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From the Kyoto Protocol to the fossil fuel market

A model analysis

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Abstract

Implementation of the Kyoto Protocol will change the energy markets. The resulting price shifts will represent important terms-of-trade changes. The paper explores how the different countries' relationship to the fossil fuel markets will cause variations in the costs from implementation of Kyoto Protocol. The paper furthermore analyses how the geographical distribution of abatement efforts will be altered if emission trading is allowed.

According to the presented analysis Russia and the other economies in transition to a market economy (EIT-countries) will experience net gains from implementation of the Kyoto Protocol. An important prerequisite is however, that emission trading takes place without restrictions. The USA is a likely dominant quota buyer. This quota import gives nevertheless surprisingly small net cost reductions. The inclusion of benefits from revenue recycling, so-called double dividends, is an explanatory factor at this point. These benefits are probably important for the different countries' choice between quota trade and domestic abatement measures.

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1 Introduction

The Kyoto Protocol commits the Annex B countries to reduce their emissions of CO₂ and other greenhouse gases (GHGs). The purpose of this paper is to explore how some essential differences in starting points across the Annex B countries might cause considerable differences in the costs of achieving the commitments specified in the Kyoto Protocol.¹ The paper analyses how the distribution of costs could be altered if emission trading between countries is allowed, and how this trade might change the geographical distribution of abatement efforts.

The roles of the fossil fuel markets are pivotal for the present analysis. Because CO₂ is the most important GHG and because emissions of CO₂ mainly are attached to combustion of fossil fuels, implementation of the Kyoto Protocol will directly affect the demand for these fuels. Hence, the fossil fuel markets will be moved to a new equilibrium. The resulting price changes are likely to bring about terms-of-trade changes of considerable importance for several countries.

In this paper we apply ACT, a numerical model developed at Center for International Climate and Environmental Research in Oslo (CICERO).² The core of the model and its theoretical background are described in detail in Holtmark (1998).³ Basic in ACT are regional and global fossil fuel markets which determine the fossil fuel prices. The oil and coal markets are assumed to be global, while three regional natural gas markets are built into the model. One gas market is in North America, where both the USA and Canada are producers of gas with a net export of gas from Canada to USA taking place. Russia and Europe are included in a second gas market. The third gas market is found in the East-Asian/Pacific region.

National income indicators are linked to each other through the fossil fuel markets and the market for tradable quotas. The policies, which are assumed to be implementation of emission taxes, will affect the collection of public revenue in the different countries.⁴ The revenue could be 'recycled' into the private sector by reducing existing distortionary taxes. The implementation of the Kyoto Protocol could in other words be part of or generate a 'green' tax reform. Possible benefits from such a reform (double dividends) are taken into account in the numerical analysis.

The paper is organized as follows. The next section gives an overview of the numerical model ACT. The third section describes how behavior is modeled, while section 4 discusses shortly some limitations and advantages of the model. A box within section 4 provides a less mathematical description of ACT. Section 5 presents how the abatement costs of the Annex B countries. Section 6 presents possible consequences of the Kyoto Protocol, especially how

¹ The countries listed in Annex B in the Kyoto Protocol, which are the industrialised countries.

² ACT is an abbreviation for Achieving Commitments by Trading

³ Cf. also Ringius, Torvanger and Holtmark (1998) which applies a less aggregated version of the model.

⁴ A domestic system of auctioned tradable permits is likely to have mainly the same effects on public revenue, income distribution and resource allocation as a system with emission taxes. Although we discuss as if emission taxes are implemented, the results are also applicable for countries using auctioned tradable permits instead. If, however, the permits are distributed without charge to the emitters the generated public revenue is reduced compared to the taxation case. No public revenue is then available for recycling, i.e. existing tax rates could not to the same extent be reduced. Free distribution of tradable permits curtails consequently the possibility for taking benefit of an economic efficiency gain through the reduction in existing tax rates.

emission trading will redistribute abatement efforts and costs and alter the prices in the fossil fuel markets.

2 The general framework of ACT

ACT consists of a set of national income indicators or functions, one for each country or group of country.⁵ These functions consist of five elements:

$$W_n = g_n(y_{1n}, y_{2n}, y_{3n}, y_{4n}) + \sum_{i=1}^3 c_i(x_{in}) - \sum_{i=1}^3 p_i(y_{in} - x_{in}) - p_Q(E_n - Q_n) + m_n R_{Cn}$$

$$E_n = \sum_{i=1}^4 y_{in}$$

- y_{1n} , y_{2n} and y_{3n} are oil, coal and gas consumption in country n respectively. The unit of measurement is related to the carbon-content of the fuels.
- x_{1n} , x_{2n} and x_{3n} are indigenous oil, coal and gas production in country n respectively.
- y_{4n} is emissions of CH₄, N₂O, and the industrial gases measured in CO₂-equivalents.
- p_1 , p_2 and p_3 are the prices in the oil, coal and gas markets respectively. Because there are three regional gas markets there are three different gas prices as well. For purpose of exposition we ignore that here.
- p_Q is the quota price.
- E_n is the emissions of GHGs in country n .
- Q_n is the quota.
- m_n is the marginal excess burden of taxation in country n .
- R_{Cn} is the total amount of public revenue generated by taxation of fossil fuels and GHG emissions plus the revenue generated by quota sales, eventually minus the public expenditure related to quota purchase.

The first element in the welfare function is a subfunction measuring value added and consumers' surplus brought about by domestic use of fossil fuels and emissions of CH₄, N₂O, and the industrial gases. Secondly, we subtract the costs related to the indigenous production of fossil fuels (if any). The third element represents the net import bill for fossil fuels. Fourth, we include the net bill for quota purchase. Finally, we include an element, which incorporates the tax recycling benefit (the double dividend). The size of this element is a linearly increasing function of the sum of the amount of public revenue generated by taxation of GHG emissions and the net amount of public revenue generated by quota sales to other countries.

When we assume the existence of 'benefits from revenue recycling' we only claim that there is a "weak double dividend" in the terms of Goulder (1995). There is a weak double dividend simply when there are benefits from using the extra government revenue generated by the introduction of GHG emission taxes to reduce pre-existing distortionary taxes. The existence of weak double dividend is easily defended on theoretical grounds and receives wide support from several numerical calculations, cf. Hoel (1998) and Bohm (1998).

There is a so-called 'strong double dividend' from implementation of environmental taxes when these taxes give rise to welfare improvements even without counting for environmental

⁵ The elements measuring value added and the elements measuring production costs are specified with quadratic functions giving rise to linear demand and supply functions. The oil production costs within OPEC are however assumed to be constant at a level equal to 2.30 USD pr. tonnes CO₂.

gains. The existence of “strong double dividend” is on the other hand more controversial and not included in ACT. The earlier version of ACT presented in Holtmark (1997) includes “strong double dividend”.

3 Behavior

The private non-fossil-fuel-producing sector in each country maximizes the first term in the national welfare function with respect to y_{1n}, y_{2n}, y_{3n} and y_{4n} . We could define a welfare function for this sector as follows:

$$V_{Pn}(P_{1n}, P_{2n}, P_{3n}) = \max_{y_{1n}, y_{2n}, y_{3n}, y_{4n}} \left\{ g_n(y_{1n}, y_{2n}, y_{3n}, y_{4n}) - \sum_{i=1}^4 P_{in} y_{in} \right\}$$

$$P_{in} = p_i + t_{in} + t_{Cn}, i = 1, 2, 3$$

$$P_{4n} = t_{Cn}$$

- t_{in} is tax on fossil fuels in the reference case.
- t_{Cn} is a GHG emission tax in country n .

The producers of fossil fuels behave as price takers and maximize their profit. There is however one exception: OPEC is considered as an oil producer who maximizes its profit taking into account the relationship between the market price and its own production. The profit functions for the other fossil fuel producers are:

$$\Pi_{in}(p_{in}) = \max_{x_{in}} \left\{ p_i \left(\sum_m x_{im} \right) - c_{in}(x_{in}) \right\}, i = 1, 2, 3.$$

The governments, on the other hand, maximize their national welfare functions as defined above. Their only policy instrument in this maximization is the emission tax t_{Cn} . The national welfare functions are consequently:

$$V_n = \max_{t_{Cn}} \left\{ V_{Pn}(P_{1n}, P_{2n}, P_{3n}) + \sum_{i=1}^3 \Pi_{in}(p_{in}) + (1 + m_n) R_{Cn} \right\}$$

4 Limitations and advantages of the model concept

Due to the formulation of ACT, the structures of the countries' energy demand, prior tax distortions and the size of the marginal excess burden of taxation in the different countries are important factors behind the models' estimates of the simultaneous abatement costs. The presented numerical examples illustrate how the distribution of gains and losses among the Annex B parties are sensitive to the different countries' links to the fossil fuel markets and their current and potential fossil fuel taxation schemes.

It should, however, be emphasized that ACT is a partial and static model, and that damage costs from climate change are not included in the concept. Dynamic aspects of the countries' climate policies, as emphasized by for example Nordhaus and Yang (1996), are for example not taken into account in the present analysis. Costs in relation to movement from one equilibrium to another are furthermore ignored.

Some relevant structural characteristics of the national economies that are emphasized by other studies, as for example DFAT and ABARE (1995) and Burniaux et al. (1992), are only partly incorporated. In contrast to the mentioned studies the present study analyses, however, in further detail the countries' fossil fuel taxation policies under the implementation of the Kyoto protocol, and to what extent these taxation policies influence the distribution of costs and benefits of an agreement. Unlike the mentioned studies, the present study directs the focus towards the links between a possible climate agreement and both the current and potential fossil fuel taxation policies in the light of public budget constraints.⁶

⁶ Although there is a vast amount of literature on the costs of combating greenhouse gas emissions, a large part of the literature is focused only on the measurement of the direct abatement costs. Surprisingly, most of the studies take into account neither the gains from revenue recycling nor the benefits or losses from changes in terms-of-trade (cf. Ekins (1995) and Hoeller and Wallin (1991)). Some examples of model studies taking terms-of-trade effects into account are Burniaux et al. (1992), DFAT and ABARE (1995). None of these studies analyze the benefits of revenue recycling. Several other studies, for example Jorgensen and Wilcoxon (1993), emphasize on the other hand the importance of taking revenue recycling into account, but ignore the terms-of-trade effects of several countries implementing climate policies at the same time. The contribution of our analysis is to give some indications on how the costs of the Kyoto Protocol will vary among the Annex B countries when dead-weight-loss from taxation, gains from revenue recycling and terms-of-trade effects are taken into account. This is done while taking into account the effect of all the Annex B countries implementing efficient abatement measures at the same time.

ACT - Achieving Commitments by Trading

A model for analysis of economic consequences of the Kyoto Protocol

- ACT is a *top-down* model.
 - ACT includes all gases listed in the Kyoto Protocol.
 - The Annex B countries maximise country specific welfare functions subject to national GHG-emission constraints and public budget constraints. The national welfare functions are linked to each other through the global and regional fossil fuel markets and the quota market.
 - The national welfare functions include five elements:
 - a) value added and consumers' surplus from both private and public sector consumption of oil, coal and gas and emissions of other GHGs
 - b) profit in indigenous production of fossil fuels
 - c) costs related to fossil fuel import
 - d) net income from quota sales
 - e) benefits from recycling the revenues collected by fossil fuel taxation and net income from quota sales, i.e. weak double dividend.
 - The national abatement costs are equal to the reduction in consumers' surplus and value added from fossil fuel consumption and emissions of the other GHGs minus the benefits from revenue recycling. The different national fossil fuel consumption patterns together with the size of the fossil fuel taxes in 1990 are the main factors behind the estimated abatement cost functions for CO₂ in the different countries and regions. The higher was the share of coal in countries' total fossil fuel consumption in 1990, the lower are (broadly speaking) the estimated abatement costs. Concerning the non-CO₂ gases abatement cost patterns are assumed to be the same in different regions and countries.
 - The assumed size of the marginal excess burden of taxation (MEB), which is equal to the marginal cost of public funds minus one, is basic when the benefits from revenue recycling is calculated. The MEBs are calibrated to the values that imply that zero GHG emission taxes are optimal as long as the countries are not subject to emission constraints nor experience any environmental benefits from GHG abatement. The MEB is 0.04 in USA and Japan, 0.08 in EU and in Canada, 0.02 in Australia, 0.09 in Norway and 0.11 in other OECD-countries, and zero in the EIT-countries.
 - The governments are assumed to use fossil fuel taxes on consumption as their climate policy instrument. The results could however also be interpreted as if the governments use auctioned tradable permit systems.
 - The supply in the oil market is modelled with OPEC as a dominant supplier behaving strategically, while the rest of the oil supply is a 'competitive fringe' with supply elasticity of 0.75. There are also a global market for coal and three regional markets for gas with endogenous prices. These four markets are assumed to be competitive. Supply elasticities are 0.75 in the gas markets and 1.0 in the coal market.
- The direct demand price elasticities vary between -0.21 (oil in Finland) and -0.57 (gas in the EIT-countries). The demand cross price elasticities varies between 0.0 and 0.30.
- In the cases where emission trading is allowed a competitive quota market is also included. The quota price is endogenous and secures equilibrium in the market.

5 Abatement costs

The purpose of the presented model simulations is firstly to give an idea of how emission trading within different frameworks could alter the countries total costs, both the direct abatement costs and secondary costs (and benefits) related to terms of trade changes etc. Secondly, we also want to provide some information on possible absolute levels of the costs.

Although the numerical examples are useful to both these purposes, one should be careful when interpreting the results. It is important to underline that not least the absolute level of the different countries calculated abatement costs are difficult to predict, especially when we look several years into the future. The absolute level of the abatement costs will for example depend on the technological possibilities for switching to new renewable energy sources at the actual point in time. The economic costs connected to new renewable energy are changing rapidly and are therefore hard to predict without a considerable degree of uncertainty when we look forward to the first commitment period (2008-2012).

In this study we use ACT to give us information about annual abatement costs in the first commitment period. Technological development is likely to reduce the abatement costs before these points in time are reached. Other changes in the world economy might also adjust the costs. Although we are fully aware of the likeliness of such changes to take place we have not incorporated such a technological development. Hence, from that point of view there is a danger that ACT in general exaggerates the abatement costs in 2010.

Figure 1 presents the models estimates of the marginal abatement costs of reducing emissions of GHGs.⁷ Sweden's rapidly increasing marginal abatement costs are explained by the relatively high fossil fuel taxes in this country (in 1990) and the low consumption of coal and reflects furthermore the fact that electricity is produced almost without use of fossil fuels in Sweden.

The high abatement costs in Norway can be explained by similar reasons. The somewhat lower average fossil fuel taxes in Norway (in 1990) explain why the estimated marginal abatement costs are lower in Norway compared to Sweden.

ACT estimates the marginal abatement costs in Denmark to be higher than in Finland, although Denmark uses coal intensively, not least in power production. The explanation is connected to the structure and level of fossil fuel taxes in these countries in 1990. The fossil fuel taxes in Denmark were relatively high and are assumed to have led to relatively efficient use of fossil fuels.⁸ The average oil tax in Finland was, on the other hand, in 1990 at a level equal to about 50% of the average oil tax in Denmark in that year, cf. appendix A.

⁷ The abatement cost functions presented here are different from those presented in Holtmark and Hagem (1998). This is due to the choice of estimates for the marginal excess burden of taxation (the MEBs). In the model version applied in the present paper the MEBs are calibrated to values that imply that zero GHG emission taxes are optimal as long as the countries are not subject to emission constraints nor experience any environmental benefits from GHG abatement. With this calibration method the possibilities for 'strong double dividend' are ruled out. Cf. the box below.

⁸ This argument is based on the assumption that high fossil fuel taxes leads to high costs of curbing CO₂-emissions further. It is reasonable to assume that the tax already has caused an efficient use of fossil fuel. Hence, low-cost options for reduced consumption of the fuels are already exploited.

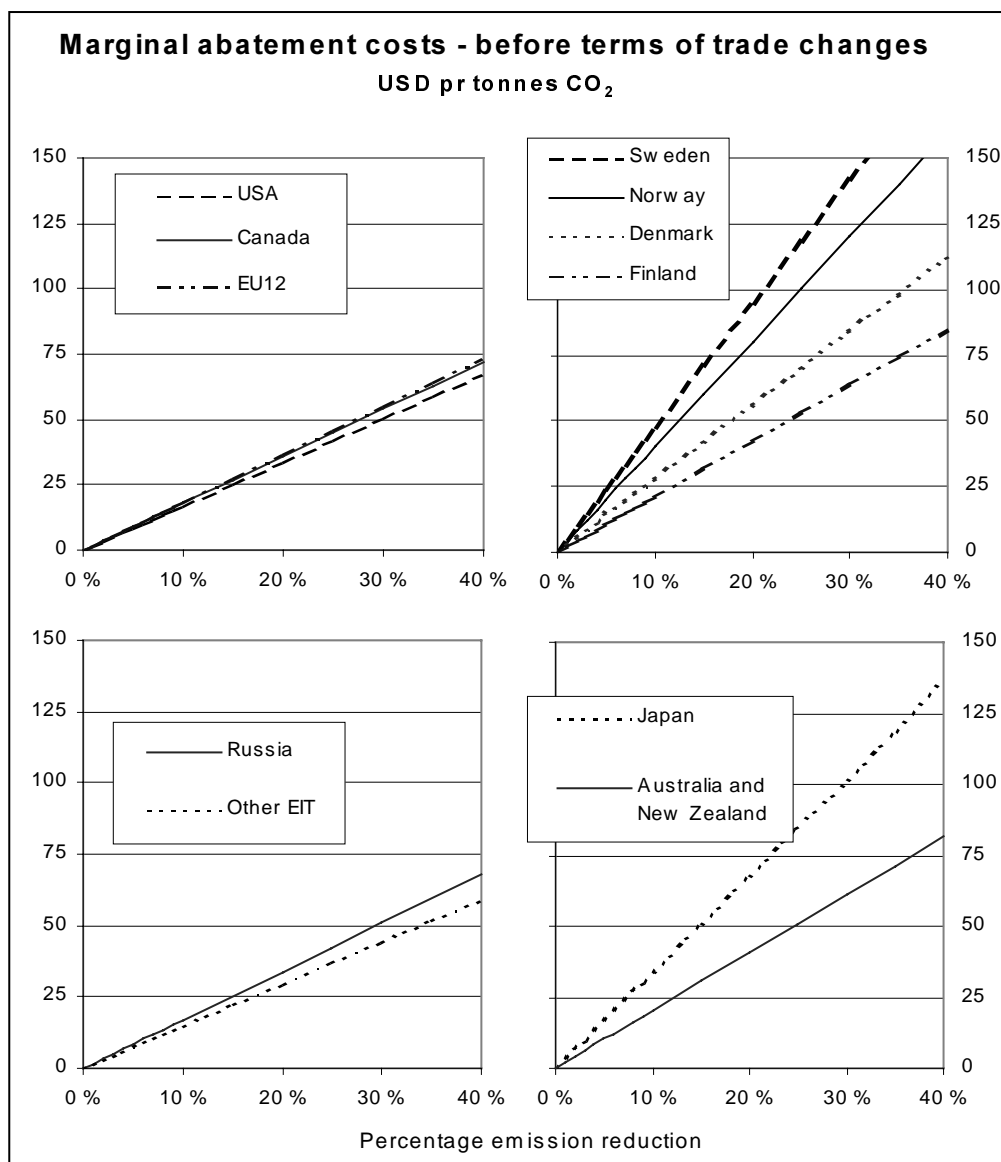


Figure 1: Estimated marginal abatement costs (USD pr. tonnes CO₂ equivalent) of reducing emissions of GHGs. Benefits from revenue recycling are taken into account, but terms of trade changes are not.

The marginal abatement costs in Japan increase relatively fast. This is explained by among other factors the assumed somewhat inelastic demand for fossil fuels in Japan. EU has implemented considerable higher oil taxes than the USA and Canada. That should lead to higher abatement costs in Europe. However, the intensive use of coal in Europe draws in the other direction. Hence, the model finds that the abatement costs are relatively similar in Europe and the USA and Canada.

Figure 2 shows the models estimated *total* cost curves for the different countries and groups of countries before terms of trade-changes are taken into account. The costs are measured as income loss in percentage of the GDP in 1990. The double dividends, i.e. benefits from revenue recycling are included. These cost curves capture that the use of emission taxes will

generate public revenue, which could be reimbursed to the private sector. It is assumed that the reimbursement implies reduction of other taxes. Reduced tax rates will in general increase the efficiency of the economies and hence adjust the net cost curves downwards.

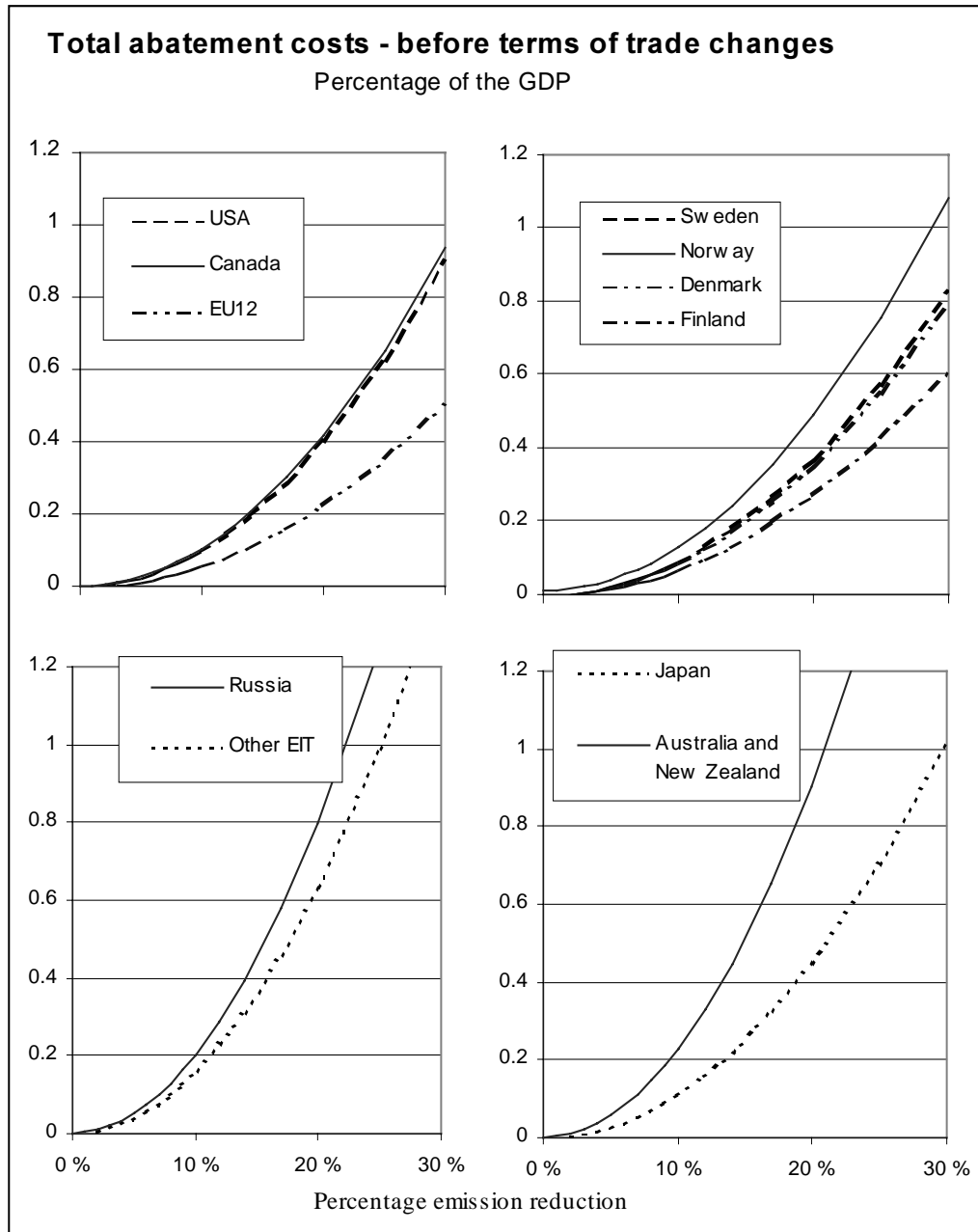


Figure 2: Estimated abatement costs. Terms of trade-changes are not taken into account, but the benefits from revenue recycling are included.

In order to understand the differences between the cost curves in figure 1 (marginal costs in USD pr. tonnes CO₂ equivalents) and figure 2 (total costs in percentage of GDP) we should keep in mind that in figure 1, we measure absolute costs along the vertical axes, while we measure the total costs relative to the countries' respective GDP in along the vertical axes in figure 2.

The change from absolute costs to costs in relation to GDP explains also to a large part why the cost curve of the USA now is elevated compared to the cost curve of EU, while it was slightly below in Figure 1 which measured marginal costs in absolute terms.

From figure 2 we see that the cost curves all start at origo. This is a result of the calibration method for parameters representing the marginal excess burdens of taxation, see the box above with some key features of ACT. Due to this calibration method we rule out ‘no regret’ options or so-called ‘strong double dividend’. The cost curves would, however, be steeper if we had not included benefits from revenue recycling, i.e. weak double dividend.

6 Some possible consequences of the Kyoto Protocol

By the use of the numerical model ACT presented in the previous sections, this section presents numerical examples in order to illustrate some economic consequences of the Kyoto Protocol and especially how transboundary emission trading between countries will alter the distribution of costs. The numerical examples will furthermore provide some ideas of which countries are likely sellers and buyers in the quota market and a likely level of the quota price.

Table 1: BAU-emissions of CO₂ (million tonnes) and other greenhouse gases (OGHG, million tonnes of CO₂ equivalents) in 1990 and 2010, the Kyoto quotas and the emission reduction commitments.

| | Emissions 1990 CO ₂ | Emissions 1990 OGHG | Sum emissions 1990 | BAU Emissions 2010 CO ₂ | BAU Emissions 2010 OGHG | Sum 2010 BAU emissions | Quota | Reduction commit- ment |
|----------------|--------------------------------------|---------------------------|--------------------------|---|----------------------------------|------------------------------|---------|------------------------------|
| USA | 4957.0 | 784.0 | 5741.1 | 6097.1 | 720.6 | 6817.7 | 5339.2 | 1478.5 |
| Canada | 462.6 | 103.1 | 565.8 | 550.5 | 110.1 | 660.7 | 531.8 | 128.8 |
| EU12* | 3121.5 | 749.9 | 3871.4 | 3304.6 | 592.8 | 3897.4 | 3581.4 | 316.0 |
| Denmark | 60.2** | 19.6 | 79.8 | 66.0 | 17.6 | 83.6 | 63.0 | 20.5 |
| Finland | 53.9 | 10.9 | 64.8 | 63.3 | 12.0 | 75.3 | 64.8 | 10.5 |
| Sweden | 61.3 | 11.2 | 72.4 | 72.3 | 12.4 | 84.7 | 75.3 | 9.4 |
| Norway | 35.5 | 18.6 | 54.1 | 49.0 | 15.5 | 64.5 | 54.6 | 9.9 |
| Other OECD | 47.2 | 12.9 | 60.2 | 46.7 | 11.2 | 57.8 | 55.9 | 1.9 |
| Russia | 2388.7 | 594.8 | 2983.5 | 2221.5 | 594.8 | 2816.3 | 2983.5 | 0.0 |
| Other EIT | 1690.9 | 428.5 | 2065.4 | 1711.8 | 317.7 | 2029.5 | 1968.7 | 60.8 |
| Australia/N.Z. | 314.4 | 202.2 | 516.7 | 402.3 | 179.3 | 581.5 | 552.1 | 29.4 |
| Japan | 1155.0 | 46.1 | 1201.1 | 1325.9 | 41.5 | 1367.5 | 1129.1 | 238.4 |
| Sum | 14348.3 | 2981.9 | 17276.2 | 15911.1 | 2625.4 | 18536.5 | 16399.5 | 2304.2 |

* EU-15 minus Denmark, Finland and Sweden.

** Adjusted to account for import and export of electricity and variations in temperature. The actual emissions were 52.3 mill. tonnes CO₂.

When the countries are free to buy or sell parts of their emission quotas in a market, they are assumed to reduce their domestic emission to the level where the marginal abatement costs are equal to the quota price. Hence, in the case with free emission trading marginal abatement costs are equal both across gases and countries and equal to the quota price.

It is important to underline that the numerical examples do not take into account that the Kyoto Protocol states that quota import should be supplemental to domestic abatement efforts. In the actual model framework the governments simply minimize their costs, and do not take any environmental considerations into account. It should furthermore be noticed that the possibility for joint implementation projects and Clean Development Mechanism (CDM) and its influence on the quota market is not taken into consideration here. If, however, emission rights could be achieved through CDM, this could constitute a ceiling for the quota price.

Annex B in the protocol specifies flat rate emission reductions within the European Union member countries. However, in accordance with article 4 the EU member countries are free to redistribute the commitments between them selves. In the presented numerical examples the internal EU-distribution agreed upon in June 1998 is therefore used as our starting point. That means for example that Denmark is assumed to reduce its emissions by 21% below the 1990 level, Finland must return to the 1990-emission while Sweden is allowed to increase the emissions by 4%. The Nordic EU-countries are treated separately, while the model aggregates rest of the EU-countries to one unit (labeled EU12 in the tables).

The assumptions about the countries' BAU emissions in 2010 are based on emission scenarios presented in national communications when this is possible. Some reported emission scenarios appear however unrealistically low. The BAU emissions of these countries are therefore adjusted upwards to what we see as a more realistic level, cf. **Table 1**. Where the emission scenarios are not presented in national communications, the assumed BAU-emissions are taken from Alfsen, Holtmark and Torvanger (1998).

Table 2: Abatement of CO₂ and other greenhouse gases (OGHG) and quota import in the three scenarios. Million tonnes CO₂ equivalents.

| | No trade | | Annex II trade | | | Free trade | | |
|----------------|-----------------|-------|-----------------|-------|--------------|-----------------|-------|--------------|
| | CO ₂ | OGHG | CO ₂ | OGHG | Quota import | CO ₂ | OGHG | Quota import |
| USA | 1406.3 | 71.0 | 1126.5 | 57.8 | 293.0 | 783.6 | 41.1 | 652.6 |
| Canada | 119.0 | 9.8 | 103.2 | 8.5 | 17.0 | 72.1 | 6.1 | 50.5 |
| EU12* | 313.0 | 25.8 | 600.2 | 46.0 | -307.4 | 413.7 | 32.8 | -107.7 |
| Denmark | 20.3 | 2.7 | 9.0 | 1.3 | 12.8 | 6.2 | 0.9 | 15.9 |
| Finland | 9.0 | 0.9 | 9.7 | 0.9 | -0.8 | 6.7 | 0.7 | 2.4 |
| Sweden | 6.9 | 1.0 | 5.6 | 0.9 | 1.5 | 3.9 | 0.6 | 3.4 |
| Norway | 9.3 | 3.0 | 4.0 | 1.3 | 7.0 | 2.8 | 1.0 | 8.6 |
| Other OECD | 1.5 | 0.4 | 3.7 | 0.8 | -2.6 | 2.6 | 0.6 | -1.2 |
| Russia | -31.5 | 0.0 | -33.2 | 0.0 | 0.0 | 286.0 | 35.2 | -488.8 |
| Other EIT | 54.7 | 5.7 | 54.6 | 5.8 | 0.0 | 244.8 | 18.9 | -203.2 |
| Australia/N.Z. | 24.8 | 4.5 | 96.9 | 14.6 | -82.2 | 67.2 | 10.4 | -48.2 |
| Japan | 233.8 | 4.4 | 173.1 | 3.3 | 61.7 | 120.2 | 2.4 | 115.6 |
| Non Annex B** | -319.3 | - | -324.7 | - | - | -298.4 | - | - |
| Sum | 2167.2 | 129.2 | 2153.4 | 141.4 | 0.0 | 2009.7 | 150.6 | 0.0 |

* EU-15 minus Denmark, Finland and Sweden.

** No abatement is assumed to take place in the non-Annex B countries. The negative numbers in this row reflect increased CO₂-emissions in the region due to carbon leakage, i.e. increased use of fossil fuels because of the price drops in the markets. The emissions of OGHG are not calculated for this region.

The Russian BAU-emissions in 2010 are assumed to be 7% lower than they were in 1990. Since the Russian emission quota is equal to the 1990 emissions, we assume 167 million tonnes 'hot air' from Russia measured in CO₂ equivalents. There might turn out to be 'hot air' also in other EIT-countries, but this possibility is ruled out here due to both our assumptions about BAU-emissions in 2010 and to the aggregation of the other EIT countries to one unit. Three cases are analyzed. Firstly, we look at the case where no emission trading is allowed to take place. Secondly, we look at the case where emission trading is free within Annex B

while the EIT-countries are not allowed to take part in emission trading. Thirdly, we look at the case where the Annex B countries are free to sell and buy quotas.

The distribution of the abatement efforts across the different gases and regions in the three cases as well as the trade movements in the quota market are listed in table 2. One should note that in the cases where the EIT-countries are not allowed to sell emission quotas, the Russian emissions of CO₂ are estimated to be 31-33 million tonnes higher than in BAU. This is a sort of carbon leakage due to the price drop in the fossil fuel markets caused by the abatement policies in the other Annex II countries. Such a leakage could take place because the Russian emission target is assumed to be non-binding.

A more serious carbon leakage is likely to take place in the non-Annex B countries. This carbon leakage is estimated to be around 14% of the total abatement within the Annex B region and of approximately the same size as the total abatement within EU.

Table 2 shows also the different countries and regions import of emission quotas in the three scenarios. Together with the EIT-countries the European Union are assumed to be the main quota sellers when emission trading is free. The EU is however going to sell a larger amount of quotas in the case with trade limited to the Annex II area due to the higher quota price in this case. The USA is the main quota buyer because of the high-expected emission growth in this country. In the case with trade only among the Annex II countries, the quota price is estimated to be USD 30.4 pr. tonnes CO₂ equivalent. In the case with free trade among the Annex B countries, the quota price is estimated to be USD 21.6 pr. tonnes CO₂ equivalent.

Figure 3 provides an overview of the calculated costs of the Kyoto Protocol. In these net-cost-estimates both abatement costs, losses and gains from terms-of-trade changes and benefits from revenue recycling are included. A first impression of the simulation is that the costs of the assumed climate protocol are relatively low in most of the countries in question, even without emission trading. We must here keep in mind that we deal with annual costs of emission reductions. They will therefore constitute income losses that have to be taken into account every year during the first commitment period.

According to the numerical examples, only Norway experiences net costs above 1% of the GDP. This is mainly explained by the oil and gas export from this country and the calculated price drop especially in the oil market following from the implementation of the Kyoto Protocol. Not least important in this respect is the fact that a large part of the profit in this country's oil and gas production is directly allocated into public budgets. Norway has imposed especially high profit taxes in the petroleum-producing sector, but public income is also generated through direct public ownership in the production of oil and gas. Reduced oil prices in the world market will therefore bring about reduced public revenue in Norway and hence force the Norwegian government to increase existing distortionary taxes.

Having a look at the scenario where emission trading is allowed, a noteworthy result is that the EIT-countries and the non-Nordic EU countries will experience net gains from the implementation of the Kyoto Protocol. As far as EU is concerned this is firstly explained by the considerable terms-of-trade gains that EU will experience mainly as a result of the drop in the oil price and the gas price. The second explanation, which also involves the EIT-countries, is the inclusion of the income these countries receive from their participation in the

quota market. According to the simulations the EIT-countries are the main quota sellers, but also EU is selling quotas.

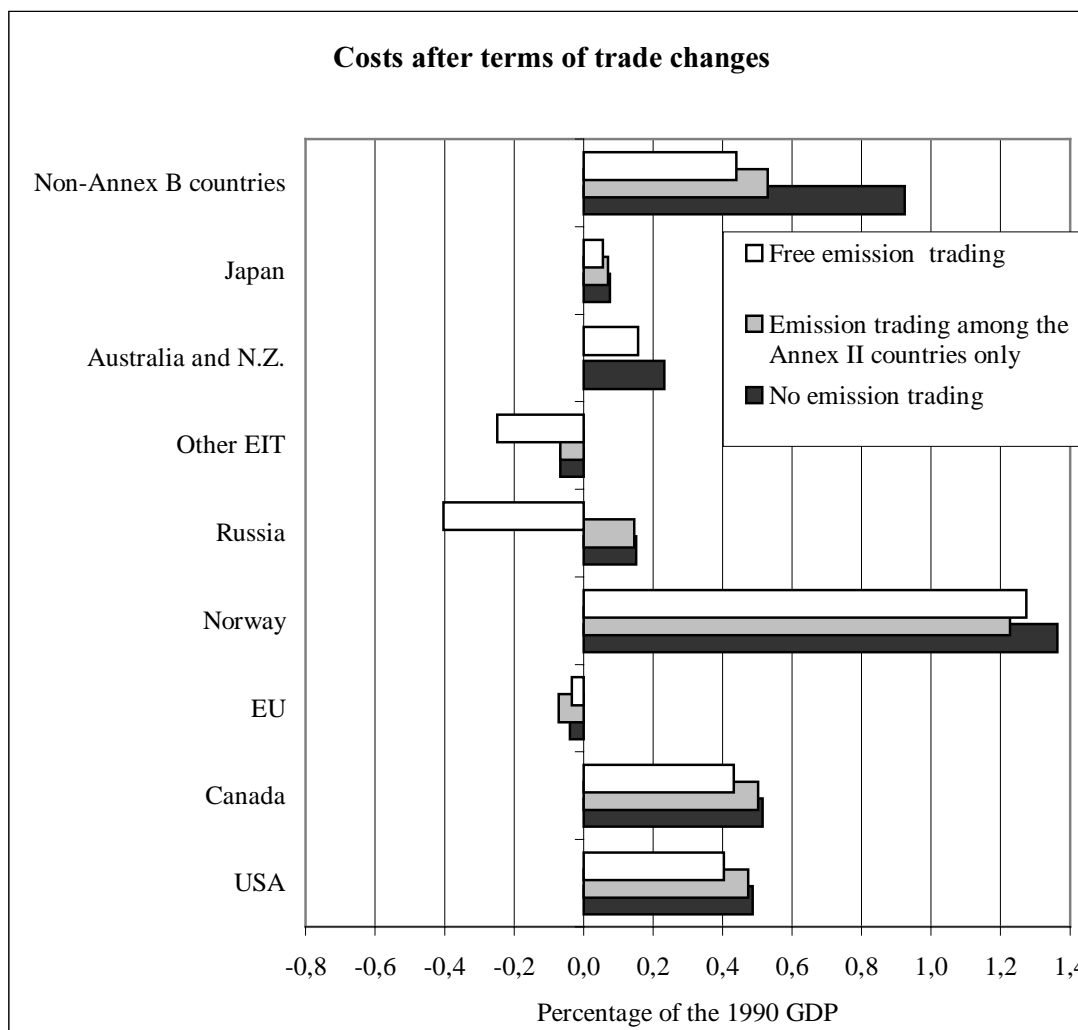


Figure 3: Costs of the Kyoto Protocol. The EU-differentiation agreed upon in June 1998 is internalized. Terms-of-trade effects are taken into account.

According to the simulations also Sweden should expect a small net benefit from the Kyoto Protocol. The main explanation is the burden-sharing rule within EU, which allows Sweden to increase its emission from 1990 to the first commitment period by 4%. That implies an emission reduction from the BAU-level of 11%. This number should be related to figure 1 and 2. From figure 2 we see that an emission reduction in Sweden of 11% implies abatement costs below 0.15% of GDP. The Swedish costs are nevertheless significantly smaller due to this country's gains from lower fossil fuel prices.

Denmark is committed to reduce the emission to a level 21% below the 1990-level. With our assumptions about the BAU-emissions in 2010 this implies an emission reduction from BAU of 25% and consequently Denmark experiences higher abatement costs than Sweden and Finland (emission reduction from BAU of 14%).

The USA experiences also relatively high costs, especially when this country is not allowed to buy quotas. Explanatory factors are the terms of trade changes and this country's role in the fossil fuel markets, as well as the expected BAU emission growth. The USA is a considerable producer of oil, coal and gas. Hence, while Japan and the EU experience large terms of trade gains due to price drops in the oil and coal markets, the US does not experience terms of trade gains of the same order of magnitude.

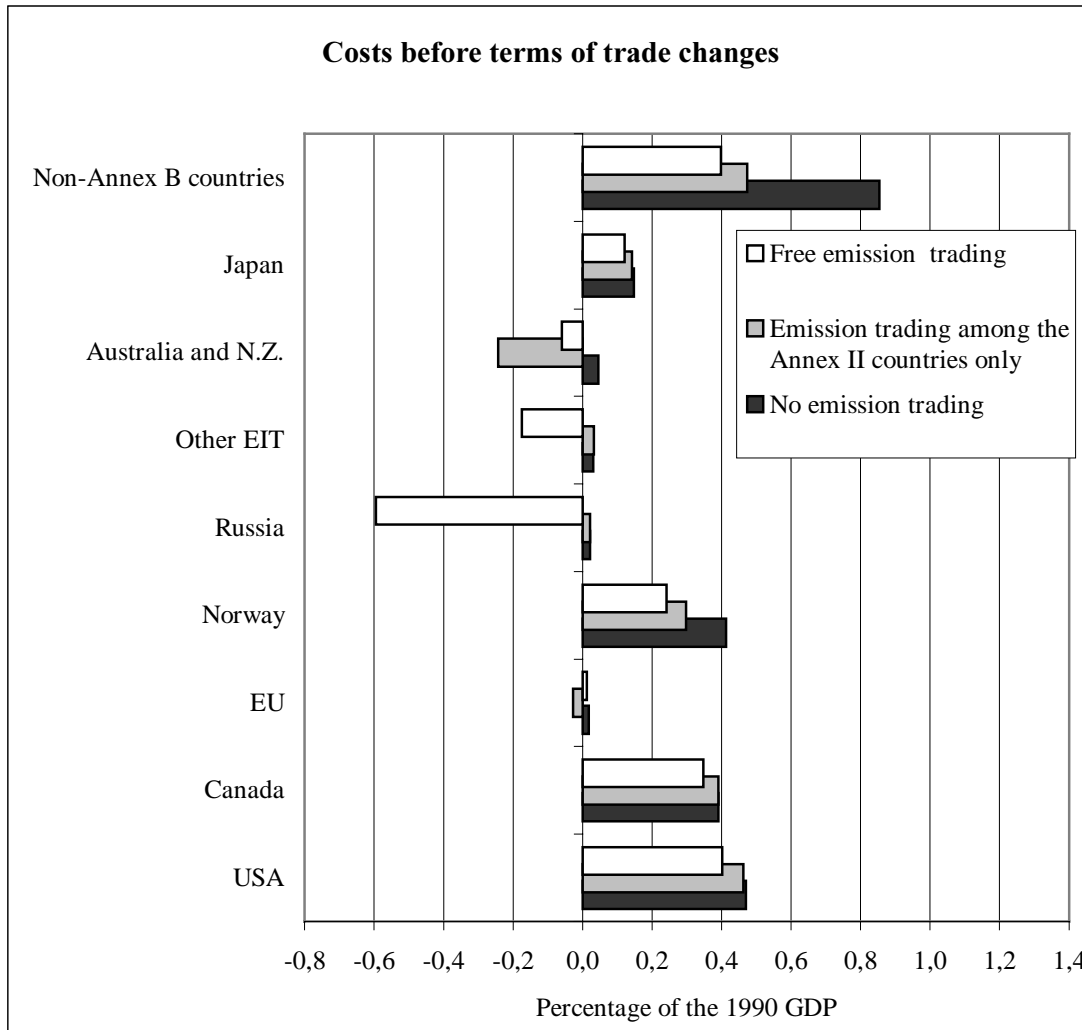


Figure 4: Costs when the terms-of-trade effects are *not* taken into account.

In both cases where emission trading is taking place, the USA is a buyer of quotas. In the case where the EIT-countries are allowed to take part in the emission trading, the USA is buying emission quotas equal to 12% of the initial number of quotas. Hence, the US emissions in that case are estimated to be 4.6% higher in 2010 that they were in 1990.

Especially Denmark and Norway but also Canada, USA, Australia and the EIT countries will receive significant benefits from emission trading. This is both related to especially high or low abatement costs in these countries or high or low emission reduction requirements. Countries with more average abatement cost patterns will not benefit to the same extent from

emission trading. The emission targets of Australia and Russia are for example likely to give these countries the possibility to attain gains from quota sale.

Figure 4 shows the estimated costs when terms of trade changes are not taken into account. This diagram constitutes a good starting point for increased understanding of the estimated abatement costs in figure 3, which include terms of trade changes. The costs of the fossil fuel exporters are reduced while the costs of the net importers are increased if we compare with the costs including terms of trade changes. We should furthermore note that some countries according to the numerical examples would experience net gains from the Kyoto Protocol even when terms of trade changes are not taken into account. This is basically a result of income from quota sales.

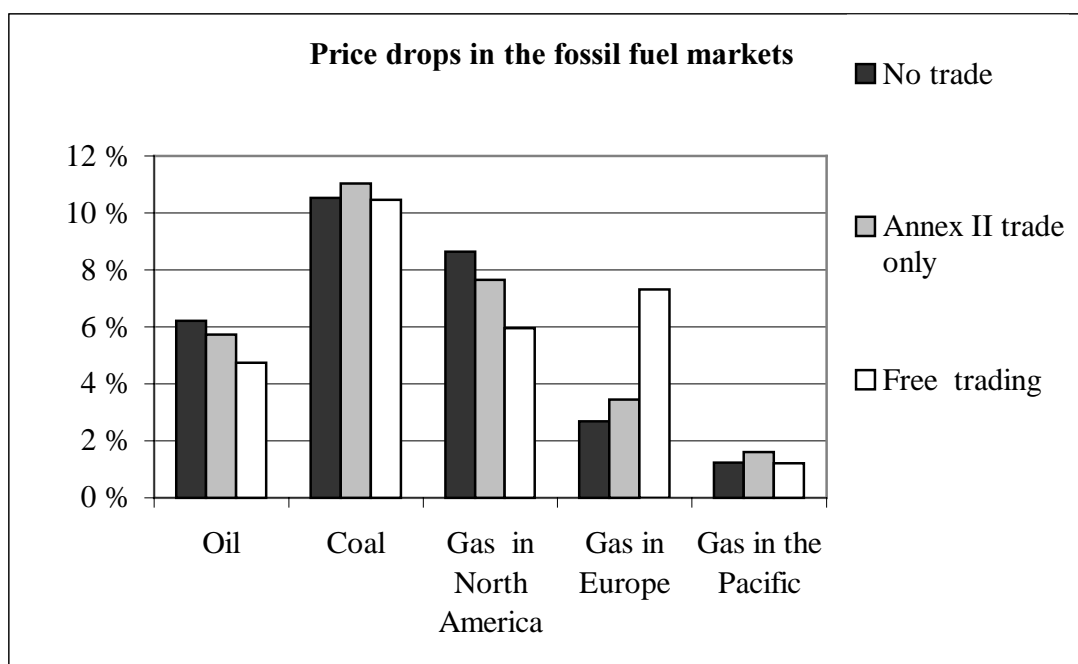


Figure 5: Estimated price changes in the fossil fuel markets.

Figure 5 provides an overview of the estimated price changes in the fossil fuel markets that are likely to follow from the implementation of the Kyoto Protocol. From a Norwegian point of view it is interesting that free emission trading is likely to enhance the price drop in the European gas market. The reason is the resulting redistribution of abatement efforts from countries where gas consumption plays a minor role for the GHG-emissions, to countries where combustion of natural gas is more important in this respect.

A result of the price drop in the fossil fuel markets is increased emissions of CO₂ in the non-Annex B countries, so-called carbon leakage, cf. table 2.

7 Conclusion

We have used a numerical model in order to provide an overview of the main economic consequences of the Kyoto Protocol. The analysis and the model concept has given emphasis to the inclusion of double dividends, or benefits from revenue recycling, in the abatement cost estimates. Furthermore, it is given attention to the links between different countries' abatement efforts and the equilibrium in:

- the three regional gas markets in North America, Europe and the Pacific region,
- the oil market,
- the market for quotas.

OPEC is assumed to behave strategically in the oil market.

We have analyzed three cases. In one case the possibility for emission trading was ruled out. In a second case countries in transition to a market economy (the EIT-countries) were not allowed to take part in the quota market. In the third case there was no restrictions on the quota market. We compared the implementation costs in the three cases and the trade patterns in the two last cases.

The analysis suggests that the EIT-countries will experience the largest benefits from emission trading and will be dominant on the supply side in the market. USA will be a dominant buyer of quotas, but will not to the same extent experience reduced implementation costs. The inclusion of benefits from revenue recycling is crucial for this result. The simulations indicate that the EU will not be an important participant in the quota market as long as the EIT-countries are included in the market.

The simulations indicate furthermore that EU, due to price drops in the fossil fuel markets, will experience negative net costs although not far from zero.

An interesting result, which should be further investigated and tested for robustness, is the links between the price changes in the fossil fuel markets and the trade movements in the quota market. The simulations indicate that emission trading leads to an enhanced price drop in the European gas market, while the oil price reduction at the same time is decreased.

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Appendix A: Fossil fuel taxes in 1990 and fossil fuels production and consumption patterns in the 2010 BAU-scenario*

| | Production (Mill. tonnes CO ₂) | | | Consumption (Mill. tonnes CO ₂) | | | Taxes (USD/tonnes CO ₂)* | | |
|------------------------------|---|------|------|--|------|------|---|------|------|
| | Oil | Coal | Gas | Oil | Coal | Gas | Oil | Coal | Gas |
| USA | 1655 | 2695 | 1131 | 3102 | 2311 | 1338 | 15.8 | 0.0 | 0.0 |
| Canada | 354 | 177 | 223 | 298 | 113 | 148 | 31.4 | 0.0 | 0.0 |
| EU12 | 298 | 828 | 287 | 1745 | 1107 | 453 | 66.5 | 0.1 | 13.0 |
| Denmark | 2 | 0 | 0 | 34 | 27 | 5 | 82.1 | 25.9 | 0.0 |
| Finland | 0 | 0 | 0 | 42 | 15 | 6 | 41.8 | 2.2 | 2.2 |
| Sweden | 0 | 0 | 0 | 61 | 10 | 2 | 87.6 | 38.4 | 25.8 |
| Norway | 427 | 0 | 154 | 39 | 3 | 6 | 47.0 | 23.9 | 0.0 |
| Other OECD | 0 | 0 | 0 | 43 | 2 | 3 | 49.2 | 1.0 | 0.6 |
| Russia | 1548 | 639 | 1027 | 749 | 655 | 787 | 0.0 | -1.0 | -0.9 |
| Other EIT | 53 | 1030 | 182 | 455 | 954 | 400 | 0.0 | -1.0 | -0.9 |
| Australia and New Zealand | 117 | 540 | 53 | 150 | 203 | 58 | 50.1 | 0.0 | 0.0 |
| Japan | 0 | 25 | 5 | 917 | 340 | 118 | 26.9 | 0.0 | 0.1 |

* The estimated average tax rates are taken from ECON (1995), which presents average fossil fuel taxes in the OECD countries from 1980 to 1994. The tax rates presented there are based on weighting energy taxes by product and sector. The information on taxes is based on IEA Energy Prices and Taxes. The information on taxes has been supplemented with EU's oil price statistics, 'Oil Bulletin' and with direct contact with national administrations. The weights are based on 'Basic Energy Statistics'. The Basic Energy Statistics have been supplemented with oil industry information and EU statistics on the use of leaded and unleaded gasoline and on the breakdown of heavy fuel oil according to sulphur content (relevant for countries differentiating heavy fuel oil taxes according to sulphur content). The calculation of the average taxation by sector takes into account the exempted use of energy within the sector. Concerning gasoline the taxes are for premium gasoline. Taxes for leaded and unleaded gasoline (where relevant) have been weighted with the consumption of the two qualities. For countries differentiating the tax between high and low sulphur, taxes are represented by the tax on the typical quality in industry and power generation.

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