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GLOBAL TRADEABLE CARBON PERMITS, PARTICIPATION INCENTIVES, AND TRANSFERS

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1. Introduction

THIS PAPER examines the feasibility of alternative tradeable permits regimes to stabilize global carbon dioxide emissions at their 1987 level by the year 2000.[1] An optimal policy response to global climate change would be a cooperative agreement in which each country reduces emissions until the marginal costs of reductions for each country are equal to the sum of marginal benefits of reductions across all countries (Hoel, 1990; 1991a, b). However, reliable estimates of marginal benefits of greenhouse gas reductions are simply not available, and therefore, one can only strive for cost efficiency in meeting emissions targets. Some countries may consider the costs of greenhouse gas reductions to exceed potential benefits and therefore may not be willing to participate in a treaty unless suitably compensated. Furthermore, a treaty must also address the free rider problem.

Most OECD countries are committed to stabilizing their carbon emissions at 1990 levels by the year 2000, and some to reduce emissions to 80–60% of 1990 levels by the year 2005 or 2010. However, most non-OECD countries are reluctant to reduce emissions to combat global climate change, arguing instead that such policies would forestall their development and that the stock of greenhouse gases in the atmosphere is primarily due to historical emissions from OECD countries and the former Soviet Union, and it is they who should be made to bear the costs of such abatement policies.

This paper evaluates alternative permit allocations for a global tradeable permit regime that minimizes costs of stabilizing world carbon emissions from fossil fuel combustion at 1987 levels by the year 2000. Particular attention is paid to the issue of inducing broad participation in a treaty. Alternative permit allocations are evaluated in terms of costs or benefits of participating in a global permit system as well as efficiency gains of inducing broader participation. The paper is organized as follows. Section 2 is concerned with current and projected carbon emissions. Section 3 details marginal cost functions and determination of equilibrium permit prices. Section 4 evaluates the costs and benefits of alternative permit allocations and incentives to participate in an international treaty. A final section summarizes main conclusions.

[1] According to Nordhaus (1991a), carbon dioxide emissions are responsible for about 80% of global warming potential associated with the accumulation of all greenhouse gases in the atmosphere.

2. Current and projected carbon emissions

The sample countries were selected on the basis of their share of world emissions, *per capita* emissions, and/or their emissions per dollar of GDP in order to have a diverse representation. Nine lower income, five middle income, four emerging market economies, all 24 OECD countries are included (see Table 1).[2] The sample countries accounted for almost 90% of world carbon emissions from fossil fuel combustion in 1987. The shares of world emissions from the OECD countries and the non-OECD sample countries were about 46% and 43% respectively. The remaining non-OECD countries are aggregated and presented as the 'rest of world'. The share of world emissions is as high as 10% for China, 18% for the former Soviet republics (12% for Russia), and 22% for the United States. *Per capita* emissions vary from 30 kg in Bangladesh to 5,930 kg in Luxembourg. Emissions per dollar of GDP vary from 0.06 kg in Switzerland to 2.06 in North Korea.

Projections of carbon emissions to the year 2000 for the same sample countries are presented in Table 2. Total world carbon emissions from fossil fuel combustion are projected to be 36% higher in year 2000 relative to the 1987 emission level. This implies an average annual growth rate of 2.4%. The share of world carbon emissions for the OECD countries are relatively unchanged from 1987. However, China's share of world carbon emissions are projected to increase from 10% to 14%. Emissions shares in most of the other low and middle income countries are also projected to increase significantly. Former Soviet republics' share is projected to decline from 18% to 13% as a result of economic restructuring. Emissions shares are also projected to decline in the eastern european countries. Carbon emissions *per capita* are projected to increase from 1,112 kg to 1,254 kg for the world as a whole, while emissions per dollar of GDP are projected to decline from 0.34 to 0.31 as a result of increased efficiency in energy use.

3. Marginal cost functions and equilibrium permit price

The purpose of a tradeable emissions permit regime is to limit aggregate emissions to a targeted level. We consider the year 2000 to which carbon emissions are projected as a baseline scenario of business as usual. The equilibrium permit price in the year 2000 is determined by the aggregate permit level (world emissions in 1987) and the marginal cost function of emission reductions in each country.[3] At the present time, country specific marginal cost functions are not available for most non-OECD countries. Even for OECD countries estimated cost functions are mostly based on different models and

[2] Some of these countries no longer exist, i.e. the Soviet Union, Yugoslavia and Czechoslovakia.

[3] See Koseobud *et al.* (1991), Quinn *et al.* (1992), and South *et al.* (1991) for a discussion and estimates of walfare gains of initial allocations of multiperiod undated permits to allow intertemporal efficiency.

TABLE 1
Carbon emissions and GDP data for selected countries—1987

	GDP per capita (US $)	Carbon emissions (000 tons)	Percent of world emissions	Carbon emissions to GDP (kg/US $)	Carbon emissions per capita (kg/cap)
Bangladesh	166	3,155	0.06	0.18	30
Nigeria	229	8,962	0.16	0.37	84
China	286	569,900	10.38	1.87	533
India	322	145,400	2.65	0.57	182
Pakistan	325	13,154	0.24	0.39	128
Indonesia	443	26,258	0.48	0.35	153
Zimbabwe	598	4,160	0.08	0.77	463
Egype	709	19,037	0.35	0.54	380
North Korea	889	39,203	0.71	2.06	1,834
Mexico	1,715	77,200	1.41	0.55	943
Brazil	2,145	50,300	0.92	0.17	356
South Africa	2,493	75,900	1.38	0.92	2,292
Venezuele	2,629	23,307	042	0.49	1,276
South Korea	3,121	44,900	0.82	0.34	1,067
Poland	1,700	125,700	2.29	1.96	3,338
Yugoslavia	2,700	32,839	0.60	0.52	1,403
USSR	2,900	1,012,900	18.45	1.23	3,578
Czechoslovakia	2,400	64,000	1.17	1.71	4,110
Switzerland	26,115	10,330	0.19	0.06	1,580
Iceland	21,873	481	0.01	0.09	1,955
Norway	19,963	8,580	0.16	0.10	2,048
Denmark	19,830	16,610	0.30	0.16	3,238
Sweden	19,257	15,150	0.28	0.09	1,812
Germany	16,754	266,700	4.86	0.20	3,427
Finland	18,070	14,420	0.26	0.16	2,925
Luxembough	16,331	2,200	0.04	0.36	5,930
France	15,913	91,000	1.66	0.10	1,636
Austria	15,441	13,000	0.24	0.11	1,717
The Nethererlands	14,521	35,600	0.65	0.17	2,428
Belgium	14,457	26,000	0.47	0.18	2,637
Italy	13,176	97,000	1.77	0.13	1,691
United Kingdom	12,024	154,000	2.80	0.23	2,707
Ireland	8,353	7,540	0.14	0.25	2,120
Spain	7,452	43,600	0.79	0.15	1,123
Greece	4,619	14,370	0.26	0.31	1,437
Portugal	3,612	7,700	0.14	0.21	758
Turkey	1,293	34,150	0.62	0.50	649
Japan	19,437	237,100	4.32	0.10	1,942
United States	18,434	1,246,100	22.69	0.28	5,112
Canada	16,056	109,100	1.99	0.26	4,221
Australia	11,364	63,900	1.16	0.35	3,932
New Zealand	10,749	5,700	0.10	0.16	1,709
OECD		2,520,331	45.90	0.20	3,015
Rest of World		634,394	11.55	0.55	639
World		5,491,000	100.00	0.34	1,112

Sources: World Resource Institute; World Bank.

TABLE 2
Projections of carbon emissions for selected countries—2000

	Carbon emissions (000 tons)	*Percent of world emissions*	*Carbon emissions per capita (kg/cap)*	*Carbon emissions to GDP (kg/US $)*
Bangladesh	8,078	0.11	58	0.29
Nigeria	13,161	0.17	82	0.44
China	1,074,631	14.28	839	1.46
India	291,640	3.88	294	0.60
Pakistan	24,804	0.33	161	0.39
Indonesia	41,066	0.55	195	0.29
Zimbabwe	5,048	0.07	397	0.66
Egypt	40,605	0.54	642	0.61
North Korea	44,617	0.59	1,614	2.06
Mexico	113,371	1.51	1,098	0.55
Brazil	89,141	1.18	506	0.18
South Africa	104,629	1.39	2,351	0.98
Venezuela	30,150	0.40	1,244	0.52
South Korea	90,059	1.20	1,905	0.28
Poland	125,700	1.67	3,210	1.73
Yugoslavia	32,839	0.44	1,298	0.46
USSR	1,012,900	13.46	3,441	1.08
Czechoslovakia	64,000	0.85	3,953	1.50
Switzerland	13,363	0.18	1,866	0.05
Iceland	622	0.01	2,401	0.08
Norway	11,099	0.15	2,515	0.09
Denmark	21,487	0.29	4,081	0.14
Sweden	19,598	0.26	2,169	0.08
Germany	345,005	4.59	4,376	0.18
Finland	18,654	0.25	3,639	0.14
Luxembourg	2,846	0.04	7,474	0.32
France	117,718	1.56	2,009	0.09
Austria	16,817	0.22	2,109	0.10
The Netherlands	46,052	0.61	2,832	0.15
Belgium	33,634	0.45	3,324	0.16
Italy	125,480	1.67	2,159	0.11
United Kingdom	199,215	2.65	3,412	0.20
Ireland	9,754	0.13	2,638	0.22
Spain	56,401	0.75	1,434	0.13
Greece	18,589	0.25	1,835	0.27
Portugal	9,961	0.13	968	0.18
Turkey	44,177	0.59	657	0.44
Japan	306,714	4.08	2,416	0.09
United States	1,611,963	21.43	5,886	0.24
Canada	141,132	1.88	4,922	0.23
Australia	82,661	1.10	4,301	0.30
New Zealand	7,374	0.10	1,993	0.14
Total OECD	3,260,317	43.34	3,611	0.17
ROW	1,056,313	14.04	823	0.55
World	7,523,069	100.00	1,254	0.31

Source: Model Calculations.

assumptions. We have therefore chosen to apply the following marginal cost function (assuming zero intercept) derived by Nordhaus (1991a, b) based on a survey of cost studies in OECD countries.

$$R = 1 - e^{-0.0054MC} \tag{1}$$

where R is percentage emissions reductions and MC is marginal costs of reductions (US \$/ton).[4] It is plausible that costs of reductions are lower in countries that have done very little to improve energy efficiency. In particular, there may be net economic gains from initial carbon reductions in countries with significant fossil fuel subsidies (Churchill and Saunders, 1991; Larsen, 1993; Larsen and Shah, 1994; Larsen and Shah, 1992a, b; Shah and Larsen, 1992a) such as the former Soviet Union, China, and Venezuela. We assume that all countries by year 2000 would have reached the point at which marginal costs are non-negative, and therefore marginal costs of reductions are zero for the first unit of carbon emission. Each country is assumed to reduce emissions until the marginal costs of reductions are equal to the emission permit price.[5] The equilibrium permit price, given the cost function in (1), that clears the permit market and thus limits total world emissions to the 1987 level, is estimated to equal US \$58 per ton of carbon and is independent of any permit allocation.

4. Costs of alternative permit allocations

An important aspects of alternative permit allocaton schemes is the international support they may expect to receive. It is reasonable to assume that a treaty will be signed primarily by nations that expect positive net benefits from participation. In view of the scientific uncertainty at present, it is extremely difficult to incorporate benefits from greenhouse gas emission reductions in terms of damages averted by delaying the threshold of global warming. Thus the approach taken in this paper is to assume that some countries have a positive willingness to pay for emissions reductions while other countries have small or zero willingness to pay. Permit allocations must then be such that the countries with negligible or zero willingness to pay are induced to participate in a treaty. Furthermore, countries with a positive willingness to pay must also gain from such an allocation compared to the case with emissions reductions exclusively in the latter countries.[6] In particular, it is assumed that OECD countries have positive willingness to pay for emission reductions, while non-OECDs have negligible or zero willingness to pay.

[4] The studies upon which this marginal cost function is based ignore possible benefits of local pollution reductions associated with reductions in carbon intensive energies such as fossil fuels. For further discussion and empirical evidence see Glomsrod *et al.* (1992), Shah and Larson (1922a, b) and Summers (1991).

[5] For cost efficient national policy responses, see Pearce (1991) and Poterba (1991).

[6] Bohm (1992) considers the impact on negotiated allocations in the case of no permit trade versus the case of allowing permit trade. Other effects of unilateral reductions such as increased emissions in countries not participating in a treay due to shifts in the marginal benefit curve (Hoel, 1991b) or changes in comparative advantage are also ignored.

Each country will reduce emissions until marginal costs of reductions are equal to the permit price of US \$58 per ton of carbon. If the number of emissions permits is less (greater) than baseline emissions minus reductions, the country will purchase (sell) permits for US \$58 per ton of carbon. The net costs or benefits in US dollars of alternative permit allocations, with linear approximation of the marginal cost function over the relevant range, are given by

$$C_j = P^*[E_j^P - (E_j - E_j^R)] - 0.5P^*E_j^R \tag{2}$$

where P^* is the permit price, E_j^P is the allocated permit volume, E_j is the baseline (year 2000) emissions, and E_j^R is emissions reductions in country j. The first term on the right-hand side of (2) is the costs (−) or revenues (+) from permit purchases or sales, and the second term is the cost of emissions reductions with E_j^R given by (1) multiplied by the baseline emissions. Thus given the permit price, baseline emissions and cost function, the net costs or benefits are determined by the permit allocation scheme.

The permit allocations considered are: (i) by population; (ii) by GDP; (iii) by a combination of population and GDP; (iv) to each non-OECD country equivalent to its projected baseline emissions and to OECD countries as a group equivalent to the world emissions target minus non-OECD permits; and (v) unilateral reductions by the OECD countries.

4.1. *Permit allocation by population*

The permit allocation by population is calculated for the year 2000 by

$$E_j^P = E^P\ (POP_j/POP_w) \tag{3}$$

where E_j^P is emissions permits allocated to country j (units of thousand tons), E^P is world permit level ($E^P = \Sigma_j E_j^P$), POP_j is the projected population of country j, and POP_w is the projected world population. E^P is in this case equivalent to 1987 world emissions. Permit allocation per capita is the same in all countries and is given by $E^P/POP_w = 0.915$ tons of carbon.

Permit allocations relative to projected baseline emissions in the year 2000 are presented in Table 3. The ratio is greater than one, i.e., allocations are larger than projected emissions, for all the low-income sample countries expect for North Korea. The ratio is less than one for all the middle-income, emerging market economies and OECD countries, except for Brazil and Turkey. OECD countries as a group would only receive permits equivalent to 25% of their projected emissions.

From (2) and (3) the net costs or benefits relative to GDP are given by

$$C_j/GDP_j = P^*\ 1/gdp_j[E^P/POP_w - (1 - 0.5R)E_j/POP_j]$$

where gdp_j is *per capita* GDP for country j. Given the permit allocation *per capita* and (1), we have

$$C_j/GDP_j = P^*\ 1/gdp_j[0.915 - 0.865E_j/POP_j] \tag{4}$$

TABLE 3
Ratio of permit allocation to carbon emissions (year 2000)

	Allocation by population	*Allocation by GDP*	*Non-OECD fully covered**
Bangladesh	15.75	0.77	1.00
Nigeria	11.17	0.51	1.00
China	1.09	0.15	1.00
India	3.12	0.37	1.00
Pakistan	5.70	0.57	1.00
Indonesia	4.70	0.78	1.00
Zimbabwe	2.30	0.34	1.00
Egypt	1.43	0.37	1.00
North Korea	0.57	0.11	1.00
Mexico	0.83	0.41	1.00
Brazil	1.81	1.27	1.00
South Africa	0.39	0.23	1.00
Venezuela	0.74	0.43	1.00
South Korea	0.48	0.79	1.00
Poland	0.29	0.13	1.00
Yugoslavia	0.71	0.49	1.00
USSR	0.27	0.21	1.00
Czechoslovakia	0.23	0.15	1.00
Switzerland	0.49	4.22	0.38
Iceland	0.38	2.85	0.38
Norway	0.36	2.49	0.38
Denmark	0.22	1.56	0.38
Sweden	0.42	2.71	0.38
Germany	0.21	1.25	0.38
Finland	0.25	1.58	0.38
Luxembourg	0.12	0.70	0.38
France	0.46	2.48	0.38
Austria	0.43	2.29	0.38
The Netherlands	0.32	1.52	0.38
Belgium	0.28	1.40	0.38
Italy	0.42	1.99	0.38
United Kingdom	0.27	1.13	0.38
Ireland	0.35	1.00	0.38
Spain	0.64	1.69	0.38
Greece	0.50	0.82	0.38
Portugal	0.95	1.22	0.38
Turkey	1.39	0.51	0.38
Japan	0.38	2.55	0.38
United States	0.16	0.92	0.38
Canada	0.19	0.97	0.38
Australia	0.21	0.74	0.38
New Zealand	0.46	1.60	0.38
Total OECD	0.25	1.28	0.38
ROW	1.11	0.41	1.00
World	0.73	0.73	0.73

Note: *Non-OECD countries are allocated emissions permits equivalent to projected baseline emissions. OECD countries as a group are allocated permits equivalent to the targeted world emissions less permits allocated to non-OECD countries. Each OECD country recives permits in proportion to their projected baseline emissions.
Source: Authors' calculations.

From (4), we observe that the break-even point is 1.058 tones of carbon baseline emissions *per capita*. The net benefits (net costs) are decreasing (increasing) in *per capita* baseline emissions and decreasing (decreasing) in *per capita* GDP. The net benefits and costs of this allocation in the year 2000 are presented in Table 4. Brazil, Portugal, Turkey, and all the low-income sample countries except for North Korea, would benefit from this permit allocation scheme. In particular, the net benefits for Bangladesh and Nigeria would be more than 25% of GDP in year 2000, and more than 11% for Pakistan. From (4) and Table 2 we see that this is because of the low *per capita* baseline emissions and the low *per capita* GDP. The net costs would be as large as more than 5% of GDP for Poland and Czechoslovakia as a result of high *per capita* baseline emissions and relatively low *per capita* GDP. The net costs to the OECD as a group would be more than 0.6% of GDP. The net costs are high for OECD countries such as Luxembourg, Australia, the United States, and Canada because their baseline *per capita* emissions are signficantly higher than in most other OECD countries.

Given the net costs involved for most of the middle-income countries and particularly the emerging market economies, these countries are unlikely to participate in a global treaty based on a permit allocation by population. The sample countries in these groups are projected to contribute more than 20% of world emissions in the year 2000, and therefore participation by these groups is vital for an efficient global treaty. Furthermore, several large OECD countries may also be reluctant to participate given that they experience net costs of about 1% of GDP.

4.2. *Permit allocation by GDP*

The permit allocation by GDP is calculated for the year 2000 by using the following expression

$$E_j^P = E^P(GDP_j/GDP_w) \tag{5}$$

where GDP_j is country j's GDP in millions of US dollars, GDP_w is aggregate world GDP in the same units in year 2000, and E^P is equivalent to 1987 world emissions. Permit allocation per dollar of GDP is given by $E^P/GDP_w = 0.23$ kg of carbon.

Permit allocation relative to projected baseline emissions in the year 2000 are presented in Table 3. The ratio is less than one for all the low-income sample countries in contrast to the case of permit allocaton by population. It is also less than one for the middle-income (except for Brazil) and the emerging market economies as in the case of allocation by population. Thus, the high income countries of the OECD end up with more permits than the baseline emissions, except for Luxembourg, Australia, the United States, and Canada, and relatively lower income OECD countries such as Greece and Turkey.

From (1), (2), (5) and permit allocation per dollar of GDP, we have

$$C_j/GDP_j = P^*[0.23 - 0.865E_j/GDP_j] \tag{6}$$

TABLE 4
Net costs (−) or benefits (+) as a percentage of GDP of alternative permit allocations (year 2000)

	Allocation by population	*Allocation by GDP*	*Non-OECD fully covered*	*OECD unilateral reductions*
Bangladesh	25.38	−0.16	0.23	
Nigeria	26.63	−0.93	0.35	
China	1.92	−6.06	1.15	
India	7.92	−1.73	0.47	
Pakistan	11.11	−0.68	0.31	
Indonesia	6.41	−0.14	0.23	
Zimbabwe	5.58	−2.04	0.52	
Egypt	1.98	−1.75	0.48	
North Korea	−3.58	−9.10	1.62	
Mexico	−0.10	−1.46	0.43	
Brazil	0.97	0.42	0.14	
South Africa	−2.72	−3.63	0.77	
Venezuela	−0.39	−1.30	0.41	
South Korea	−0.64	−0.13	0.22	
Poland	−5.83	−7.39	1.36	
Yugoslavia	−0.42	−0.99	0.36	
USSR	−3.79	−4.16	0.85	
Czechoslovakia	−5.56	−6.28	1.18	
Switzerland	−0.12	1.04	−0.15	−0.30
Iceland	−0.22	0.91	−0.22	−0.44
Norway	−0.26	0.85	−0.26	−0.51
Denmark	−0.54	0.58	−0.41	−0.81
Sweden	−0.21	0.89	−0.24	−0.47
Germany	−0.69	0.40	−0.51	−1.02
Finland	−0.51	0.59	−0.41	−0.80
Luxembourg	−1.38	−0.30	−0.91	−1.81
France	−0.22	0.85	−0.26	−0.51
Austria	−0.25	0.82	−0.28	−0.55
The Netherlands	−0.47	0.57	−0.42	−0.83
Belgium	−0.55	0.50	−0.46	−0.91
Italy	−0.29	0.74	−0.32	−0.64
United Kingdom	−0.69	0.31	−0.56	−1.12
Ireland	−0.68	0.18	−0.64	−1.26
Spain	−0.18	0.64	−0.38	−0.75
Greece	−0.58	−0.07	−0.78	−1.55
Portugal	0.09	0.38	−0.53	−1.04
Turkey	1.36	−0.92	−1.26	−2.50
Japan	−0.25	0.87	−0.25	−0.50
United States	−1.01	0.08	−0.70	−1.38
Canada	−0.92	0.14	−0.66	−1.31
Australia	−1.16	−0.23	−0.87	−1.72
New Zealand	−0.33	0.60	−0.40	−0.79
Total OECD	−0.62	0.43	−0.50	−0.99
ROW	0.80	−1.47	0.43	
World	−0.24	−0.24	−0.24	

Source: Authors' calculations.

From (6) we see that the break-even point is 0.26 kg of carbon baseline emissions per dollar of GDP, and the net benefits (net costs) are decreasing (increasing) in baseline emissions per dollar of GDP. The net benefits of this allocation in the year 2000 are presented in Table 4. All the OECD countries, except for Turkey, Luxembourg, Australia, and Greece, would benefit under this permit allocation. Even though the United States and Canada would receive less permits than their baseline emissions, they would still benefit from this allocation because their baseline emissions per dollar of GDP are less than 0.26 kg (see Table 2). All the low-income, middle-income countries (except Brazil) and the emerging market economies would experience net costs from this allocation. In particular, the net costs would be large for North Korea, China, Pland, Czechoslovakia, and USSR because of their high baseline emissions per dollar of GDP.

Given the estimated high net costs, most non-OECD countries are unlikely to participate in a global treaty based on a permit allocation by GDP. Non-OECD countries as a group are projected to contribute more than 56% of world carbon emissions in the year 2000 and therefore represent a group whose participation is vital for an efficient global treaty. Thus a permit allocation by GDP appears even less likely to induce broad participation than an allocation by population. Furthermore, negotiations regarding an allocation by GDP will also have to resolve the problematic issue of determining the level of a common currency GDP.

4.3. *A permit allocation by a combination of population and GDP*

A permit allocation that is based on a combination of population and GDP is unlikely to induce any broader participation than an allocation by population because the middle-income countries and the emerging market economies will end up with net costs under both allocations and therefore under any allocation that is also a combination of the two (Table 4).

4.4. *A permit allocation that fully covers non-OECD projected emissions*

An alternative allocation, given that allocations by population or GDP are unlikely to induce paritipation from all important groups, is identified: non-OECD countries are allocated emissions permits equivalent to projected baseline emissions in year 2000

$$E_k^P = E_k \tag{7}$$

for each country k of the non-OECDs. The OECD countries as a group are allocated permits equal to the targeted world emissions minus permit allocations to the non-OECDs

$$E_{OECD}^P = E^P - E_{non-OECD}^P \tag{8}$$

The permits to the OECDS as a group can be distributed to each OECD country by several allocation schemes. We have arbitrarily chosen that each

OECD country is allocated permits in proportion to their projected baseline emissions

$$E_l^P = E_l E_{OECD}^P / E_{OECD} \tag{9}$$

where E_l is baseline emissions for country l and E_{OECD} baseline emissions.[7] Permit allocations relative to projected baseline carbon emissions for the year 2000 are presented in Table 3. The ratio is equal to one for all the non-OECD countries, and 0.38 for all the OECD countries.

From (1), (2) and (7), we have that the net benefits relative to GDP for the non-OECD countries are

$$C_k/GDP_k = 0.135P^*E_k/GDP_k \tag{10}$$

and from (1), (2) and (9), that net costs relative to GDP for the OECD countries are

$$C_l/GDP_l = -0.485P^*E_l/GDP_l \tag{11}$$

These net benefits and costs for the year 2000 are presented in Table 4. Net benefits relative to GDP are highest (more than 1% of GDP) for North Korea, Poland, Czechoslovakia, and China, and the net costs are highest (more than 0.85% of GDP) for Turkey, Luxembourg, Australia, and Greece. The average costs to the OECD countries are estimated at 0.50% of GDP.

All the non-OECD countries would benefit from this allocation,[8] and are therefore far more likely to participate in a global treaty under this permit allocation compared to the allocations by population, GDP, or some combination of the two.

4.5. *Unilateral reductions by the OECD countries*

As an alternative to allocations that potentially could induce participation from the non-OECD countries, the OECD countries could unilaterally reduce emissions so as to stabilize world emissions at 1987 levels. In this case the same quantity of permits would be allocated to the OECDs as under the allocation in which the projected emissions of the non-OECDs are fully covered, and we assume that permits to each of the OECD countries continue to be allocated in proportion to their baseline projected emissions. However, the OECDs can now only trade permits among themselves, and not with the non-OECDs. In this case the equilibrium permit price is estimated at US $181 per ton of carbon as compared to US $58 if all countries participate. The costs relative to GDP

[7] An interesting alternative allocation is one in which permits are allocated so as to equalize costs relative to GDP for each OECD country. Given relatively large differences in *per capita* income, and perhaps marginal cost functions, this can give rise to a very different permit allocation than an allocation that is proportional to projected emissions (see Bohm and Larsen, 1994).

[8] See Bohm and Larsen (1994) for an allocation under which non-OECD countries (Eastern European countries and states of the former Soviet Union in their case) receive permits so as to cover the costs of emissions reductions, i.e., without net benefits.

for the year 2000 are presented in Table 4. The costs are on average 0.99% of GDP, or almost twice as high as under the allocation in which the projected emissions of the non-OECDs are fully covered. The cost efficiency gains to the world as a whole is about 68%, which is significantly higher than the cost reductions to the OECD countries under the permit allocation in which the non-OECDs receive permits equivalent to their projected emissions. This is because a proportion of efficiency gains accrue to the non-OECD countries.

4.6. *A comparison of costs and benefits of alternative permit allocations*

We have evaluated five alternative permit allocations in terms of their costs and benefits to participating countries and their likely merits to induce broad participation from OECD and non-OECD countries. An allocation by GDP is rather unlikely to induce participation from the non-OECD countries given the high net costs involved, although this allocaton would result in net benefits to most of the OECD countries. An allocation by population would be less costly for the OECD countries than unilateral reductions. However, most of the middle income and emerging market economies would be unlikely to participate if permits are allocated relative to population. We observed that the allocation in which the projected baseline emissions were fully covered for the non-OECDs would involve less average net costs for the OECDs than if permits were allocated by population, or OECDs were to undertake unilateral reductions. The non-OECD countries would realize net benefits from this allocation. This leads us to conclude that the allocation in which non-OECDs are fully covered in terms of their projected baseline emissions could be attractive to both OECD and non-OECD countries. However, a potential problem with the latter allocation scheme is that net benefits relative to GDP for non-OECDs would be larger for non-OECDs with higher emissions per dollar of GDP, such as China, North Korea, and Poland, and therefore countries that have achieved higher energy or carbon emission efficiency at their own cost prior to an international treaty would not be rewarded. One may argue that this consideration is not important for non-OECD countries because those that have achieved higher energy or carbon emission efficiency have done so on national interest grounds. OECDs with higher energy efficiency would nevertheless be rewarded. For instance, the costs relative to GDP for the United States would be more than twice those for France if the marginal cost function in (1) is reasonably correct for both countries. However, if marginal costs are lower in OECDs with relatively low carbon or energy efficiency, the cost difference between low and high carbon efficiency OECD countries would be less than those reported in Table 4.

The allocation scheme in which non-OECDs are fully covered is noteworthy as developing countries are not forced to reduce emissions that may slow their development efforts and OECD countries do not assume an unrealistic cost burden of emissions reductions. An additional merit of this allocation scheme is that it recognizes that OECDs had the advantage of unrestricted emissions during their own development path, while non-OECDs are far from having used their 'quota'. Smith (1991) developed a 'natural debt index' to illustrate this point by examining data on accumulated historical emissions. Furthermore, an international treaty on greehouse gas emissions reductions needs to be such that countries have an incentive to partipate. A simple but useful perspective may be to have an allocation scheme at relatively low cost to OECDs, but which allows large enough transfers to induce participation from non-OECD countries. The allocation scheme presented here, in which projected emissions of non-OECD countries are fully covered, may satisfy such a condition.

4.7. *The free rider problem*

An optimal policy response to global warming would be a cooperative agreement in which each country reduces emissions until the marginal costs of reductions for each country are equal to the sum of marginal benefits of reductions across all countries. In this case the marginal costs of reductions for any given country are generally larger than the marginal benefits to that country alone. Thus the country is generally better off by not partipating in the treaty, i.e. by being a free rider, if a similar treaty is established among the remaining countries.

The free rider problem is therefore an issue with respect to the permit allocations evaluated in this paper. We have estimated the costs and benefits of participating in a global treaty based on marginal costs of emissions reductions and permit allocations, ignoring benefits (or possibly costs for some countries) of greenhouse gas reductions in terms of climate changes. In this case, countries for which participation involves net costs after emissions reductions and permit trade, would in general be better off by not participating. However, countries for which participation involves net benefits would be worse off by not participating. In fact these countries would have zero benefits if they do not participate.

Of those we have evaluated, the permit allocaton that we found most likely to induce the broadest participation, and at significantly lower costs for the OECDs than unilateral reductions, was the one in which each non-OECD country is allocated permits equivalent to its projected baseline emissions and the OECDs are allocated permits equivalent to the targeted world emissions minus permits to the non-OECDs. Under this permit allocation, all the non-OECD countries would be worse off if they do not participate in the treaty. However, the free rider problem would remain among the OECD countries because their participation would involve net costs. In particular, this could be a problem among the lower income OECD countries. These countries might demand a larger volume of permits to participate.

4.8. *Variations in marginal cost functions*

A final consideration is possible deviations from the assumption of uniform marginal cost functions. We will consider one special case: suppose that the

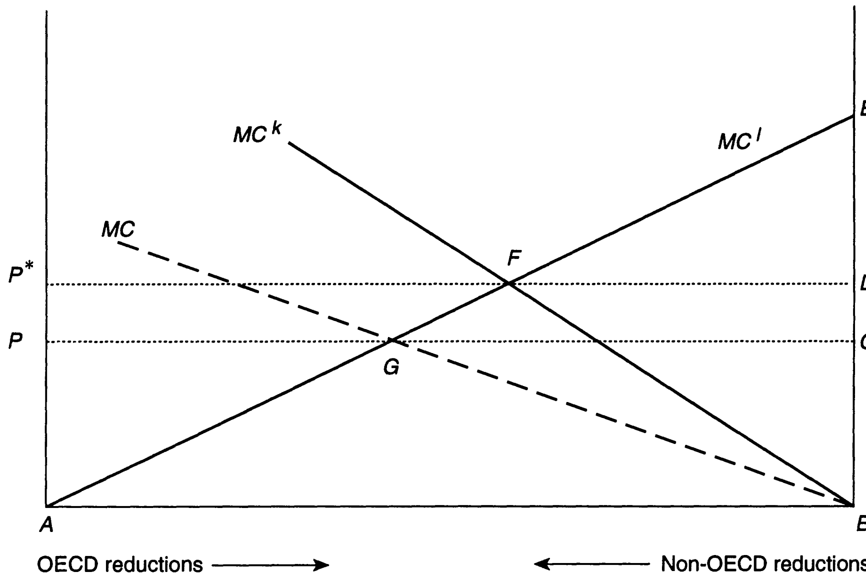

FIG. 1. Costs/benefits of emissions reductions and permit trade

OECD countries have the marginal cost functions as in (1), but that the non-OECD countries have lower marginal costs of emissions reductions than OECD countries because, on average, OECDs have already exploited the lower cost options of improving their energy efficiency and reducing reliance on fossil fuels. With lower marginal costs in non-OECDs the equilibrium permit price will be lower, given the same world emissions target and baseline emissions. Emissions reductions would then partially shift from OECDs to non-OECDs where costs are lower. Thus the total cost to the OECDs of achieving the world emissions target will be lower. This implies that the costs to OECDs, as presented in Table 4, are overstated if the marginal costs in OECDs are no higher and the marginal costs in the non-OECDs are lower. This is illustrated in Fig. 1 with a linear approximation of the marginal cost function in (1). For the equilibrium permit price P^*, and marginal cost functions MC^l and MC^k for the OECDs and non-OECDs respectively, the total costs to the OECDs are the area $ABDF$. In case the marginal costs in the non-OECDs are lower, say MC, the costs reductions for the OECDs are the area $CDFG$.

Lower marginal costs in the non-OECD countries would also impact on their net benefits or costs. Under the allocation in which the non-OECDs receive permits equivalent to their projected emissions, and their marginal cost functions are given by MC^k, their net benefits are the area BDF. If marginal costs are lower, say MC, the net benefits are BCG. This area could be larger or smaller than BDF, depending on the decline in permit price relative to the increase in carbon reductions in the non-OECDs. Net benefits increase with an increase in the elasticity of the MC^l curve (OECD). The MC curve in Fig. 1, i.e. eq. (1) as estimated by Nordhaus (1991a), is inelastic in the relevant range, and thus net benefits of the non-OECDs would be lower than presented in Table 4 if marginal costs of emissions reductions for the non-OECDs are lower than assumed.

5. Conclusions

This paper has evaluated alternative tradeable permit allocations in a global permit regime for stabilization of world emissions at 1987 levels by the year 2000. An allocation by population is likely to be unacceptable to most middle income countries as well as to the emerging market economies of Easten Europe and the former Soviet Union because of the large net costs involved. An allocation by GDP will most likely be unacceptable to almost all non-OECD countries because they would end up bearing a large proportion of the costs of emissions reductions. Furthermore, an allocation based on a combination of population and GDP is unlikely to induce partipation from most middle income and emerging market economies because of the net costs involved under allocations by both population and GDP.

An alternative allocation scheme, proposed here, entails that non-OECD countries are allocated permits equal to their projected emissions, and the OECD countries and allocated permits equal to the world emissions target minus the permit allocations to the non-OECD countries. Such a scheme may be able to generate sufficient support for a viable international agreement on greenhouse gas emission reductions as it represents a reasonable allocation scheme given that the OECDs have a higher willingness to pay for emissions reductions, and the fact that non-OECDs are only responsible for a significantly smaller part of the stock of greenhouse gases in the atmosphere. Under this permit allocation, non-OECD countries would benefit from participation, and the net costs to the OECD countries would be only one-half of the costs of unilateral OECD reductions. The cost savings would be even larger if marginal costs of reductions in the non-OECD countries are lower than in the OECD countries.

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