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Abstract

We examine the effects on GNP for groups of countries after introducing different schemes of tradable CO_2 emission rights. The analysis is based on a numerical general equilibrium model of the world economy. The development of prices and trade of energy carriers and emission rights are investigated.

1 Introduction

The purpose of this paper is to investigate economic effects of introducing an international agreement on CO_2 emission rights. These effects will depend partly on how the rights are distributed among countries, and partly on the possibility of introducing a world market for trade in emission rights.

In the following, we will take a closer look at two ways of allocating emission rights that have received some attention in the discussion on international CO_2 agreements:

- Each country receives emission rights proportional to the country's present level of CO_2 emissions.
- Each country receives emission rights proportional to the size of its population.

In both cases it is assumed that CO_2 emissions for the world as a whole will be fixed at 1990 level.

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The effects of these allocation schemes will be analyzed with and without the assumption of a world market for trade in emission rights, and we will also compare them to the economic prospects in a case without any abatement of CO_2 emissions whatsoever. The distributional effects of the two schemes will differ. By allocating emission rights in proportion to the size of each country's population, poor and heavily populated countries (with a low per capita level of emissions) will be able to increase their income by selling unused emission rights on the international market. By allocating emission rights in proportion to the present level of emissions, poor countries will not receive emission rights that can generate such an income. A third and more extreme allocation scheme that has also been subject to discussion, is to allocate emission rights in inverse proportion to each country's historically accumulated CO_2 emissions. The basic idea behind this scheme relies on a principle of fairness, which maintains that all nations should have the same possibilities for economic development without regard for the limitations set down by environmental pollution. An allocation based on this scheme will involve an even greater transfer of income from rich to poor countries than what will be achieved by allocation in proportion to each country's population size. It is hard to see how the rich part of the world would endorse an agreement with an allocation scheme like that. In this paper we have chosen not to discuss this scheme any further.

2 Existing literature

In the last decade, a considerable literature on international CO_2 agreements has emerged. One can find both purely theoretical papers (e.g., Hoel (1990a, 1991a, 1991b), Chichilnisky and Heal (1993a, 1993b, 1993c, 1994), Chichilnisky, Heal, and Starrett (1993)), and applied works where the authors use general equilibrium models both for particular nations, and for the world as a whole. Below is a brief survey of the applied works.

Some authors merely extrapolate CO_2 emissions under the assumption that no measures are introduced that will reduce the emission level. Lashof (1991) estimates that the total level of CO_2 emissions per year will double towards 2030/2040. Sathaye and Ketoff (1991) consider the largest countries in the third world. They estimate that emissions from countries like China, India, Mexico, Brazil, Korea, Indonesia, Venezuela, and Nigeria, may increase by a factor of 3.5 in the next 30 years. Their numbers are based on a reasonably optimistic estimate of economic growth in these countries. There is also a relatively early paper by Edmonds and Reilly (1983) regarding measures to curb CO_2 emissions. They examine demand functions for fossil fuel in different regions of the world and extrapolate emissions to 2050. In particular, they consider which unilateral measures USA can be expected to introduce

Several papers inquire into the costs of reducing emissions. Most of them analyze the situation for particular countries, like Bergman (1990) for Sweden, and Prost and Van Regemorter (1991) for Belgium.[1] These all assume a fixed emission goal for the country, and investigate the costs of reaching this goal. In most of these papers, national equilibrium models are employed to compute the costs. Nordhaus (1990) uses a technological approach by analyzing the costs related to available technology, and considers several greenhouse gases. Nordhaus (1991) also estimates the benefits by such an emission abatement, and he computes optimal paths for emissions of CO_2. His data relates primarily to USA, however, he tries to generalize them in order to make them apply globally

Several of the studies emphasize that the costs associated with the initial reductions in CO_2 emissions are actually quite low. Nordhaus (1990) cites an EU study that maintains that for some countries, the initial costs may actually be negative. This is because of already existing inefficiencies in the energy markets (e.g., coal subsidies).

Some papers consider the emission problem from a global point of view. The starting point in Whalley and Wigle (1991) is not unlike our own. They divide the world into three regions: developing countries, industrialized countries, and oil exporting countries. Energy carriers are divided into two groups, fossil and others. They use a one period model, and there is thus no adaptation over time. The scenarios they consider are rather extreme; for instance, they investigate how it would be possible to achieve a 50 per cent reduction in global CO_2 emissions.

Another model with a global view is one by Manne and Richels (1991a, 1991b). Results from this model have been presented in several papers. The model divides the world into the following regions: USA, the rest of OECD, the East Block countries, China, and the rest of the world. This choice of regions shows that the authors are primarily concerned with the effects on the consumption side, and not so much with possible effects for producers through a decline in the price of crude oil and other energy carriers. This model is special in the sense that it evaluates scenarios to 2100 in 10 years periods. The model is solved simultaneously for all periods, so that dynamics and long time perspectives are taken into account. However, the system of equations then becomes so large that the authors have to exclude trade between regions for any particular goods. Trade in emission rights and a numeraire commodity is computed iteratively outside the original model. The model contains a well developed energy side, where alternative energy sources are included as backstop technologies that effectively determines a price ceiling for traditional energy. Costs are estimated according to present technology, and technological progress is not taken into account. The ceiling is reached in 2050. The remaining parts of the economy receive a more summary treatment. In the scenarios, it is assumed that there will be a smooth transition from a system where emission rights are distributed in proportion to each region's present level of emissions, towards a system where emission rights are distributed in

[1] Pearce (1991) lists several studies

proportion to each region's share of world population (as these shares were in 1990). This transition is assumed completed in the year 2100. It is also assumed that there will be a very strong economic growth in China. Due to this, and the fact that China primarily uses coal as its source of energy, and does not trade in energy carriers, China emerges as the major looser.

Another model (GREEN) was developed at OECD (OECD, 1991; Burniaux, Martin, Nicoletti, and Martins, 1991). This model is very large, and includes trade between nine regions with a fairly detailed energy side. However, the supply of oil in the model is perfectly elastic, and this implies that the price to producers before CO_2 emission taxes is exogenously given. Their results are somewhat similar to ours, both regarding the relative effects between regions, and the magnitude of these effects. However, as a consequence of oil having perfect elasiticity of supply, regions with large imports of oil (like Japan) are relatively worse off in their analysis.

3 The model

The computations we describe are based on a somewhat changed and extended version of the model VEMOD that was developed in the World Market Prospects Project under the supervision of Professor Victor D. Norman (Haaland and Norman, 1986; Haaland, Norman, Wergeland, and Rutherford, 1987). This is a numerical general equilibrium model for international trade, based on the theory of comparative advantages, as it has been developed in the tradition following Ricardo-Viner-Jones and Heckscher-Ohlin. The model is a neo-classical growth model that generates sequences of static general equilibrium solutions. Growth is based on a putty-clay principle with constant savings rates, where investors are assumed to have rational expectations. The model is calibrated for 1979, and then extrapolated to 1990. With this year as a starting point, we investigate the effects of introducing restrictions on CO_2 emissions to the year 2008. However, when interpreting the results we present, one should take into account that "VEMOD is a theoretical model with numbers, not an empirically based model of world production and trade." (Haaland et al., 1987, p. 269). The reader is hence encouraged not to put too much emphasis on the actual figures presented, but rather concentrate on the qualitative arguments that are employed.

In the original model, trade takes place between the following six regions: Western Europe, North America, Japan, OPEC, developing countries that does not export oil, and newly industrialized countries (NIC, that is Argentina, Brazil, Mexico, Hong Kong, Singapore, and South Korea). Due to the high level of CO_2 emissions in China, Eastern Europe, and the former Soviet Union, these regions must be included when we consider abatement of CO_2 emissions. It is a common assumption that China will be one of the regions with the strongest growth in energy consumption. In addition, China possesses the world's largest coal reserves. It is difficult, however, to include these countries in the model in the same manner as the other regions; partly because of a lack of sufficient data, partly because these countries do not have well functioning markets, and partly because of difficulties that would be involved in modeling the significant structural changes that is expected to take place in some of these countries. When extending the original model, we therefore represent this part of the world simply by supply and demand functions for oil/gas, and similarly for coal. In this way, losses or gains in the markets for energy and emission rights can be computed for China and the former East Block in addition to the regions originally included in VEMOD. However, the model will give estimates on the effects on GNP growth for the originally included regions only.[2]

Each of the six original regions contain four production sectors. The production functions are nested CES-functions, so that it is possible to have different elasticities of substitution between different pairs of production factors. There is furthermore a consumption sector in each region that consumes energy, production factors, and end products, and this sector is modeled by nested CES-functions as well.

Compared to the original model, we made the treatment of energy more detailed by decomposing the aggregate energy commodity into oil/gas on one hand and coal on the other. In addition, OPEC's supply of crude oil was made elastic (it was completely inelastic in VEMOD). This gives us the possibility to analyze how CO_2 emissions decrease as a consequence of substitution from coal to oil/gas. This decrease is in addition to the decrease that results from reduced consumption of aggregate energy. The possibilities of substitution may also imply different changes in income for coal producers vs. oil/gas producers when emission rights are introduced. The decomposition of aggregate energy into oil/gas and coal is also carried through for the consumption sector. In different sectors there are different elasticities of substitution between the energy carriers, reflecting differences in technological possibilities. It is assumed that energy carriers can be traded freely between regions, and for the sake of simplicity, transportation costs are assumed to be negligible.

When it comes to emission rights, it is a condition in the model that these must be used in a fixed proportion to the energy carrier. Coal requires more emission rights per energy unit than oil/gas. Furthermore, the model includes a market for international trade of emission rights within each period. Economic efficiency requires that there should also be a market for trade in emission rights between different periods. However, we were not able to implement this, as each period in the model is solved separately. Anyway, in order that a system with intertemporal trade in emission rights should function satisfactorily, one would in advance have to decide the actual level of future emission rights, and the market would have to be convinced that these levels were not to be renegotiated.

[2]Compared to the original model, we have also extended the OPEC region with countries that have a significant oil production relative to energy consumption Egypt, Angola, Colombia, Trinidad, Oman, Malaysia, and some other very small countries. This was done in order to emphasize the difference between oil producing and non-oil producing countries.

As we run through the periods, old capital will depreciate and new capital will be added. Capital is sector specific in the sense that existing capital can not be transferred to other sectors. New capital (investments) are flexible, however, and can be freely allocated between sectors. Investments are determined separately in each region.

There are three exogenous conditions that determine economic growth in the model The first one is the annual population growth in each region. Typically, this growth is highest in poor countries and lowest in Western Europe and Japan. Secondly, savings is an essential part of growth. In the model, savings is a fixed proportion of annual GNP, and is in equilibrium equal to investments The savings rates are based on historical observations, and are highest in Japan The third condition is the assumption of some technological progress. This progress is neutral in the sense that it does not favor any particular factor of production, and is the same in all regions.

4 Results

We will in the following concentrate on three main effects from abating CO_2 emissions:

- The effects on GNP growth for each region, and for the world as a whole
- Trade patterns and market prices for emission rights.
- The effect on price and international trade of oil/gas and coal.

The effect on GNP growth in each region may be taken as an indicator of the extent to which the region will be willing to participate in a possible abatement agreement.

In our model, quantity units for all commodities and production factors are chosen so as to make all prices equal to 1 in the first period, except for the price of emission rights. This means that oil and coal are not measured by any common standard, like energy equivalents. Emission rights are measured in units that makes one emission right give permission to emit CO_2 corresponding to the consumption of one unit of oil. In this way, the price of emission rights can be directly compared to the price of oil. Consumption of one unit of coal requires almost exactly two emission rights in our model.

In subsequent periods, prices are defined relative to one of the commodities, the "High-Tech" commodity, which functions as a numeraire, and thus has the price 1 in all periods. For this reason, some care should be taken when comparing prices from different periods. However, it is unproblematic to compare the prices of energy and emission rights across scenarios, sine the relative prices of other commodities and production factors change very little from one scenario to another.

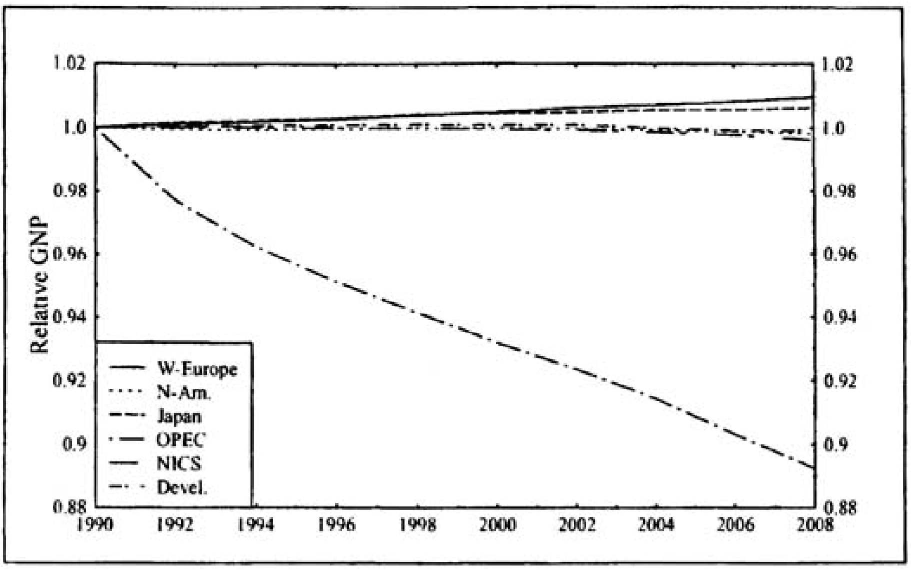

Figure 1: GNP development when emission rights are distributed in proportion to 1990 emissions. The numbers are relative to the development when there are no restrictions on emissions.

4.1 A scenario with no CO_2 abatement

In this case, the annual GNP growth will vary between 2% and 3.5% to 2008. Japan is expected to experience the highest growth rate because of a high savings rate, while OPEC, NIC, and poor developing countries will see growth at a lower level. The lowest growth will be found in North America and Western Europe, partly because of a low savings rate, and partly because of low population growth. Globally, the emission of CO_2 will increase with 40% down to 2008, and that means an annual growth of 1 7%. CO_2 emissions grow somewhat slower than GNP because of technological progress, and also because oil becomes relatively more expensive compared to other production factors.

To 2008 the price of oil/gas increases by about 30% compared to the price of the numeraire commodity. The relative price of coal, on the other hand, will only increase by about 1.1%. Prices of other commodities and production factors change considerably less than the oil price. Consumption of coal increases by about 60%, while consumption of oil/gas increases by 30%. This difference is due to the assumption that coal has a higher elasticity of supply than oil/gas.

4.2 Tradable emission rights distributed in proportion to 1990 level of CO_2 emissions

In this scenario it is assumed that there is no growth in the level of CO_2 emissions. In Figure 1, the GNP development in each region is displayed.

	W Eur	N Am	Japan	OPEC	NICS	Dev count	Former comm
Population 1990	9.2	6.3	2.6	10.7	6.1	35.6	29.5
Emissions 1990	19.3	28	6.1	2.1	4.7	7.2	32.6
Rights exp./imp. 2008	1.8	0.5	-1.7	-0.8	-0.6	-0.7	1.5

Table 1: The distribution of emission rights and trade in emission rights measured as percentages of total amount of emission rights.

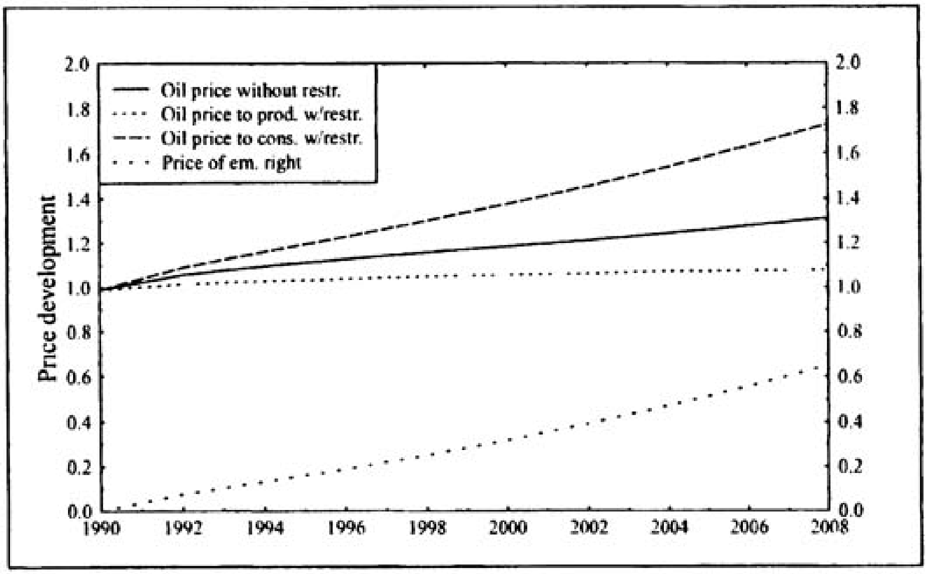

Figure 2 The price of oil with and without emission restrictions to producers and consumers.

Along the vertical axis we measure GNP in a region relative to the region's GNP level when there are no restrictions on CO_2 emissions. The surprising conclusion is that *for five of the six regions, restrictions on CO_2 emissions hardly matters at all.* In Western Europe and Japan, GNP is actually 0.9% and 0.64% (respectively) *higher* in 2008 than it would be without restrictions, while in NIC it is 0.4% lower. For North America and developing countries the effect is only slightly negative (0.2% and 0.14%, respectively). The major looser is OPEC, who experiences a decrease in GNP of more than 10% compared to their GNP level without CO_2 restrictions.

The distribution of emission rights in this scenario is shown in Table 1, and the development of prices of oil and emission rights[3] is shown in Figure 2. The price of emission rights increases smoothly to 2008, where it is 0.65. This

[3]We assume competitive market for emission rights. Problems caused by large countries (e.g., USA) using their market power to influence the price of emission rights are not accounted for here (Hoel, 1991a)

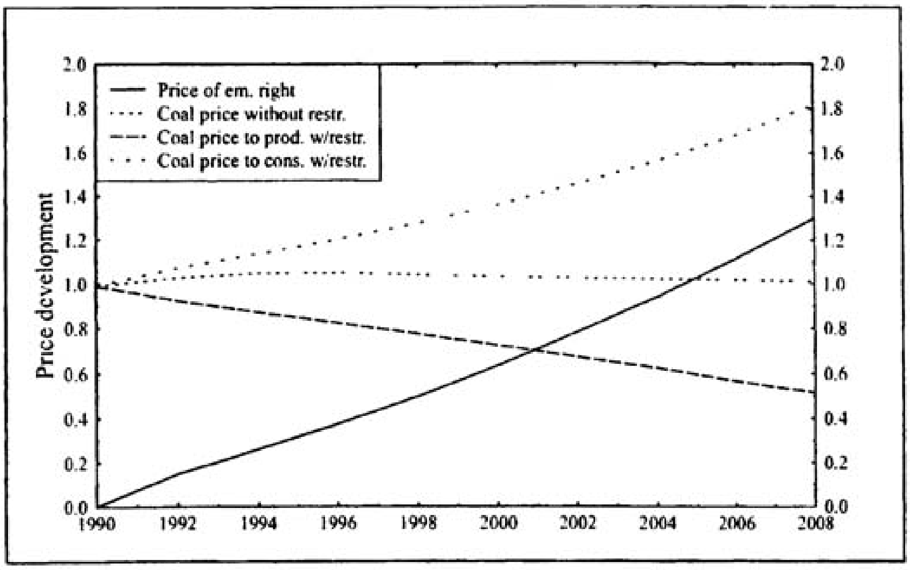

Figure 3: The price of coal with and without emission restrictions to producers and consumers.

means that in 2008 the cost of one emission right equals 65% of the cost of one unit of the numeraire commodity The cost of emission rights constitutes about 37% of the price of oil paid by end consumers. The trade in emission rights in this scenario is rather limited and constitutes only 3.8% of the total amount of emission rights in 2008 (see Table 1).

Due to the requirement of emission rights, the actual price to end consumers for coal and oil/gas is higher than the price received by producers. The difference equals the price of one emission right multiplied by the number of emission rights that is needed to consume one unit of the energy carrier (i.e., one for oil/gas and two for coal). Prices to consumers and producers for oil/gas are shown in Figure 2. We see that the price to consumers increases by about 70% to 2008, while the price to producers increases by 8%. For coal, prices to consumers and producers are shown in Figure 3. The price to consumers increases by about 80%, while the price to producers decreases by 50%.

Regarding the observation that the effect on world GNP is rather small, it is important to consider the difference between old and new capital. With existing capital, there are limited possibilities for substitution between oil/gas and coal, while new capital is more flexible with respect to the type of fuel that is used (the decision can be made at the time of investment). As old capital is replaced, oil/gas can be substituted for coal, since oil/gas is less demanding in its requirement for emission rights. This means that the use of oil/gas increases relatively to the use of coal, and there is then more energy behind each emission right. In addition, new capital is more effective in its use of energy.

The division between oil/gas exporting regions and oil/gas importing regions is essential in determining GNP development. The important point is what happens to the price to producers. A region is *allotted* emission rights and does not have to buy emission rights unless it wants to increase its emission level The region can thus credit itself with the difference between prices to producers and consumers. At the same time, the region faces a much slower increase in the price of oil/gas to producers than what would be the case without restrictions on CO_2 emissions. The net effect on GNP for a region that imports oil/gas is thus not very strong. On the other hand, the net effect will be very large for an oil/gas exporting region like OPEC. The reduction of the price of oil/gas to producers implies a considerable income redistribution towards regions that import oil/gas. A similar effect is present in the coal market, where exporters face an even more unfavorable price development then exporters of oil/gas. This may be why North America comes out slightly worse than Western Europe, in addition to the fact that Western Europe is a larger importer of oil/gas.

There are three main reasons for the low level of trade in emission rights: Emission rights are at the outset distributed in proportion with the regions' share of total emissions; the model covers a relatively short time span; and the regions are very aggregated. Regarding the last point, it is reasonable to assume that trade in emission rights can be considerable between countries within one and the same region. It would thus be too simple to conclude that there is no significant trade in emission rights in this scenario. However, our results regarding limited trade between aggregated regions agree with the findings of Manne and Richels (1991a).

4.3 Nontradable emission rights distributed in proportion to 1990 level of CO_2 emissions

Since trade in emission rights is relatively limited between regions, removing the possibility of trade will not have any major effects on GNP development compared to the previous scenario. On the other hand, considerable regional differences in the prices of emission rights emerge (see Figure 4). We see that the price is particularly high in the OPEC region, and lowest in Western Europe. This illustrates that different regions face very different possibilities of reducing CO_2 emissions. The model assumes that OPEC will experience a high economic growth rate, and in addition, the energy consumption in this region is strongly directed towards oil. This means that the possibilities for a reduction of CO_2 emissions as a consequence of substitution from coal to oil is limited in this region. Western Europe, on the other hand, finds itself in the opposite situation, with low growth and ample possibilities for substitution away from coal. Furthermore, it turns out that the transition from coal to oil/gas on the global scale is somewhat less extensive in this scenario than in the previous one.

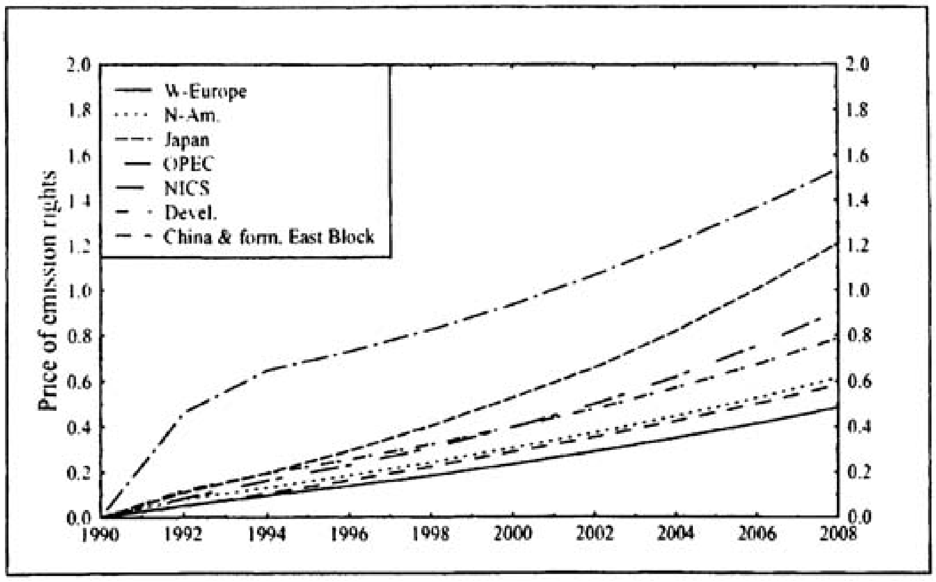

Figure 4: Regional prices of emission rights when trade is not possible.

4.4 Tradable emission rights distributed in proportion to present share of world population

The distribution of emission rights in this scenario is shown in Table 1. If we compare this to the scenario where emission rights are distributed in proportion to present emissions, we see that there has been a large transfer of rights from Western Europe (10.1% of the total amount of rights) and North America (21.7%), and to some extent from Japan (3.5%). The recipients of these emission rights are mainly the poor part of the world (28.4%) and OPEC (8.6%). NIC has received 1.4%, while China and the former East Block countries have lost 3.1%. However, it turns out the the new distribution scheme does not have any significant effect on the price development for any of the commodities and production factors. The difference in the prices of emission rights is also very small (in the order of 0.1%). The difference between the two scenarios therefore reduces to a pure transfer between regions. This affects GNP both directly, and indirectly through accumulated savings.

In Figure 5, where emission rights are distributed in proportion to present share of population, we display GNP development for each region relative to GNP in the scenario where rights are distributed in proportion to the present level of CO_2 emissions. We see that it is the poor part of the world that will benefit most from this transfer. In 2008 their GNP is 9.3% higher in this scenario. OPEC will also gain, and experiences a relative GNP increase of 6.4%. This implies that the total loss for OPEC by introducing a scheme with emission rights is an annual GNP reduction of 5.1%.

The transfers are paid by the OECD countries. For North America, the

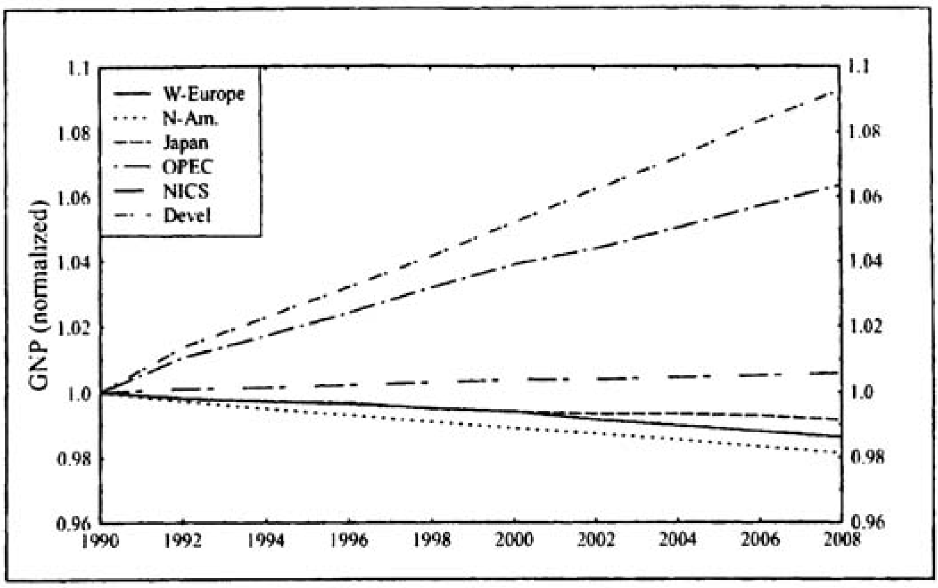

Figure 5: GNP development when emission rights are distributed in proportion to share of world population. The numbers are relative to the development with rights distributed in proportion to present level of emissions.

relative loss is about 1.9%, Western Europe 1.4%, and Japan 0.85%. Since Western Europe and Japan benefitted from introducing a scheme with emission rights, the total loss for these two regions are only 0.4% and 0.3%, respectively. NIC does not experience any significant change, as they receive about the same amount of rights in both scenarios.

It would be possible to investigate the consequences of nontradable rights with this distribution scheme, too. However, this would imply that emission rights would be unused in some regions, and would get a very high price in other regions. In the long term, it would involve shutting down a large part of energy intensive production in the OECD countries, with a corresponding increase of this production in the third world. In light of the present political climate, such an alternative looks very unrealistic.

5 Concluding remarks

The main conclusion to be drawn from our investigation is that freezing the level of CO_2 emissions will not have such a contractive effect on the world economy as many have feared. However, there will be large regional differences depending on the extent that regions import or export oil/gas and coal OPEC may come out as the major looser, and will have to transfer to other regions a large part of the resource rent they otherwise stand to collect if there continues to be no restrictions on CO_2 emissions. The effect on other regions than OPEC will be considerably less, and Western Europe may even increase its GNP as a consequence of the restrictions. Regional effects will also depend on the way emission rights are distributed. If they are distributed proportional to population, OPEC will be slightly better off compared to a scenario where rights are distributed proportional to present emissions. Those developing countries that do not export energy will considerably improve their situation in this case

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