1.17	1.15	1.66	1.62	1.54

1997=1

Looking first at the prices net of the emission tax , we see that net prices for fossil fuels (oil, coal and gas) fall with rising abatement levels, as a result of the decreasing demand. By the same effect the MACs fall with increasing abatement and decreased energy demand in the remaining Annex B countries. The difference is always the strongest for coal with its high carbon content, while mostly the smallest for gas with its low carbon content. Looking now at the gross fossil fuel prices that include the emission tax, it is no surprise to see that they increase with increasing abatement levels. As expected the increase is strongest for the carbon intensive coal. What is interesting though is, that with more abatement in the remaining Annex B regions, gross coal and gross gas prices rise while gross oil prices fall. The explanation is that for gas on the one hand the rise in net price was relatively low, so that the drop in the MAC dominates. The carbon content of coal on the other hand is more than twice as high as the carbon content of gas. Thus, the drop in abatement costs dominates the price increase. Oil finally has a relatively low carbon content and in addition the price for oil increases more than the one for gas. Here, the world market effect dominates the marginal abatement cost effect.

Finally, table 4 reports the results of the simulations with different trade elasticities for some (representative) abatement levels. The results are not surprising. First, in line with trade theory, marginal abatement cost decrease with rising international trade, as trade in goods and services is a substitute for emission trading. The decrease in MACs from the LOWTR to the HIGTR scenario depends on the abatement level and the scenario. It is naturally higher with unilateral action (Scenario UNI) than in the Kyoto case (scenario AXB). Altogether the decrease is the lowest in the USA (1-3%), followed by ANC(2-8%) and WEU (6-11%). In the FEB abatement is very cheap so that small absolute changes in MACs lead to large relative changes that can be as high as 40% in the UNI scenario. The changes are larger for energy exporting regions (FEB, ANC) than for importing regions (USA, WEU, JPN). Japan which almost imports all of its energy, plays a special role. Here MACs even rise slightly with higher trade elasticities, as the domestic energy price is basically the same as the import price which is not necessarily larger with larger trade elasticities.

The second expected result is, that the magnitude of the shift of the MACC from the UNI to the AXB scenario increases with increasing international trade elasticities for ANC, FEB, USA and WEU. The change is the largest in the FEB with a high trade volume in energy and low domestic price. If we compare the energy importing countries USA

Table 4: Variation of the Armington trade elasticities

Red*	LOWTR			normal			HIGTR		
GtC	UNI**	AXB**	Δ(%)	UNI**	AXB**	Δ(%)	UNI**	AXB**	Δ(%)
WEU									
0.05	20.13	30.66	52.3	19.53	30.36	55.4	18.13	28.98	59.9
0.11	42.84	53.07	23.9	41.62	52.35	25.8	38.65	49.58	28.3
0.21	98.45	108.1	9.8	96.24	106.8	11.0	89.19	100.3	12.4
0.32	173.6	182.6	5.2	170.40	180.7	6.0	157.2	168.3	7.1
JPN									
0.02	21.04	33.54	59.4	21.08	33.67	59.7	21.16	33.54	58.5
0.04	46.08	58.79	27.6	46.43	59.28	27.7	46.38	59.08	27.4
0.08	111.7	124.8	11.7	112.9	126.3	11.8	112.3	125.7	11.9
0.12	206.6	219.7	6.4	209.3	222.9	6.6	infes	218.3	
ANC									
0.01	16.24	27.14	67.1	15.37	26.80	74.3	14.82	26.54	79.0
0.03	34.88	45.53	30.5	33.67	44.99	33.6	32.35	44.07	36.2
0.05	81.67	91.76	12.4	79.66	90.79	14.0	76.25	88.07	15.5
0.08	146.6	156.0	6.4	143.3	154.3	7.6	136.4	148.4	8.8
USA									
0.09	18.59	22.90	23.2	18.34	22.90	24.9	17.99	22.68	26.1
0.17	38.7	43.06	11.2	38.32	42.97	12.1	37.65	42.50	12.9
0.35	86.81	91.39	5.3	86.34	91.36	5.8	84.76	90.17	6.4
0.51	153.0	158.0	3.3	152.6	158.3	3.7	149.0	155.4	4.3
FEB									
0.05	13.47	18.83	39.8	11.67	18.44	58.0	9.71	17.47	79.9
0.09	27.84	32.79	17.8	24.34	30.90	26.9	20.12	27.80	38.2
0.18	60.84	65.02	6.9	53.18	59.44	11.8	43.26	50.91	17.7
0.27	103.0	106.5	3.4	88.59	94.76	7.0	70.22	78.01	11.1

* corresponds to the abatement level of 5, 10, 20 resp. 30% reduction in the benchmark with "normal" trade elasticities

** marginal abatement cost in US$/tC

and WEU the effect is larger in the WEU with its larger import share and its larger domestic energy prices. Japan with its import share close to 1 is again a special case, her the magnitude of the shift falls slightly for high trade elasticities and low abatement levels. Summarized we can expect though, that with the increasing globalization that MACCs become less and less robust.

6 Example: Emission trading and the withdrawal of the USA from the Kyoto Protocol

We have seen in the last section that the withdrawal of the USA from the Kyoto Protocol causes a shift in the MACCs in the rest of the world. Now we use this example, to compare the results of a partial equilibrium analysis of international emission trading based on the two different sets of MACCs - the one generated by assuming emission reductions in all Annex B regions including the USA (scenario AXB) and the one generated by assuming emission reductions in all Annex B regions but the US (scenario NOUS). In this example we ignore the issue of hot air and assume that only WEU, JPN and ANC participate in the market for emission permits.

In the first step, using the data from section 3, we estimate MACCs of the form

$$MAC(Q) = aQ^2 + bQ + c$$

were Q is the level of abatement in MtC compared to the benchmark. Note that different from (Ellerman and Decaux 1998) we include a constant c in the equation. The reason is that, compared to the benchmark, energy prices increase and thus "demand" for CO_2 emissions decreases in both scenarios AXB and $NOUS$. Thus, more is emitted without emission restrictions. Table 5 shows the estimated values for the parameters a, b and c in the different scenarios using standard OLS. All parameters are highly significant and the R^2 is in all cases above 0.99. The results show again that with the withdrawal of the USA, the curves shift as explained in section 3: while the parameters a and b hardly vary, the constant c is lower in NOUS.

Table 5: Estimated coefficients for $MAC(Q) = aQ^2 + bQ + c$

	NOUS			AXB		
	a	b	c	a	b	c
WEU	0.001	0.205	12.252	0.001	0.204	18.863
JPN	0.011	0.410	16.484	0.011	0.420	23.511
ANC	0.015	0.620	11.921	0.015	0.615	17.991
USA				0.0004	0.097	13.864

In the second step, we now calculate the permit price and associated abatement levels in the case of emission trading by setting equal all MACCs of the participating countries under the constraint that the sum of all abatements remains the same as under the no trading scenario. The results from this partial equilibrium analysis are shown in table 6 together with the results of using the DART model to simulate international emission trading.

Comparing first the permit prices 1a and 1b and also 2a and 2b, we see that partial equilibrium models cannot capture all effects of emission trading. Still, the calculated permit price deviates only by 2% from the general equilibrium price. More interesting is to compare the prices 2b) and 2c). The permit price in 2b) was calculated using the *correct* MACCs that where generated under the assumption that

Table 6: Permit prices under international emission trading

	Scenario	method of calculation	permit price in US$/tC
1a)	AXB	DART	78.56
1b)		MACCs from AXB	76.94
2a)	NOUS	DART	59.51
2b)		MACCs from NOUS	58.43
2c)		MACCs from AXB	64.97

the USA do not restrict their emissions. 2c) was calculated using the *wrong* MACCs that assumed that the USA fulfill their Kyoto commitment. We see that the difference between the two prices cannot be neglected. In this case it is around 11%. Thus, using the same MACCs for different abatement scenarios does indeed lead to a miscalculation of the permit prices. The abated quantities though, are not much affected. The reason is, that all the MACCs shift by approximately the same amount and without changing the curvature so that all prices fall. Figure 3 illustrates the two cases. The solid curves are the correct MACCs generated under the assumptions of scenario NOUS, the thin, dotted curves are the MACCs generated under the assumptions of scenario AXB. The permit price under emission trading is the MAC at which the sum of the associated abatement levels in all regions equals the sum of the abatement levels of the Kyoto Protocol. The thick line at MAC = 58.4 is the permit price that results under emission trading from the thick set of curves, the thin, dotted line at MAC = 65.0 is the permit price that results from the thin, dotted set of curves. The associated quantities each country is abating can be found at the point where the price line intersects with the MACC of the country. Figure 3 shows that the optimal quantities remain practically the same with the shift of the MACCs.

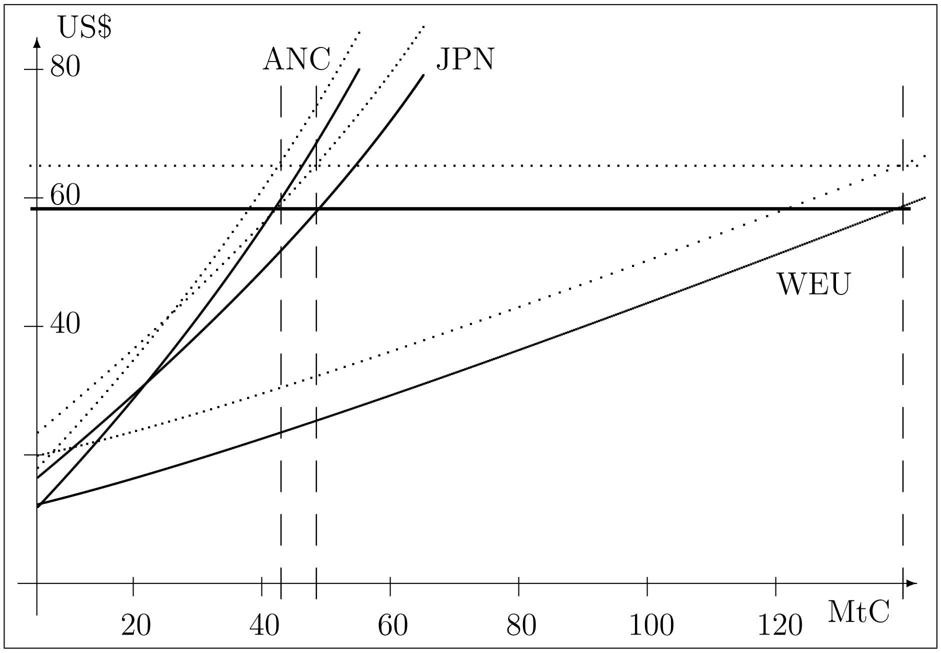

Figure 3: Emission trading equilibria with different MACCs

7 Conclusions

In this paper we have analyzed the dependency of a region's marginal abatement cost curve on the abatement level in the rest of the world. We show that both are linked through world energy prices. When one region increases or decreases its abatement effort, it decreases resp. increases its demand for energy. If the region is large enough, this also significantly affects the world market prices for energy. If prices rise for example, this curbs demand for fossil fuels and thus emissions in other regions. As a result the same reduction target becomes less binding and the marginal abatement costs associated with this target fall. The magnitude of this effect depends on one hand on the magnitude of the induced change in the world market price of fossil fuels and on the other hand the dependence of a country on the world market. The first is influenced by the level of the change in the abatement effort in the country that initiates the changes and its elasticity of energy demand. The second is i.a. determined by the importance of international trade, i.e. the trade elasticities. As one can expect the shift in the MACC is larger the more the country is trading with the rest of the world.

We have quantified the shift in the MACCs for different scenarios and especially for the withdrawal of the United States from the Kyoto Protocol. The results show that energy prices do indeed play a decisive role. The relative difference in marginal abatement costs can be as high as 75% for very low abatement levels. Since after the conferences in Bonn and Marrakech we can expect that the actual Kyoto targets are quite low and thus will be located in a range, where the differences in the MACCs can not be neglected. With the ongoing globalization the shifts will become even stronger so that they can no longer be ignored entirely. This implies that partial equilibrium models that rely on MACCs that have been generated for one reduction scheme produce incorrect results if they are used for other policy scenarios. This paper illustrates how the results can be biased. The direction and the strength of the bias can be used to improve the interpretation of the results of existing partial equilibrium models.

In summary, our results show that marginal abatement costs and marginal abatement cost curves depend strongly not only on factors such as the energy supply structure and the technologies but also on domestic and foreign energy prices which are influenced by the abatement efforts in the rest of the world and the intensity of trade. Hence, regional marginal abatement cost curves are interdependent and policy dependent. For future research it will be interesting to assess the factors that influence marginal abatement costs in more detail and also to compare MACCs from different models.

References

Blanchard, O., P. Criqui, and A. Kitous (2002). After the Hague, Bonn and Marrakech: the future international market for emission permits and the issue of hot air. Cahier de Recherche 27, Institute d'Economie et de Politique de l'Energy, Paris.

Boehringer, C. (2001). Climate politics from Kyoto to Bonn: From little to nothing?!? Discussion Paper 01-49, ZEW, Mannheim.

Boehringer, C. and A. Loeschl (2001). Market power in international emission trading: The impacts of U.S. withdrawal from the Kyoto Protocol. Discussion Paper 01-58, ZEW, Mannheim.

Criqui, P., F. Cattier, P. Menanteau, and M. Quidoz (1996). Poles 2.2 reference guide. Technical report, Institute of Energy Policy and Economics.

Criqui, P., S. Mima, and L. Viguir (1999). Marginal abatement cost of CO_2 emission reductions, geographical flexibility and concrete ceilings: an assessment using the POLES model. *Energy Policy 27*, 585–601.

den Elzen, M. G. J. and S. Both (2002). Modelling emission trading and abatement cost in FAIR1.1. RIVM report 728001/021, Netherland National Institute of Public Health and the Environment (RIVM).

den Elzen, M. G. J. and A. P. G. de Moor (2001). Evaluating the Bonn Agreement and some key issues. RIVM report 728001/016, Netherland National Institute of Public Health and the Environment (RIVM).

den Elzen, M. G. J. and A. P. G. de Moor (2002). Evaluating the Bonn-Marrakech Agreement. *Climate Policy 2*.

Ellerman, D. A. and A. Decaux (1998). Analysis of Post-Kyoto CO_2

emission trading using marginal abatement curves. Report 40, Massachusetts Institute of Technology - Joint Program on the Science and Policy of Global Change.

Ghersi, F. (2001). Sap 12. Technical description, C.I.R.E.D.

Klepper, G., S. Peterson, and K. Springer (2003). Dart97: A description of the multi-regional, multi-sectoral trade model for the analysis of climate policies. Kiel Working Papers, forthcoming, Kiel Institute for World Economics.

Loeschl, A. and Z. X. Zhang (2002). The economic and environmental implications of the US repudiation of the Kyoto Protocol and the subsequent deals in Bonn and Marrakech. Nota di la Voro 23.2002, Fondazione Eni Enrico Mattei.

Lucas, P. L., M. G. den Elzen, and D. P. v. Vuuren (2002). Multi-gas abatement analysis of the Marrakech Accords. Paper prepared for the conference on Global Trading; Kiel 30. September - 1.October 2002.

Steenberghe, V. v. (2002). CO_2 abatement costs and permit's price: Exploring the impact of banking and the role of future commitment. Paper prepared for the conference on Global Trading; Kiel 30. September - 1.October 2002.

Weyant, J. P. (Ed.) (1999). *The cost of the Kyoto Protocol - A multi-model evaluation*. The Energy Journal - Special Issue.