Costs of a Ceiling on Kyoto Flexibility

Dominique Gusbin
CoHerence, Louvain-La-Neuve, Belgium

Ger Klaassen
International Institute for Applied Systems Analysis, Laxenburg, Austria

Nikos Kouvaritakis
IPTS, Seville, Spain

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International Institute for Applied Systems Analysis • Schlossplatz 1 • A-2361 Laxenburg • Austria
Tel: (+43 2236) 807 • Fax: (+43 2236) 71313 • E-mail: publications@iiasa.ac.at • Web: www.iiasa.ac.at

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Costs of a ceiling on Kyoto flexibility

Dominique Gusbin[a], Ger Klaassen[b,*], Nikos Kouvaritakis[c]

[a]*CoHerence, Cour de la Cramignon 2A, B-1348, Louvain-La-Neuve, Belgium*
[b]*IIASA, Schlossplatz 1, A-2361, Laxenburg, Austria*
[c]*IPTS, World Trade Centre, Isla de la Cartuja s/n, E-41092, Seville, Spain*

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Abstract

This paper examines the potential costs of a ceiling on the use of flexibility mechanisms in the Kyoto Protocol using POLES, a partial equilibrium model of the world energy system. The results suggest that if emission trading were restricted to Annex I countries, halving the traded volume would increase costs by 11 billion $/year. If emission trading were to operate at a global level, reducing the trade to half the perfect market volume would increase annual costs by 12 billion $/year. Global carbon emissions might however be 1% lower. The sensitivity of the results is discussed.

Keywords: Climate; Emission trading; Costs

1. Introduction

The Kyoto protocol to the UN-FCCC provides for the use of so-called flexible mechanisms to meet the agreed greenhouse gases reduction commitments (UNFCCC, 1997). These include international emission trading, joint implementation (JI) and the clean development mechanism (CDM). The major advantage of these mechanisms is that they are designed to allow the possibility of meeting the Kyoto commitments at lower costs. The principles, rules and modalities for the use of these mechanisms are however still under discussion. Different perceptions exist between especially the USA on the one hand and notably the EU on the other. One of the most controversial issues is the fact that the EU insists not only that flexibility instruments should be supplemental (that is, domestic actions should provide the main means of meeting the emission reduction commitments) but also that this should be accomplished by a concrete ceiling on the use of these flexibility instruments. Such a ceiling on the transfers of allowed (production) quotas was also originally part of the Montreal Protocol on ozone depleting substances (Klaassen, 1999). So far the USA and its allies, the so-called JUSCANZ group (consisting of Japan, USA, Canada, Australia, Norway and New Zealand as well as the Russian Federation) have fiercely opposed such a limitation on flexibility.

The purpose of this paper is to give a sound quantitative analysis of the potential costs and environmental benefits of introducing a ceiling on trading. For this purpose a new sectoral (or partial equilibrium) model of the world energy system called POLES is used.

The paper has the following structure. Section 2 describes the model and data used. Section 3 introduces the scenarios. Section 4 describes and analyses the results obtained. Section 5 discusses the sensitivity of the results. Section 6 concludes.

2. Methodology: the POLES model

2.1. Introduction

Prospective outlook for the long-term energy system (POLES) is a simulation model for the development of long-term (2030) energy supply and demand scenarios for the different regions of the world (Criqui *et al.*, 1996; European Commission, 1996). The model structure corresponds to a hierarchical system of interconnected modules consisting of three levels: (i) international energy markets; (ii) regional energy balances; and (iii) national energy demand, new technologies, electricity production and primary energy production systems. The main exogenous variables are GDP and population for each

* Corresponding author. Tel.: 0043-2236-807; fax: 0043-2236-71313.
E-mail address: klaassen@iiasa.ac.at (G. Klaassen)

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country/region, the price of energy being endogenised in the international energy market modules. The dynamics of the model correspond to a recursive simulation process in which energy demand and supply in each national/regional module respond with different lag structures to international price variations in the preceding periods (see Fig. 1). In each module, behavioural equations take into account the combination of price effects and techno-economic constraints, time lags and trends.

The remainder of this section will describe the different modules in POLES followed by an explanation of the estimation of pollution control costs with and without ceilings on the volume of emissions traded through the three flexibility mechanisms.

2.2. Description of modules

In the current version of the model, the world is divided into 14 main regions: North America, Central America, South America, European Union, Rest of Western Europe, Former Soviet Union, Central Europe, North Africa, Middle-East, Africa South of Sahara, South Asia, South East Asia, Continental Asia and Pacific OECD. For each region, the model consists of four main modules dealing with: final energy demand by sector, new and renewable energy technologies, the electricity and conventional energy and transformation system and, finally, primary energy supply. Integration of these modules is ensured in the energy markets module of which the main inputs are the import demands and

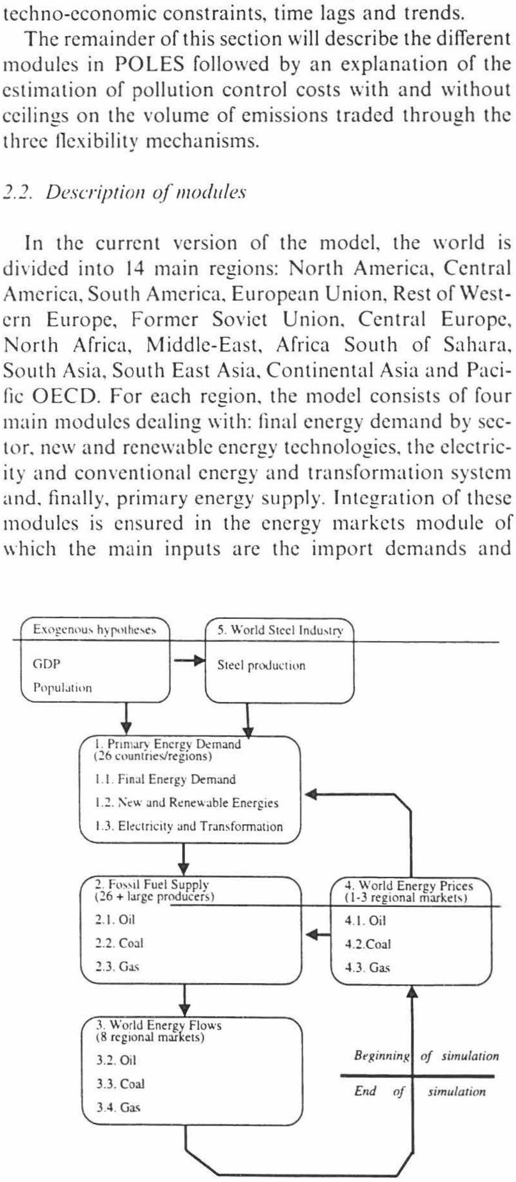

Fig. 1. Schematic overview of the POLES 2 model.

export capacities of the different regions. One world market is considered for the oil market (the "one great pool" concept), while three regional markets (America, Europe and Asia) are distinguished for coal and gas, in order to take into account different cost, markets and technical structures.

Final energy demand simulation combines the impacts of price and activity level changes with autonomous technological trends, at a relatively disaggregated sectoral level. Interfuel substitution equations account for both rigidities implied by existing equipment as well as flexibility in interfuel substitution for new equipment. In the detailed demand model for the main countries or regions, the consumption of energy is disaggregated into 11 different sectors. These sectors are homogenous from the point of view of prices, activity variables, consumer behaviour and technological change. In each sector, energy consumption is calculated separately for substitutable fuels and for electricity. Each demand equation combines income (or activity variable) elasticities, price elasticities, technological trends and, when necessary, saturation effects. The activity variables for each sector are deduced from exogenous assumptions about economic and population growth. Price elasticities are parameterised and the structure of the equations takes account of short- and long-term elasticities, with a distributed lag structure, and of asymmetries in price effects. Price effects thus depend on whether the price to the final user increases or decreases. Quantitative and qualitative analyses are used to incorporate trends or saturation effects.

The new and renewable energy module recognises the difference between technical and economic potentials as well as the time constants which characterise the diffusion processes. At the same time it introduces elements such as "learning-curves" and "niche-markets" which allow for a truly dynamic approach to the development and diffusion of these technologies. The module distinguishes 10 generic technologies which are representative of the solutions to be implemented in different types of countries and might have a non-negligible quantitative contribution in the long-term development of energy systems. The time horizon of the model (2030), in fact, makes it possible to consider that, given their development over time, technologies that might have a significant role over this horizon should today be at least identified and beyond the first stages of development.

The electricity system in any country is not only one of the main energy consuming sectors but probably also the major sector for interfuel substitution. Because of the particularly long lifetime of the equipment, this sector presents a higher price-elasticity in the long-term than in the short term. To reflect the capacity constraints in the production of electricity the module simulates the evolution of existing capacities at each period as a function of equipment development decisions taken in the preceding periods and of the anticipated demand and costs at the corresponding time. The identification of 12 technologies currently accounts for the future development of key technological options in the different regions of the world. The electricity load curve is endogenous and deduced from sectoral demand through the use of load coefficients for two typical days of the year.

Oil and gas production is simulated for each region using a full discovery-process model for the main producing countries and a more compact model for minor producing countries or regions. For each main producing country, the available data cover the estimates of ultimate recoverable resources for oil and for gas, the cumulative drilling and cumulative production since the beginning of oil and gas activity and the evolution of reserves. Cumulative discoveries are then calculated as the sum of cumulative production and remaining reserves. For countries outside OPEC ("the fringe") current production is then deduced from existing reserves through the application of a depletion ratio. OPEC countries act as the "swing producers" and adjust their production level to world demand after taking into account the production of non-OPEC countries. The process is almost similar for natural gas and coal, except that swing producers are identified as the key suppliers on the main regional markets for natural gas and coal: America, Europe and Africa, and Asia. Given the time horizon of the model, reserve constraints will not be effective for coal, and thus coal production is modelled with the use of market shares on the three main regional markets for the large swing producers.

The endogenisation of international energy prices is one of the key features of the POLES 2 model. International price equations are thus at the very heart of the recursive process which accounts for the dynamics of the lagged adjustments of energy demand and supply. The oil price is calculated at the world level; it is considered to depend in the short run on the variations in the capacity utilisation rate of the Gulf countries and in the medium and long run on the world average reserve-to-production ratio. The price of natural gas on each import market depends on the variation in the reserve to production ratio of its "core suppliers" and of the transport cost for the corresponding market. Coal production is essentially demand driven because with the time horizon of the model, coal supply is considered not to be subject to reserve or resource constraints. Variations in the price of coal in some key producer countries reflect increasing supply costs along the expansion path of production. Variations in international coal prices are derived from the variations in the production costs of these key producer countries.

2.3. Estimation of pollution control costs

Estimation of the pollution control costs of meeting the Kyoto Protocol requirements is based on the derivation of regional pollution control cost functions in the POLES model. In practice, this is done by setting different levels of explicit pure carbon taxes in the model and simulating the resulting impacts on regional CO_2 emissions. This makes uses of the equivalence of permit prices and carbon taxes under perfect information on pollution control costs. Fig. 2 shows a set of examples of regional cost functions generated by POLES depicting marginal costs as functions of the (relative) reduction in emissions compared to the reference (or Business-as-Usual) emissions in the year 2010. Total annual pollution control costs can be calculated by taking the integral of the area below the cost function up to the relevant required percentage reduction for each region.

Simulations of the use of emission trading (which is used in the remainder of the paper as shorthand for all the different forms of flexibility in the Kyoto Protocol) are relatively straightforward if the usual assumptions of perfect markets are assumed to be valid. Countries minimize costs, transaction costs and market power are

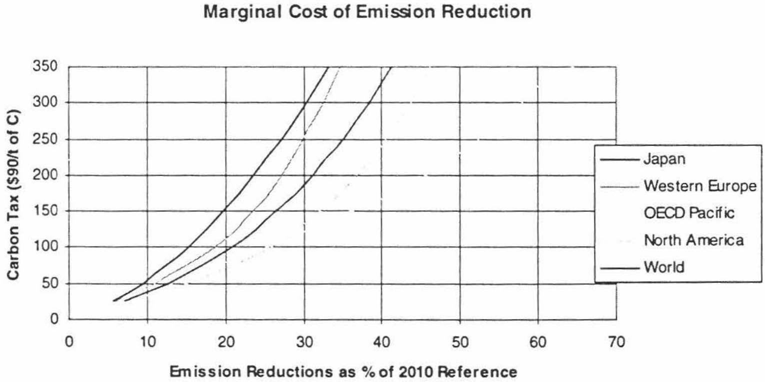

Fig. 2. Examples of regional cost functions.

absent, and information is perfect so that marginal costs are equalized across all countries for meeting a given overall limit (as specified in the Kyoto Protocol) on the greenhouse gas emissions of the countries in question.

How can these regional cost functions now be used to simulate the implementation of a ceiling on the volume of emissions each region can trade (that is buy or sell)? This is related to the way the ceiling is specified. Options under discussion are the specification of a ceiling on the volume of emissions traded as a percentage of the 1990 (base year) emissions, as a percentage of the allocated emission budget in the future (the period 2008–2012) or as a combination of the two. It is sufficient for our analysis that such ceiling on the amount of emissions traded can be translated directly into an additional constraint on the total volume of emissions in each region (after abatement). This implies that the level of emissions has to be in between a certain maximum and a certain minimum level (depending on whether the country would buy or sell emission permits). To give an example, for Japan the Kyoto Protocol mandates a 6% emission reduction for the basket of six greenhouse gases. The analysis in this paper is restricted to CO_2 so we assume that the same reductions apply also for this greenhouse gas separately. This assumption was made because we do not yet know what the "size" of reductions will be for each greenhouse gas in each country. Preliminary data for the EU suggest that this might imply that the costs of meeting the Protocol could be 5–10% higher when possible reductions in the five non-CO_2 greenhouse gases are also taken into account. In view of the projected increase in CO_2 emissions up to the year 2010 the Japanese commitment would, without trading, require a reduction in emissions in 2010 of around 25% relative to the projected business-as-usual level (or a marginal cost of around 225$/ton C, see Fig. 2). With full trade globally (no restriction whatsoever) Japan would buy emission reductions somewhere else and would reduce domestic emissions only 5% below its business-as-usual (BAU) level for 2010 at a cost of around 25 $/ton C (see Fig. 2). Setting a ceiling on the volume of emissions traded of, for example, 10% of the 1990 emissions would for Japan imply (given the expected BAU 2010 emissions) that its domestic emissions should be at least 13% lower than its 2010 BAU level. The cost functions generated by the model then immediately allow us to calculate the corresponding marginal cost (which is around 80 $/ton carbon in Fig. 2 for this specific Japanese example). In view of the assumed perfect knowledge of the 2010 BAU emissions it is thus straighforward to translate ceilings on the volumes of emissions traded into additional constraints on the domestic level of emissions.

Less obvious is what happens to the permit price in the case of restrictions on the volumes of emissions traded. This is so since the ceiling would create a wedge between the price the buyer is willing to pay for a permit and the

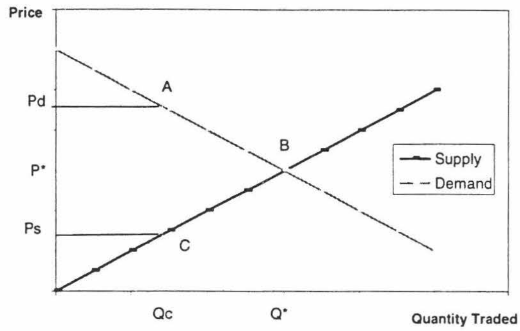

Fig. 3. A ceiling on emission trading.

minimum asking price (reflecting the marginal costs) of the seller. Fig. 3 illustrates this. The figure depicts the demand and supply of permits. Demand and supply functions reflect the (marginal) cost functions of the regions. Whether countries end up on the buyer (demand) side or the supply side is determined by their cost functions and the initial distribution of permits as settled in the Kyoto Protocol. With a perfect permit market the equilbrium price would be P^* and the equilibrium amount of emissions traded would be Q^*. If a ceiling would restrict the traded amount to Q_c, the price would end up between the maximum price (P_d) that prospective buyers would be prepared to pay and the minimum price the sellers would be asking (P_s). The welfare loss in this case would be equal to the additional pollution control costs and would be equal to the area *ABC*. In this particular case the situation is somewhat more complicated since it is not the total volume of emission permits that is restricted but the individual demands and the individual supplies. It is also not yet clear whether in practice only demands will be restricted, which might be more in line with the notion of supplemental in the Protocol, or also supplies of countries. We will return to this issue in detail in the discussion section. This shows that determining an equilibrium price in this situation is not straightforward and the model results can only be used to suggest a price range (as in Fig. 3). Fig. 3, however, shows that this only affects the distribution of the potential welfare losses of a ceiling since the overall losses are known and equal to the area *ABC*.

3. The scenarios

3.1. Introduction

The reference scenario for the current analysis is the POLES Business-as-Usual (BAU) scenario for the year 2010 without constraints on greenhouse gas emissions.

The POLES BAU scenario was revised in March 1998 to align the predictions for the Former Soviet Union (FSU) with recent IEA energy forecasts (IEA, 1997).

According to the BAU scenario, CO_2 emissions are expected to increase in 2010 by 15.5% in the EU, by 13% in Annex I countries, and by 51% worldwide compared to 1990 levels. CO_2 emissions in those countries of the Former Soviet Union which are in Annex I (industrialised countries with an emission reduction commitment under the Kyoto Protocol) would decline by about 25% between 1990 and 2010 without any additional action due to economic restructuring. The BAU scenario includes energy price increases in the framework of the overall price reform in Russia and Ukraine. This emission reduction without explicit climate policy (but definitely not without costs in view of the underlying reductions in GDP in the FSU) is called surplus emissions by some and "hot air" by others.

In the geographic disaggregation of the POLES model, the world is divided into 14 main regions, some of them being further divided into sub-regions, i.e., countries or group of countries. Some Annex I countries that are combined in POLES sub-regions (e.g., Australia, New Zealand, Poland, Hungary, Czech Republic and Slovakia; Romania, Bulgaria, Slovenia and Croatia) may have different quantified emission limitation or reduction commitments under the Kyoto Protocol. For this reason the Kyoto reduction commitments for POLES sub-regions are determined on the basis of individual countries' commitments using their respective contributions to the 1990 CO_2 emissions of the sub-region. The Former Soviet Union (FSU) region gathers together Annex I and non-Annex I countries (developing countries without an emission reduction commitment). In this case, the Kyoto commitment is only applied to a percentage of FSU emissions determined on the basis of 1994 CO_2 emissions of Annex I countries, namely Russia, Ukraine, Latvia, Lithuania and Estonia. These five countries represent approximately 75% of total FSU emissions of CO_2.

3.2. The emission trading scenarios

Five different emission trading schemes or scenarios were designed that reflect how the ceiling on flexibility mechanism is filled in. The ceiling could pertain to all flexibility mechanisms: emission trading, JI and CDM. In this case the ceiling should be applied in a global context since CDM basically allows for flexibility between Annex I and non-Annex I countries. The ceiling could also relate to emission trading and joint implementation only and would then affect trading within the group of Annex I countries only.

All emission trading scenarios take the Kyoto targets of Annex I countries as the basis. The trading of surplus or "hot air" emissions was not excluded, so that Russia and Ukraine can sell emission permits equivalent to the difference between their Kyoto targets and the level of their emissions expected under the Business-as-Usual scenario. For the global trading case we assume that the worldwide level of CO_2 emissions in 2010 under the trading regime is equal to the sum of the Kyoto commitments for Annex I countries (overall reduction of 5.2%) and the Business-as-Usual emission levels for non-Annex I countries.

The emission trading scenarios are briefly described below:

1. The Kyoto Protocol without trading.
2. Full-trade across Annex I only. This scenario assumes the establishment of emission trading (including JI) among all Annex I countries without any ceilings on the use of flexibility instruments.
3. Half-trade among Annex I. This scenario assumes a ceiling operating on all flexibility mechanisms simultaneously among all Annex I countries: the traded volumes resulting from the full-trade scenario are reduced to half. It assumes that both buyers and sellers are restricted in transferring the amounts they wanted, for example by restricting the volumes bought and sold to a certain percentage of either their 1990 emissions or their emission reduction commitment made for the period 2008-2012.
4. Full-trade worldwide (Annex I and others). This scenario assumes the establishment of emission trading (including JI and CDM) among all countries of the world, without any ceilings on the use of flexibility instruments.
5. Half-trade worldwide. This scenario also retains the assumption of halving the trade volumes as in Scenario 2, but among all countries. The traded volumes resulting from the full-trade scenario (number 3) are reduced to half.

4. The results

4.1. Introduction

The POLES model provides the elements for an economic evaluation of the Kyoto emission limitation scenario and of various forms of CO_2 emission trading. These elements include the emissions before and after trade in each country/region, the volumes traded, marginal abatement costs and total abatement costs in each country/region with and without trade, permit prices, and the total expenditures for each country/region in absolute figures and as percentages of GDP in 2010.

If the Kyoto Protocol did not allow any of the flexibility mechanisms (the no trading case) the overall effect of the Kyoto targets would be a global reduction of CO_2 emissions in 2010 by 10% (20% in Annex I countries) compared to the BAU scenario. In Annex I, CO_2

emissions would be 10% below the level of 1990. This is a higher reduction than the Kyoto commitment of reducing overall emissions by 5.2%. This results from the fact that, in this scenario, some Annex I countries (in particular Russia and Ukraine) would not be able to trade the difference between their baseline emissions and their Kyoto targets (the surplus). The order of magnitude of these surplus emissions is estimated to be slightly less than one-fourth of the overall reduction in the other Annex I countries (or 217 Mton C see Table 1 column "2010 Bau" and column "2010 Kyoto Protocol").

The total and marginal costs of meeting the Kyoto commitments without trading vary widely from one country to another. The total costs of reduction are the highest in Japan, the United States and Australia/New Zealand (0.3, 0.35 and 0.2% of GDP in 2010, respectively). They are on the order of 0.1% of GDP in Canada and the European Union, and zero or close to zero in the other Annex I countries. The marginal costs of reduction are comparable in Canada, the EU, Australia/New Zealand and the USA (in the range of 90–110 $/t C), but far higher in Japan (245 $/t C). For Annex I as a whole, the average cost of reduction is estimated at 0.2% of the GDP in 2010. The significant differences in marginal costs suggest that there are large potential gains from emission trading.

4.2. A ceiling on emission trading among Annex I countries

Emission trading (including joint implementation) could be restricted to Annex I countries. This could de facto be the case if the practical use of the Clean Development Mechanism were restricted, for example, because of high transaction costs related to the estimation of baseline emissions. This might be so since the CDM would allow Annex I countries to buy reductions in non-Annex I countries that have no agreed emission target under the Protocol and the emission reduction credits obtained would require case-by-case approval. Experience in the USA suggests that this might severely limit trading (Klaassen, 1996). Assuming trading to be restricted to Annex I countries, trading would tend to be supplemental for most countries and for Annex I countries as a whole. The acquisitions of emission reductions would represent 25% of required emission reductions in 2010 for the EU, 37% for the USA and 68% for Japan (see Table 1). About 63% of total Annex I acquisitions would be "hot air." The sellers of permits are Central European

Table 1
Emissions and acquisitions with trading among Annex I

	Emissions (Mton C)					Acquisitions (Mton C) + (buys)-(sells)		Acquisitions (+) as % of required reduction		Trade as % of 1990 emissions	
	1990	2010 BAU	2010 Kyoto protocol	2010 Full-trade	2010 Half-trade	2010 Full-trade	2010 Half-trade	2010 Full-trade	2010 Half-trade	2010 Full-trade	2010 Half-trade
Canada	125	143	117	125	121	8	4	29	15	6	3
Visegrad 4 ([a])	180	175	168	149	159	− 19	− 10			11	5
European Union	946	1093	870	925	898	55	28	25	12	6	3
Russia, Ukraine, Baltics	804	587	804	490	587	− 315	− 157			39	20
Japan	319	398	300	367	334	67	33	68	34	21	10
Rest of Cent. Europe in An.B	73	68	68	57	62	− 11	− 5			15	7
Australia, New Zealand	83	119	89	96	93	6	3	21	11	8	4
United States	1411	1870	1312	1521	1417	209	104	37	19	15	7
Total Annex I	3941	4454	3729	3729	3669	0	0				
in % of 1990		113	95	95	93						
Rest of the World	2111	4711	4711	4711	4710						
World	6052	9164	8440	8439	8380						
in % of 1990		151	139	139	138						

[a] Poland, Hungary, Slovakia, Czech Republic.

countries and in particular Russia/Ukraine. They would contribute, respectively, 9 and 91% to the volumes traded. The parties' acquisitions would constitute around 9% of total Annex I CO_2 emissions in 1990.

Restricting the scope of emission trading to Annex I countries only obviously results in lower cost savings than worldwide trading (see next section). Nevertheless, at nearly 23 billion $ per year, the potential costs are still significantly lower than the costs (54.5 billion $/year) of a Kyoto Protocol with no trading whatsoever (Table 2, columns 2 and 3). Total cost savings in Annex I are estimated at 58% of the total costs of the Kyoto Protocol without emission trading. Cost savings vary across Annex I countries. Small costs savings are foreseen for Canada and Australia/New Zealand (i.e., a decrease in the total reduction cost by less than 6% compared to the "no trading" scenario). Moderate cost savings are expected for the EU and the USA (a cost decrease of around 15%), but significant cost savings are projected for Japan (a cost decrease of around 50%). Net revenues are predicted for Central Europe and the FSU. The permit price was estimated at 66.5 $/t C.

The total reduction effort of Annex I was estimated at 0.09% of the Annex I GDP in 2010, compared to around 0.2% of GDP without emission trading. Again, cost savings include the revenues of sales of surplus emissions by Russia and Ukraine; they represent 45% of the total cost savings.

What would happen now if emission trading were restricted by means of a ceiling? The objective of this scenario is to evaluate the impact of specific ceilings on the amount a country can acquire or transfer through trading to ensure that trading is supplemental to domestic actions. The ceiling on trade is defined as follows: the emission permits an Annex I country can acquire from or transfer to another Annex I country are limited to half the volume traded without any restrictions on trading (i.e. in the full-trade scenario across Annex I only).

The results of this scenario are compared to the results of the full-trade scenario across Annex I only. The first impact of the restriction on trade — that is, in fact, the objective of the constraint — is to increase the contribution of domestic action. Parties' acquisitions would now represent less than 20% of their required reductions in 2010 (Table 1, column 10) with the exception of Japan where they still are expected to represent 35% (in the full-trade scenario, parties' acquisitions ranged from 20% to around 70%). Compared to the emission reduction efforts in 2010 acquisitions would be less important (thus "supplemental") than domestic action in every region. Compared to the 1990 emission levels, acquisitions would vary between 8 and 15%. It is clear that any suggestions to limit acquisitions to 5 or even 2.5% of the 1990 emissions would incur even higher cost penalties.

Reducing the traded volume to half would increase annual costs for the Annex I countries by 50% (from 22.7

Table 2
Costs of emission reduction in 2010 with trading among Annex I

	Costs of reduction (in mil $1990) Costs of domestic reduction			Expenditures on acquisitions	Total costs of red.	Costs of reduction as % of GDP 2010 Costs of domestic reduction			Total expenditures
	No trade	Full-trade	Half-trade	Full-trade	Full-trade	No-trade	Full-trade	Half-trade	Full-trade
Canada	1168	631	907	512	1143	0.145	0.078	0.113	0.142
Visegrad 4 (ᵃ)	37	859	350	− 1263	− 404	0.006	0.140	0.057	− 0.066
European Union	10423	5146	7203	3664	8810	0.123	0.061	0.085	0.104
Russia, Ukraine, Baltics	0	2830	0	− 20934	− 18104	0.000	0.144	0	− 0.920
Japan	11432	970	4715	4436	5405	0.311	0.026	0.128	0.147
Rest of Cent. Europe in An.B	1	338	79	− 712	− 373	0.000	0.136	0.032	− 0.150
Australia, New Zealand	1263	763	987	419	1182	0.209	0.126	0.163	0.196
United States	30211	11184	19374	13872	25056	0.355	0.131	0.227	0.294
Total Annex I	54535	22721	33613		22721	0.219	0.091	0.135	0.091
Cost savings in %		58%	38%		58%				
Permit price in $ (price level 1990) tC					66.5				

ᵃPoland, Hungary, Slovakia, Czech Republic.

to 33.6 billion $/year); a cost increase of nearly 11 billion $/year compared to the full-trade case. The estimation of annual expenditures (domestic pollution control costs plus the net payments for permit acquisitions) for each Annex I country is not straightforward. Whereas the model provides the impact of restrictions on trading on the costs of reduction realised domestically, it cannot deal with the impact on expenditures on permit acquisitions because there is no proper market clearing price for emission permits when ceilings are imposed. It can be assumed that emission trading will take place at a price somewhere between the lowest bid (78 $/t C) of the bids of the acquiring regions and the highest minimum asking price (42 $/t C) (reflecting the minimum marginal costs of reduction) of the group of supplying countries. If the price were higher than 78 $/t C some countries would find it cheaper to reduce more emissions domestically rather than to buy emission reductions abroad. If the price were lower than 42 $/ t C some regions would not be prepared to offer emissions reductions for sale since the price would not cover their marginal costs. Given this range between asking and offered prices it is also not clear whether the price will be higher or lower than the price of 66.5 $/ton C obtained under the no ceiling case.

With this ceiling on both sellers and buyers, global CO_2 emissions would be 1% lower (2% lower in Annex I) since part of the "hot air" or surplus cannot be sold. Overall global emissions would be around 60 Mton C lower than under the Kyoto Protocol without trading since the FSU and Central and Eastern Europe are now not allowed to sell all the surplus emission reductions that will occur in the BAU case. Part of these surplus reductions is now no longer available to allow buyers to increase their emissions above the agreed Kyoto targets.

4.3. *A ceiling on all three flexibility mechanisms worldwide*

In this scenario emission trading is assumed to take place both between Annex I and non-Annex I countries as well as among Annex I and non-Annex I countries. This implies that if we assume a ceiling on the three flexibility mechanisms (emission trading, joint implementation and CDM) it applies to the sum of the acquisitions acquired (for the buyers) and to the sum of the transfers (for the sellers) through all flexibility mechanisms taken together.

If we assume no constraint whatsoever, the model results show that without any ceiling (full trade), and assuming a perfect permit market, the overall result is that the Annex I region as a whole would be a net buyer of emission permits (around 437 Mton C). Non-Annex I would be a seller of permits (see Table 3, column seven, labelled "Full trade").

Table 3
Emissions and acquisitions with worldwide emission trading

	Emissions (Mton C)					Acquisitions (Mton C) + (buys)-(sells)		Acquisitions (+) as % of required reduction		Trade as % of 1990 emissions	
	1990	2010 BAU	2010 Kyoto protocol	2010 Full-trade	2010 Half-trade	2010 Full-trade	2010 Half-trade	2010 Full-trade	2010 Half-trade	2010 Full-trade	2010 Half-trade
Canada	125	143	117	138	127	20	10	78%	39%	16%	8%
Visegrad 4 ([a])	180	175	168	166	167	– 2	– 1			1%	1%
European Union	946	1093	870	1025	948	155	78	70%	35%	16%	8%
Russia, Ukraine, Baltics	804	587	804	542	587	– 262	– 131			33%	16%
Japan	319	398	300	386	343	85	43	87%	44%	27%	13%
Rest of Cent. Europe	73	68	68	63	65	– 5	– 2			6%	3%
Australia, New Zealand	83	119	89	110	100	21	11	70%	35%	25%	13%
United States	1411	1870	1312	1737	1525	424	212	76%	38%	30%	15%
Total Annex I	3941	4454	3729	4166	3861	437	219	60%	30%	11%	6%
in % of 1990		113	95	106	98						
Rest of the World	2111	4711	4711	4273	4492	– 438	– 219				
World	6052	9164	8440	8439	8353	0	0				
in % of 1990		151	139	139	138						

[a] Poland, Hungary, Slovakia, Czech Republic.

If trading were to take place worldwide, again assuming a perfect competitive market without transaction costs, it would not necessarily be supplemental to domestic action. The trade between Annex I and non-Annex I represents more than 50% (to be precise 60%) of total reductions required in Annex I countries in 2010. This implies that on average domestic actions from the buying Annex I parties would be less than 50%. This seems at odds with the notion of supplemental. Furthermore, as emission trading also takes place within Annex I, acquisitions of emission permits by individual Annex I countries could make up to 90% of the required emission reduction in 2010 (70% for the EU, 87% for Japan and 76% for the USA). Within Annex I, the sellers are Central European countries and Russia/Ukraine, which contribute respectively to 3% and 97% of the trade. The permit price for such worldwide free emission trading was estimated at 24 \$/t C.

The potential cost savings of such global emission trading, compared to a protocol without trade whatsoever, would be significant: 84% at the world level, 75% for Annex I and 56% for the EU (Table 4). Part of the Annex I cost savings results from the revenues of sales of surplus ("hot air") emissions by the FSU; these savings represent slightly more than 10% of the estimated potential cost savings. At the world level, the total reduction effort is estimated at 0.02% of the world GDP in 2010, compared to 0.1% in the "no trading" scenario. For Annex I, efforts are estimated at 0.06% of the Annex I GDP in 2010, compared to 0.2% in the "no trading" scenario. For the EU, costs as a percentage of GDP would be reduced by half, from 0.1% of the EU GDP in 2010 to 0.05%.

Let us assume that under the ceiling on flexibility countries can only trade half of what they would have traded under the perfect competitive full-trade case. In practice this implies that we set a country-specific ceiling on the volume of emission permits each party can buy either as a percentage of its 1990 (base year) emissions or its emission reduction commitments under the Kyoto Protocol (or a combination of both). This makes sense since setting a uniform ceiling (as a percentage of 1990 emissions) would tend to penalise some countries (e.g., Japan) more than others and would likely be politically

Table 4
Costs of emission reduction in 2010 with worldwide emission trading

	Costs of reduction (in mil \$1990)					Costs of reduction as % of GDP 2010			
	Costs of domestic reduction			Expenditures on acquisitions	Total expenditures	Costs of domestic reduction			Total expenditures
	No trade	Full-trade	Half-trade	Full-trade	Full-trade	No trade	Full-trade	Half-trade	Full-trade
Canada	1168	70	476	490	560	0.145	0.009	0.059	0.070
Visegrad 4 ([a])	37	85	61	− 58	28	0.006	0.014	0.014	0.005
European Union	10423	822	3793	3722	4544	0.123	0.010	0.045	0.054
Russia, Ukraine, Baltics	0	480	0	− 6286	− 5805	0.000	0.024	0	− 0.295
Japan	11432	144	3281	2047	2191	0.311	0.004	0.089	0.060
Rest of Cent. Europe in An.B	1	57	18	− 110	− 53	0.000	0.023	0.007	− 0.021
Australia, New Zealand	1263	108	512	504	612	0.209	0.018	0.085	0.101
United States	30211	1702	10934	10186	11887	0.355	0.020	0.128	0.140
Total Annex I	54535	3468	19075	10495	13963	0.219	0.014	0.077	0.056
Cost savings in %		94%	65%		74%				
Rest of the World	0	5076	1244	− 10495	− 5419	0	0.019	0.005	− 0.020
World	54535	8544	20319		8544	0.104	0.016	0.039	0.016
Cost savings in %		84%	63%		84%				
Permit price in \$ (price level 1990) tC					24				

[a] Poland, Hungary, Slovakia, Czech Republic.

unacceptable. A differentiated percentage is more in line with the differentiation of emission reductions already included in the Protocol itself.

The results of this scenario are compared to the results of the full-trade scenario worldwide. With the specified restrictions on trading, trading would become supplemental (more than 50% of the overall reductions required in 2010 in Annex I would be done domestically). Table 3 (in particular column 10 labelled "Half-trade") shows that all regions would acquire less than 50% of their needed emission reductions relative to the BAU case in 2010.

If trading were to take place worldwide, reducing the traded volumes to half would mean that annual costs would be more than twice as high (or 12 billion $/year) at the world level. Global pollution control costs would increase from 8.5 to 20.3 billion $/year. If we look at the domestic pollution control costs only (without the expenditures on emission trading or emission permits) cost increases would be significant in Japan (more than a factor of 20 higher), followed by Canada, USA, Australia, New Zealand and the EU (around a factor five higher).

As in the case of a ceiling on trading in Annex I countries, it is not possible to fix the equilibrium permit price. There is a gap between the willingness to pay of the buyers (at most 54 $/ton C) and the marginal costs of the suppliers (at least 21 $/ton C).

As a result of this limit on the volume traded, global CO_2 emissions would be 1% lower (7% lower in Annex I) than in the Kyoto Protocol with full trading since part of the "hot air" cannot be sold. Total global emissions are around 87 Mton C lower. A quick calculation shows that the implicit benefit needed per ton of carbon to outweigh the additional costs of this restriction on the flexibility mechanism would be around 135 US$/ton carbon. This appears to be an implicit benefit (or avoided damage cost) estimate which is in the higher part of the estimates (0.3 to 221 $/ton C) reviewed by the IPCC and above the average or most likely estimates that they collected (Pearce *et al.*, 1996, p. 215). It appears that the same benefit, achieved in this calculation by putting a ceiling on the flexibility mechanisms, could have been obtained at less cost by agreeing on lower initial emission ceilings in the Kyoto Protocol while maintaining full flexibility. One could also suggest, however, that if flexibility is constrained marginal costs would be higher than the marginal benefits of the Protocol and the targets of the Kyoto protocol are inefficient and should be revisited.

5. Discussion

A number of assumptions might have an important impact on the results obtained: the specification of the ceiling, the estimate of the level of surplus emissions in the Former Soviet Union, market power, transaction costs, banking and the assumptions on cost-minimising behaviour.

The way the ceiling is specified in the model calculations implies that the ceiling applies to both buyers as well as sellers. The ceiling could also take the form of a limit only on the volume of permits each buyer could obtain and not on the volumes sellers can transfer. In this case one would expect two important impacts. First, pollution control costs and permit prices would tend be lower since this design would not artificially limit the number of relatively cheap emission reductions that countries in the FSU and Eastern Europe could offer. For example, Table 3 shows that in the half-trade case acquisitions from Russia, Ukraine and the Baltic States would be restricted to 131 Mton C. Without restriction on the volume sold by each individual seller this amount would certainly be higher. This is so because the surplus emissions (the "hot air") that are available at zero marginal costs in these FSU countries would be at least 215 Mton C. Second, this implies that the 1% reduction in overall carbon emissions expected in the case of a ceiling on both buyers and sellers would also be smaller if not fully absent. This is so since a bigger part of these surplus emissions, if not all, would now be sold to reduce emissions elsewhere since these are the cheapest reductions.

The estimates of the surplus emissions in the FSU are uncertain since future emissions are inherently uncertain. A comparison with emission estimates of a recently completed IIASA-WEC study (Nakicenovic *et al.*, 1998; Victor *et al.*, 1998) suggest that the size of the surplus emissions in Russia and the Ukraine might vary between 2 and 223 Mton C in 2010. The lower value would occur under a high growth, coal intensive scenario. The higher value would apply for a modest growth case, which in the reviews of the IIASA-WEC study was believed to be the most likely variant for the FSU (Victor *et al.*, 1998). The higher value of 223 Mton C corresponds very well to the estimates of 227 Mton C used in the POLES model runs. The overall emission estimates for Annex I countries under the BAU case are also quite similar to the modest growth scenario of the IIASA-WEC study but lower than the high growth case. This would point in the direction of possibly higher costs of meeting the Kyoto Protocol and also suggest a higher potential cost penalty for putting a ceiling on emission trading among Annex I countries. Emission estimates for non-Annex I countries in the IIASA-WEC study are systematically lower than those in the POLES model. This suggests that these countries might have less cheap carbon emissions for sale than expected in the POLES model, again driving up the price. In conclusion, for high growth scenarios, the potential cost penalty of a ceiling on emission trading might be higher than the POLES model shows.

Market power might be an issue of importance certainly if emission trading were restricted to Annex I countries. With trade limited to Annex I, Russia might be supplying 70% of the emission permits (compared to 45% in the worldwide trading case). This might lead to monopoly behaviour and a limitation of the volume of permits supplied in an attempt to drive up their price. This would thus have a similar effect as a ceiling on the volume of emissions traded (amounting to a ceiling of the emissions up for sale). Similar to the theory on exhaustible resources (Dasgupta and Heal, 1979) the monopolist might thus turn out to be the environmentalist's friend since this would imply that the surplus emissions offered for sale would be reduced and global carbon emissions would be lower.

Transaction costs also work in the same direction as a ceiling on trading since they drive a wedge between the prices the supplier receives and the buyer is prepared to pay. The actual effect will depend on the form the transaction costs take (fixed, variable, etc.) (Stavins, 1994) and their levels. This might limit trade in practice and thus restrict the potential losses of setting a ceiling on the volume traded.

An additional issue of importance is that of banking. The Kyoto Protocol allows the banking of emission reductions below the required emission reductions in the first commitment period (2008–2012). This has not been taken into account in the model runs. Experience with the sulfur trading program in the USA (Klaassen, 1996) as well as theory suggests that banking is likely to occur. Over time the demand for permits is likely to increase since Business-as-Usual emissions are expected to increase further in 2020 and beyond (Nakicenovic *et al.*, 1998). Given a reduction similar to that in the Kyoto Protocol, emission reduction efforts will have to be strengthened and marginal costs will tend to be higher. If Kyoto commitments are strengthened, as is not uncommon with international environmental agreements, this upward pressure on (future) marginal costs will increase and, other things being equal, banking will increase. This implies that the cost penalty of putting a ceiling on emission trading (if this is fixed to 1990 emissions or the Kyoto commitments) might not be so high since the volume traded in the first period would be lower anyway because of banking.

Finally, an issue of relevance is the assumed cost minimising behaviour of the regions. It might be so that countries do not minimise costs but maximise benefits. In this case they would also account for any secondary benefits (in the form of reduced particulate or sulphur emissions for example) that domestic emission reductions would tend to have as advantages over reductions in other countries. If these domestic (marginal) benefits are positive this implies that the demand for emission trading would be smaller (a downward shift in the demand curve in Fig. 3). On the other hand, if these benefits also occur in countries supplying permits, the supply might also increase (since the net marginal costs of supply would be lower because of the domestic benefits) (an upward shift in the supply curve in Fig. 3). The net effect of this will then depend on the extent of the (secondary) benefits and their valuation in each region.

In summary it appears that a different ceiling specification (only buyers and not sellers restricted), market power, transaction costs and banking suggest that the potential cost penalty of a ceiling on emission trading might be smaller than the model calculations suggest. Uncertainty on future emissions points to perhaps higher costs than expected. Putting a ceiling only on the buyer side is (like monopoly power) likely to imply lower environmental benefits than the simulation model results suggest. The effect of including (secondary) benefits in the behavioural assumptions is ambiguous.

6. Concluding observations

This paper examined the potential costs and benefits of a specific ceiling on the use of the Kyoto flexibility mechanisms by both sellers and buyers, to ensure that these flexibility mechanisms are supplemental to domestic action.

The results suggest the following conclusions if trading is restricted to Annex I.

- Even without constraints on emission trading, trading might be supplemental except for one region (Japan);
- Reducing the traded volume in Annex I by half would increase annual total Annex I costs by 50% (or 11 billion \$/year). On the other hand, global emissions would be 1% lower since part of the surplus emissions ("hot air") cannot be sold.

If trading were to take place worldwide, the main findings are the following:

- Without restrictions on the use of flexibility mechanisms trading would not necessarily be supplemental. Acquisitions could constitute up to 90% of the reduction in 2010.
- Reducing the traded volume to half the volume traded in a competitive market would make the worldwide trading supplemental. However, the price to be paid is a doubling of the annual reduction costs (by 12 billion \$(1990)/year). Global emissions would be 1% lower since part of the "hot air" cannot be sold.

Discussion of the sensitivity of these results suggests that a different ceiling specification (only buyers and not sellers restricted), market power, transaction costs and banking might imply that the potential cost penalty of a ceiling on emission trading might be smaller than the model calculations suggest. Uncertainty on future emissions points to perhaps higher costs than expected.

The effect of including (secondary) benefits in the behavioural assumptions is not straightforward. Putting a ceiling on the buyer side only is (like monopoly power) likely to imply lower environmental benefits than the simulation model results suggest. This implies that not only the level of the ceiling but also its design matter for welfare losses.

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