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CO_2 mitigation costs and ancillary benefits in the Nordic countries, the UK and Ireland: A survey

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CO_2 mitigation costs and ancillary benefits in the Nordic countries, the UK and Ireland: A survey[1]

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Abstract

This paper provides a survey of top-down modelling studies on mitigation costs and ancillary benefits in the Nordic countries, the UK and Ireland. Special emphasise is put on results concerning revenue recycling, double dividend, distributional effects, and ancillary benefits. According to the papers surveyed, modest emissions restrictions as those given by the Kyoto Protocol, can be met without substantial costs for the countries studied.

Key words: Global warming, mitigation costs, double dividend, ancillary benefits

JEL classification: D58, Q43.

1. Introduction

Global warming was put on the political agenda by the middle of the 1980's, and around 1990, several countries, among them the Scandinavian countries, announced national emissions targets for carbon dioxide (CO_2) emissions. This encouraged several national modelling teams to analyse the economic effects of meeting these targets. After the introduction of the UN Framework Convention on Climate Change in Rio in 1992, and finally the signing of the Kyoto Protocol in 1997, national studies of greenhouse gas emission targets, and the introduction of measures to reduce greenhouse gas emissions (e.g., taxes, tradable or non-tradable quotas and voluntary agreements) increased rapidly. In addition, more studies focused on international treaties instead of unilateral emissions reductions, which has significant impacts on the prices of internationally traded goods.

Mitigation studies mainly follow two traditions; top-down and bottom-up analysis. The fundamental difference between them can be summed up as follows: top-down models begin with aggregated information and disaggregate, while bottom-up models begin with disaggregated data and aggregate. The former approach is a product of the field of economics, and the latter has its origins in engineering. Top-down models are a broad category of models that include general equilibrium, partial equilibrium and macroeconomic models, while bottom-up models focus on the energy sector and the technologies of energy production and address economic concerns only secondarily.

This paper provides a survey of the greenhouse gas mitigation costs and the ancillary benefits (or secondary benefits) of greenhouse gas abatement in Northern Europe; the Nordic countries (Norway, Sweden, Denmark, Finland)[2], the United Kingdom and Ireland. Modelling the economy-energy-environment interactions has a long tradition in these countries[3], and most of the studies conducted in Europe on ancillary benefits have been done for this region. The Nordic countries were early to announce carbon

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[2] We have not found any studies on Iceland, however, a CGE model for Iceland exists, see Hall and Clements (1998).

[3] The pioneering study on mitigation costs and ancillary benefits in this region and probably in Europe was Bye et al. (1989).

emissions targets and to introduce carbon taxes. In addition all these countries have signed the Kyoto Protocol. As national models are often more detailed, and as we have to limit the extent of the study, we do not concentrate on regional studies for instance for the European Union, where some of these countries are included, but choose to study national models or models that cover the Nordic countries. Also, we concentrate on top down models, as we are particularly interested in the impacts of greenhouse gas mitigation on such factors as welfare or GDP (gross domestic product), employment and income distribution, and not so much on detailed sector impacts.

The countries focused on in this study share many similarities, especially Ireland and the UK on one side and the Nordic countries on the other side. They belong to the same geographic area, have similar culture and welfare systems. However, they are also different in several respects. First, while the UK and Denmark are densely populated, the other Nordic countries and Ireland have a relatively small population compared to the land area. Second, the tax level and therefore also tax distortions are much higher in Nordic countries than in the UK and Ireland. This may for instance affect the conclusions of introducing carbon taxes and recycling the tax revenue. Third, the industry structure is different in the countries. One example is the difference between fossil fuel importing and fossil fuel exporting countries. Fossil fuel importing countries (e.g., Sweden, Finland and Ireland) may reduce their dependency of fossil fuels as the prices increase, and also capture some of the oil rent by introducing national carbon taxes. On the other hand, an international carbon treaty may substantially hit oil and gas producing countries such as Norway, as lower oil and gas prices give a reduced petroleum wealth. Finally, and maybe the most important difference when it comes to mitigation costs, is the energy system and especially the production of electricity. This is important for the possibilities of substituting towards less polluting technologies. While the electricity production is almost carbon-free in Norway (hydropower) and Sweden (primarily hydro and nuclear power), Denmark, Finland, the UK and Ireland has a potential for substituting from coal (and peat) use towards use of natural gas in electricity and district heating production.

Macroeconomic modelling of the impacts of environmental policy has different traditions in the different countries. While it has a long tradition in Norway, it is less used in, e.g., Ireland. Studies on secondary benefits of CO_2 mitigation are mainly done in Norway and the UK. However, a few studies have also been conducted for Sweden. The tradition of publishing the studies in international journals also varies a lot among the countries, e.g., Denmark has completed several studies, but very little is published internationally.

The paper mainly surveys studies that have been produced after the IPCC SAR (Second Assessment Report) process (IPCC, 1996). We started up by basically concentrating our effort on studies that have been published in peer-reviewed journals or books, and mainly in English. However, as mentioned above, as many of the national studies have only been published in working paper series, we also had to include them. There may be some studies not included in this survey, but we hope that the most important modelling attempts are presented. Instead of organising the paper according to country results, we have arranged it on the basis of the effects of greenhouse gas mitigation. Thus, in spite of the differences that exist between countries, this allows for the possibility to draw some general conclusions.

2. Impacts on GDP and welfare

There has been a large discussion in the literature about the aggregate impacts of carbon policies. The net cost is often measured by a reduction in GDP or a welfare index. Most economists agree that GDP is not a good measure of welfare, see, e.g., the discussion in Brekke and Gravingsmyhr (1994). However, as many studies report impacts on GDP, we will in this section report impacts on both GDP and economic welfare, usually measured by a utility function.

There are several reasons why different models may give different results even for the same economy and for the same regulation. The following list gives some reasons why studies differ and is therefore important in understanding the results presented:

- Type of model: The costs may differ dependent on if the model is, e.g., static or dynamic or if it is a general or partial equilibrium model. E.g., a CGE (Computable General Equilibrium) model calculates the long run equilibrium, and may not take into consideration short term rigidities.
- Aggregation level: In general, the more aggregated the model is, the higher may the cost be. This is due to reduced abilities of readjustments.
- Baseline assumptions: The reference scenario is crucial. E.g., the higher emissions in the reference scenario, the higher are the costs of reaching a given emission target.
- Substitution possibilities: In general, the better the substitution possibilities are in production and consumption, the lower are the costs of regulation.
- Costs and availability of technology: Models without a backstop technology will, e.g., tend to estimate higher economic impacts of a regulation than a model with a carbon-free backstop technology.
- Number of greenhouse gases: If the aim is to reduce an aggregate of GHG (greenhouse gas) emissions, the costs will be lower if we have the option of reducing several gases rather than CO_2 emissions only.
- Feedback from the environment to the economy: If these feedback's are modelled, the costs of reducing pollution will also be lower.
- Endogenous technological change: If greenhouse gas agreements induces technological change, a model with endogenous technological change may give lower costs of meeting a certain target than a model with exogenous technological change.
- Recycling of tax revenues: Regulation costs will be lower if carbon tax revenues are used to reduce other distortionary taxes than if they are distributed lump sum. The costs and the effects of recycling are also very dependent on the existing taxes in the economy, which varies between different countries.
- Number of policy instruments: More policy options will in general reduce the costs. Including, e.g., reforestation as a policy instrument may reduce abatement costs.
- International co-operation: Flexible mechanism such as joint implementation and international emission permit trade, will in general reduce costs compared to unilateral emission reductions as there are more policy instruments. However

effects of an international agreement on prices of traded goods such as oil may make the picture more complicated.

Various policy instruments have been compared along the following lines: Does the instrument lead to an efficient allocation of emission reductions? Does it lead to revenues that may be recycled to the economy? Is the recycling of revenues used to reduce distortionary taxes? In this survey we will mainly focus on the impacts of carbon taxes or emission permits, as these instruments have been mostly analysed in national studies. Then the question of revenue-making and how the extra revenues are recycled back into the economy is obviously crucial.

Much of the debate in later years has been circled around the notion of double dividends, i.e., are benefits obtained by the policy in addition to the environmental benefits? The motivation for this is that the tax revenues from a carbon tax or auctioned permits may be used to reduce distortionary taxes in the economy, which will have beneficial impacts. However, there has been some confusion about this notion.

It seems to be usual to distinguish between at least two forms of double dividends (following Goulder, 1995b): Strong double dividends occur if the substitution of the carbon tax for another distortionary tax involves a zero or negative costs (excluding any positive environmental effects).[4] Weak double dividends occur if the same tax swap leads to cost savings relative to the case where tax revenues are redistributed by lump-sum transfers. As Goulder points out, the weak double dividend notion is relatively uncontroversial. The implication of this is that carbon policies that raise revenues for the government are preferable to policies that do not, assuming the policies are identical in other respects.

Thus, the most interesting discussion is related to the notion of strong double dividends. In order to clarify the discussion, the total costs of a tax swap have been divided into three parts (see, e.g., Bovenberg and de Mooij, 1994, Goulder, 1995b, and Parry, 1997). The first part is the <u>direct costs</u> of a carbon tax assuming no initial

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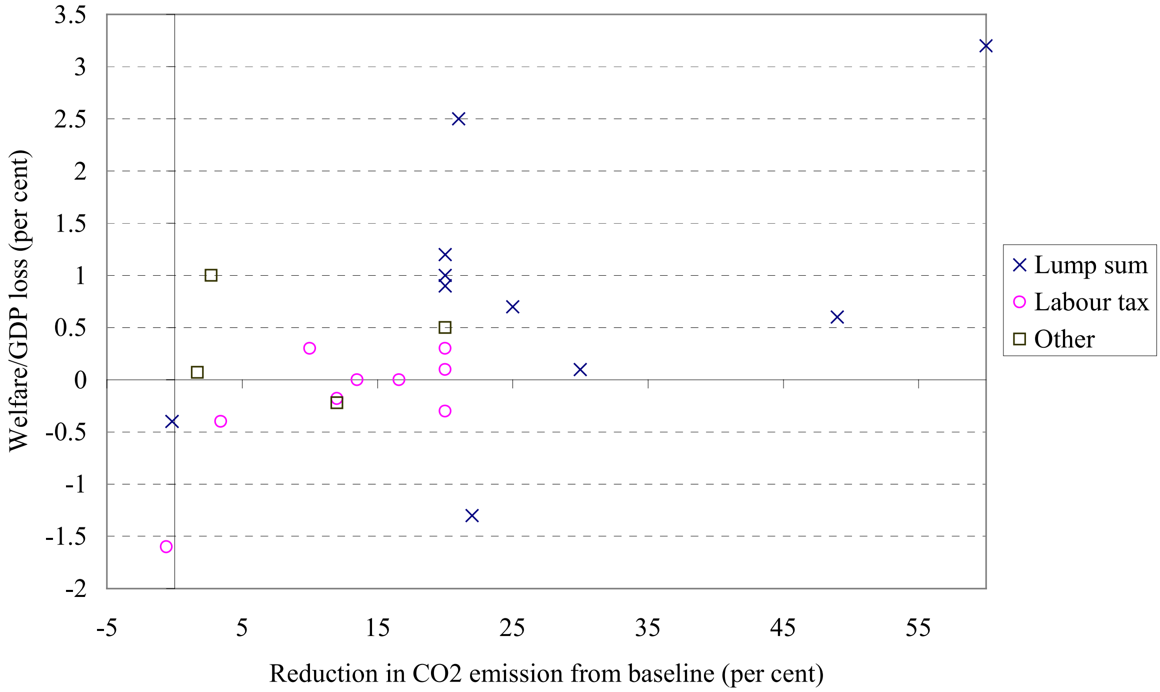
[4] Goulder (1995b) also requires that the distortionary tax should be a typical one.

tax distortions. The second part is the so-called tax interaction effect, which are the extra costs due to the carbon tax reinforcing the existing distortionary taxes. One reasoning behind this effect is that increasing the taxes of energy implicitly increases the tax burden on labour, as consumer prices increase. The higher the tax wedge already existing in the labour market is, the higher may this effect be. The third part is the so-called revenue recycling effect, which are the benefits from using the extra tax revenues to reduce other taxes making a distortion in the economy. One way of recycling the tax revenues is reducing the taxes on labour. For economies with high tax wedges in the labour market as the Scandinavian countries, this may give a high cost reduction. A strong double dividend is obtained if the third part is at least as large as the two former parts. Note that for a policy that does not raise extra revenues only the two first parts are relevant, which means that the total costs are necessarily positive and higher than the direct costs.

One result from the theoretical literature is that when the economy is initially in a second best optimum the revenue recycling effect may not even be high enough to counter the tax interaction effect, i.e., that the total costs of the tax swap exceeds the direct cost of the carbon tax (see, e.g., Bovenberg and de Mooij, 1994). However, if there are initial distortions in the tax system or in the market, a double dividend may be found (see, e.g., Bovenberg and Van der Ploeg, 1998). Also, several numerical studies, particularly in Europe, find that the revenue recycling effect exceeds not only the tax interaction effect, but also the direct costs, i.e., strong double dividends are obtained (see, e.g., Barker and Rosendahl, 2000). Such results are especially found in models where markets (the labour market in particular) are out of equilibrium, or where the labour supply is wage sensitive. One critical question is of course why such a tax reform has not been introduced earlier, if it leads to pure economic benefits.

Figure 1. Welfare (or GDP) loss and CO_2 emission reduction in various mitigation cost studies with uniform CO_2 taxes or emission permit auction.



We will start by reviewing studies with uniform carbon taxes or an auction of emission permits, and distinguish between various forms of recycling. Figure 1 sums up the results of all these studies by plotting the percentage reduction in CO_2 emissions against the percentage welfare (or GDP) loss, where the definition of welfare excludes environmental benefits, but otherwise differs between studies. The sort of recycling is characterised by different mark symbols. Table 1 presents an overview of the different studies. In section 2.2 we go on to investigate the effect of tax exemptions and free (i.e., grandfathered) permits.

Table 1. CO_2 mitigation costs studies with uniform taxes or permit auction.

Study	Country	Recycling	Welfare measure	Carbon tax ($/tC)	CO_2 reduction (%)	Welfare loss (%)
Håkonsen and Mathiesen (1997)	Norway	Lump sum	Welfare index		20	1
Aasness et al. (1996)	Norway	Lump sum	Welfare index	238	22	-1.3
Brendemoen and Vennemo (1994)	Norway	Lump sum	GDP	700	60	3.2
Jensen (1998)	Denmark	Lump sum	Welfare index	147	20	1.2
Gørtz et al. (1999)	Denmark	Lump sum	Welfare index	158	20	0.9
Frandsen et al (1995,96)	Denmark	Lump sum	GDP	147	25	0.7
Nilsson (1999)	Sweden	Lump sum	GDP	367	21	2.5
Bergman (1995)	Sweden	Lump sum	GNI	440	49	0.6
Honkatukia (1997)	Finland	Lump sum	Welfare index		-0.2	-0.4
Jerkkola et al. (1993)	Finland	Lump sum	GDP		30	0.1
Bye (1999)	Norway	Labour tax	Welfare index	367	13.5	0
Håkonsen and Mathiesen (1997)	Norway	Labour tax	Welfare index		20	0.3
Gørtz et al. (1999)	Denmark	Labour tax	Welfare index	169	20	-0.3
Jensen and Rasmussen (1998)	Denmark	Labour tax	Welfare index		20	0.1
Hill (1999)	Sweden	Labour tax	Welfare index		10	0.3
Honkatukia (1997)	Finland	Labour tax	Welfare index		-0.6	-1.6
Barker et al. (1993a)	UK	Labour tax	GDP	90	12	-0.18
Barker (1997)	UK	Labour tax	GDP	184	16.6	0
Fitz Gerald and McCoy (1992)	Ireland	Labour tax	GDP	90	3.4	-0.4
Andersen et al. (1998)	Denmark	Indir. and income tax	GDP	26	1.7	0.07
Gørtz et al. (1999)	Denmark	VAT	Welfare index	172	20	0.5
Barker et al. (1993a)	UK	VAT	GDP	90	12	-0.22
Fitz Gerald and McCoy (1992)	Ireland	Debt repayment	GDP	90	2.7	1

2.1 Uniform carbon taxes and permit auctions

2.1.1 Recycling through lump sum transfer

In this section we will review the results of introducing uniform carbon taxes or permit auctions, with lump sum transfers of the tax revenues. Thus, they are not used to reduce distortionary taxes, and therefore strong double dividends are not attainable. We present the studies in a country-wise order, starting with the Nordic countries.

Until late 1990's Norwegian studies in this field were not concerned with different kinds of revenue recycling. Most of the studies are based on a computable general equilibrium model called MSG (Multi Sectoral Growth), which has been used in Norwegian long-term planning for many years. E.g., Brendemoen and Vennemo (1994) use the MSG-5[6] model to study the impacts of a global climate treaty on the Norwegian economy. Global emissions of CO_2 should not increase between 1987 and 2000. From there on, a growth of 0.6 per cent per year is allowed. The global carbon tax is calculated to $315 in 2000 and $700 in 2025 (1987 prices) per ton of carbon. The Norwegian GDP growth rate is reduced by 0.1 per cent, leading to 3.2 per cent lower GDP in 2025 than in baseline. CO_2 emissions for Norway are reduced by 60 per cent in this scenario, which is higher than the 47 per cent reduction globally. *Imports* fall more than exports. One reason is that Norwegian products are less CO_2-intensive than many international competitors' products, giving a lower increase in domestic prices compared to foreign prices.

Johnsen *et al.* (1996) studies the impacts of a number of unilateral CO_2 taxes on the Norwegian economy by using a version of the CGE model MSG-EE, which is specially developed for analysing energy and environmental policies (see Alfsen *et al.*, 1996). A tax in the order of $50 per ton CO_2 is required in order to stabilise national emissions in year 2020 at the 1989 level, giving a GDP loss of 0.5 per cent. Compared to baseline, CO_2 emissions are reduced by 21 per cent. At the other extreme, increasing the tax level to $750 per ton CO_2 reduces emissions in 2020 by 48

[6] MSG-5 is the fifth generation of the MSG model developed at Statistics Norway.

per cent and GDP by 2.9 per cent. Aasness *et al.* (1996) use the same model and reference scenario, but focus on welfare effects rather than changes in GDP only. Introduction of CO_2 taxes to stabilise emissions in 2020 reduces GDP by 0.7 per cent, but increases national real disposable income and private consumption in fixed prices. The difference in sign is due to a positive *terms of trade effect*; some of the CO_2 taxes will be paid by foreigners through exports. Export is concentrated on relatively few intermediate goods with varying prices. Imports are more diversified and average import prices thereby fluctuate less than export prices. To keep the trade balance constant, imports must be reduced less than exports in volume, giving increased consumption.

Another CGE model for the Norwegian economy is the SNF model. Håkonsen and Mathiesen (1997) use this static model to study the impacts on welfare of uniformly reducing the Norwegian CO_2 emissions in 2000. The sectoral aggregation SNF model is made especially for analyses of climate policies, i.e., activities are aggregated that have similar emissions compared to production.[7] This is not necessary the case in the MSG model. Welfare is measured by a combined index of commodity and leisure consumption. When CO_2 emissions are reduced by 20 per cent (i.e., stabilising emissions at 1990 level), welfare is reduced by 1 per cent when tax revenues are redistributed through lump sum transfers.

For Denmark, Frandsen et al. (1995, 1996) analyse carbon abatement using a static, multisectoral CGE model, GESMEC (General Equilibrium Simulation Model of the Economic Council). In all scenarios, emissions are reduced by 25 per cent in 2005 compared to the baseline. In the main scenario, a unilateral *tax* of DKK 300 ($40) per ton CO_2 is levied on all fossil energy consumption from 1990. *Private consumption* in 2005 is reduced by 0.3 per cent, and *GDP* is reduced by 0.7 per cent. However, in a short run (8 years) analysis where adjustment costs are taken into account, the GDP loss is as high as 3.9 per cent, and a CO_2 tax of DKK 700 ($90) is required. In the long run (i.e., without adjustment costs), there is a convex relationship between emission reduction and abatement costs, e.g., the consumption loss in 2005 is almost 3 times as large when emissions are reduced by 35 per cent. Simulations also show that

[7] See Mathiesen (1999) for more information on the model and a survey of studies conducted on it.

internationally co-ordinated carbon taxes will give a slightly less consumption loss for Denmark than a unilateral introduction of carbon taxes as the Danish terms-of-trade is not worsened in the same way.

In Jensen (1998) the effects of a unilateral reduction of CO_2 emissions by 20 per cent is studied in an adapted static version of the MobiDK (Ministry of Business and Industry, Denmark) core model, a multi-sectoral computable general equilibrium model of the Danish economy. Jensen finds that a tax of approximately DKK 300 ($40) per ton of CO_2 is needed. This generates welfare losses of 1.2 per cent, which are higher than in Frandsen et al. (1995,1996). This is mainly due to simplifications in the latter studies such as finite trade elasticities for non-energy goods, no distortionary pre-existing taxes, and no labour-leisure choice. All these assumptions work in favour of lower welfare costs.

Gørtz *et al.* (1999) combine the two general equilibrium models GESMEC and MobiDK to construct a new static model called ECOSMEC for the Danish economy (see also Gørtz and Hansen, 1999). They investigate several CO_2 tax scenarios, with special focus on imperfections in the energy production sector. In addition to perfect competition, they examine the effects of average cost pricing, pure monopoly and free entry oligopoly. With a uniform CO_2-tax and lump sum recycling, reducing CO_2 emissions by 20 per cent gives a GDP reduction of 0.2 to 0.3 per cent under the various assumptions about market structure. Furthermore, welfare (households' utility as a function of consumption and leisure) falls by 0.9 to 1.1 per cent. Consequently, different competition regimes seem to have very little impact on the effect of CO_2 taxes. The size of the tax varies from DKK 247 (oligopoly) to 304 (perfect competition) per ton CO_2 (i.e., around $35 to $45). Varying the substitution elasticities between input factors in production has also little influence on the results.

A study on Sweden is Bergman (1995) that uses a slightly revised and elaborated version of the CGE model presented in Bergman (1991) to analyse impacts of unilaterally reaching CO_2-emission goals. Three emission targets are analysed for the year 2000; 60, 50 and 40 million tons of CO_2, where 60 million tons are roughly equal to the 1990 level. Baseline emissions in 2000 are estimated to be almost 79 million tons. The tax needed for the different emissions levels is rising from SEK 250 ($30) to

SEK 900 ($120) per ton of CO_2. The impacts on full-employment GDP and GNI (gross national income, i.e., a measure of the purchasing power of the aggregated factor incomes) are quite limited (0.2 per cent for GDP at the most). However, the GNI loss is about three times as high as the corresponding GDP loss, reflecting a deterioration of terms of trade. Thus, the uniform CO_2-tax may give a costly restructuring of the export-oriented industry.

Also studying Sweden, Nilsson (1999) uses the CGE model GEM-E3 for the European Union to investigate the effects of introducing unilateral CO_2 taxes. The model treats trade in goods between member countries and with the rest of the world. She examines the effects of doubling the existing CO_2 taxes, i.e., about $100 per ton CO_2. Tax revenues are redistributed to households in a lump sum way. According to her results, without tax exemptions the tax increase leads to a drop in CO_2 emissions by 21 per cent and a fall in GDP by 2.5 per cent in 2020. The GDP loss is particularly related to reduced export of energy-intensive goods (see also section 2.2).

The impacts for Finland are studied by Jerkkola *et al.* (1993) who use a static CGE model based on the Swedish model by Bergman (1991). They study various scenarios for unilaterally stabilising CO_2 emissions in 2000 at the 1990 level using CO_2 taxes. The emission constraint requires a 30 per cent reduction in CO_2 emissions. In some scenarios they allow for subsidies to energy intensive industries (see section 2.2). Two different assumptions are used with respect to whether different sectors are price takers or not. In the basic model the metal and chemical industries and the electrical equipment sector are price takers, whereas the Armington assumption is applied to other sectors. In the alternative model the electrical equipment sector is assumed to have influence on its product prices, whereas the pulp and paper industry is assumed to be a price taker. In both model versions, the CO_2 tax has little effect on aggregate production, i.e., GDP falls by respectively 0.1 and 0.3 per cent. However, in the basic model metal and chemical industries are completely replaced by the electrical equipment sector. In the other model version there is less reallocation between sectors. The CO_2 tax rates are respectively FIM 121 ($20) and 197 ($32) per ton CO_2.

Honkatukia (1997) examines several CO_2 tax scenarios in Finland, using a pseudo-dynamic CGE-model with monopolistic competition in the domestic markets. In all scenarios proposed CO_2 taxes for 1997 are increased proportionally by 50 to 200 per cent.[8] When the CO_2 tax is doubled, lump sum redistribution actually leads to a slight increase in both GDP and welfare (consumers' utility of consumption and leisure) by 0.8 per cent when sector investments are fixed. With aggregate investments fixed, the gain is 0.4 per cent. However, emissions are more or less unchanged in both cases. The reason seems to be that most of the carbon taxes are paid by price insensitive traffic users, whereas industry output is stimulated by higher GDP. Therefore, in Honkatukia's study there seems to be economic, but not environmental, gains from the environmental policy.

None of the studies available from the UK or Ireland present analyses of uniform CO_2 taxes or permit auctions with no recycling other than lump sum transfers.

To sum up these studies, we see from Figure 1 that the welfare (or alternatively GDP) changes vary significantly, e.g., from a gain of 1.3 per cent to a loss of 2.5 per cent for CO_2 reductions around 20 per cent. 2 out of 10 studies find welfare gains - Honkatukia (1997) finds both higher welfare and higher emissions, whereas Aasness *et al.* (1996) find welfare gains due to positive terms of trade effects. An indication of the costs of mitigation may be the ratio between the percentage welfare loss and the percentage emission reduction. Then we find that the highest mitigation costs occur in the Swedish study by Nilsson (1999) (ratio of 0.12) and the lowest costs naturally occur in the Norwegian study by Aasness *et al.* (1996) (ratio of -0.06). Since the countries reviewed in this survey differ quite much with respect to energy structure etc, one might assume that the mitigation costs would differ significantly across the countries. However, we are not able to conclude on any such differences, except perhaps for seemingly small costs in Finland. The explanation for the wide differences has more to do with the elements listed in the introduction of this chapter.

2.1.2 Recycling through tax reductions

Revenues from CO_2-taxes may be recycled through reductions in other taxes. Introducing a CO_2 tax while reducing an existing distortionary tax has *a priori* ambiguous effects on GDP. However, one would expect that the industrial structure in

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[8] Except for peat, all users are faced with the same CO_2 tax of FIM 70 ($12) per ton CO_2.

general and the production structure for electricity and other energy are important for the results. In Norway, e.g., a tax on fossil fuels may not increase prices of consumption good in the same extent as the other countries as electricity production is carbon free. Also as the petroleum sector is usually exogenous in CGE models, the revenues from CO_2 taxation may be high, giving possibilities for large reductions in other distortionary taxes. Thus, the possibilities for a strong double dividend may be good in this case. In Denmark, CO_2 taxes may give a higher impact on consumption prices, due to the production structure of electricity. This reduces consumption and, therefore, also the tax income and the possibility to reduce other distortionary taxes. Similar effects may explain the non-existence of double dividend in American studies such as Jorgenson and Wilcoxen (1993) and Goulder (1995a).

The Norwegian study by Håkonsen and Mathiesen (1997) are concerned with various sorts of revenue recycling. In contrast to the scenario with lump sum transfers presented in section 2.1.1, they construct a new tax scenario where tax revenues are used to reduce employer's social security contributions. The welfare loss from reducing CO_2 emissions by 20 per cent are significantly reduced in this scenario compared to the tax scenario with lump sum transfers, i.e. from 1 to 0.3 per cent, confirming weak double dividends. Actually, when emissions are reduced by 5-15 per cent, the tax swap is welfare improving, implying strong double dividends.

The non-environmental welfare effects of a "green" tax reform are analysed by Bye (1999), using the intertemporal general equilibrium model MSG-6. The existing (1995) CO_2 taxes in Norway vary, with the highest tax on gasoline of NOK 360 (approximately \$50) per ton CO_2. Under the tax reform, the CO_2 tax is increased to NOK 700 (approximately \$100) per ton CO_2 for all kinds of fossil fuels, and no producers or consumers are exempted. The tax revenue is rebated through a reduction in the payroll tax so that the government revenues and expenditures are unchanged from the reference path in each period. The tax is introduced in 2000. Total welfare, measured by discounted utility, increases by 0.12 per cent, while CO_2 emissions are reduced by 13.5 per cent in the long run (2050). GDP is approximately unchanged. The tax reform thus supports the double dividend hypothesis of strong form. The welfare effect is positive because the tax reform exploits existing tax wedges between consumption and saving, and between paid work and leisure.

For Denmark, Gørtz *et al.* (1999) examine to what degree various sorts of recycling affect the economic welfare effects of CO_2 taxes (see preceding subsection). CO_2 emissions are reduced by 20 per cent in all scenarios. When tax revenues are used to reduce the VAT rate, GDP increases by 0.1 per cent and welfare decreases by 0.5 per cent (with lump sum transfers GDP and welfare were reduced by 0.2 and 0.9 per cent). The increase in GDP has to do with a higher real wage due to reduced prices, which leads to increased labour supply. Moreover, reducing the labour income tax instead implies that GDP increases by 0.9 per cent and welfare by 0.3 per cent. In this case there is a significant increase in the real wage and corresponding increase in labour supply. Consequently, there is a gain in GDP and economic welfare of about 1 percentage point by reducing the distortionary tax on labour rather than using lump sum transfers. In the former case the policy leads to strong double dividends.[9]

Andersen et al. (1998) present analyses of carbon taxes in Denmark with and without revenue recycling. They use a Keynesian type macroeconometric model for *short-and medium-term analyses* called ADAM (Annual Danish Aggregated Model). The model is used in connection with a system of satellite models, EMMA, to analyse the impacts of an additional CO_2-tax of DKK 50 ($7) from 2000 onwards. Revenues are redistributed through lower indirect taxes for firms and lower income taxes for households. In this scenario GDP falls by 0.07 per cent and CO_2 emissions by 1.7 per cent ten years after the tax introduction. As a comparison, with no recycling of tax revenues the GDP loss is 0.37 per cent and the drop in CO_2 emissions is 2.2 per cent. That is, weak double dividends are obtained by reducing distortionary taxes, but the policy is not cost-free.

A dynamic version of the MobiDK model is used by Jensen and Rasmussen (1998) to study the impacts on the Danish economy of alternative CO_2 permit allocation rules. The first is a governmental *auction* of permits, where the revenue is used to reduce taxes on labour income. A unilateral emission reduction is studied, where emissions are reduced linearly from 1999 to 20 per cent below baseline in 2005. From then on,

[9] A strong double dividend may mean an increase in GDP or welfare. Here both GDP and welfare increase.

the emission cap is constant (no banking of permits is allowed). Existing CO_2 taxes and the subsidy to CO_2-free energy production are removed, which will increase efficiency compared to the baseline. The aggregate *welfare loss* (equivalent variation) from 1999 to 2040 is only 0.1 percent, as the reduction in taxes on labour income reduces inefficiency. Moreover, *labour supply* increases by almost 2 per cent. However, this scenario implies a large negative shock to energy intensive sectors and the loss of competitiveness causes a substantial decline in exports and higher imports.

Hill (1999) uses a static CGE model for Sweden to study the costs of achieving pollution reductions using environmental taxes with and without exemptions relative to using non-revenue raising instruments. In all scenarios with revenue recycling, a payroll tax is used as a replacement tax. The model is a bit different than other CGE models for the Swedish economy. Compared to Bergman (1995), the terms of trade effects are not present, as Swedish industries are price takers in the world market. The energy sector is more disaggregated and there are better substitution possibilities than in Harrison and Kriström (1996,1999) (see section 2.2). The Hicksian equivalent variation in income is used as a welfare measure. Hill finds that when a uniform, revenue-neutral CO_2 tax is introduced, aggregate welfare decreases by 0.3 per cent when emissions are reduced by 10 per cent (compared to a situation with uniform taxes and benchmark emission level). The positive revenue recycling effect from lowering the payroll tax will not exceed the negative distortions caused by the tax increase. Another finding is that the use of taxes is somewhat superior to non-revenue raising instruments for any given emission reduction level. Emission reduction between 5 and 25 per cent could be achieved at 5 - 9 per cent lower costs if tax recycling is used instead of non-revenue raising instruments.

The Finnish study by Honkatukia (1997) presents several tax scenarios with different kinds of recycling (see subsection 2.1.1). Doubling the existing CO_2 tax and distributing tax revenues by lowering employers' social security payments gives slightly improved economic results compared to lump sum transfers. With aggregate investment expenditures fixed, GDP and welfare increases by 0.8 and 1.6 per cent (vs. 0.4 per cent with lump sum). Fixing sector investment instead raises GDP and welfare gains to 1.0 and 1.9 per cent (vs. 0.8 per cent with lump sum). Emissions are actually increased by 0.6 per cent in both these scenarios. In addition to the reasons put forward in section 2.1.1, the lower labour costs stimulate industry production and therefore emissions further. Thus, using the tax revenues to reduce distortionary taxes has economic benefits here, but the environmental benefits are lacking.

For the UK, Barker et al. (1993a) employ a dynamic multi-sectoral model (MDM) to assess the macroeconomic impacts of a proposed EC carbon/energy tax starting at $3 per barrel in 1993 and increasing to $10 in 2000 (50% according to calorific value, 50% according to carbon content). MDM is an econometric model describing several industries, and includes an energy submodel and a submodel of electricity supply. The labour market does not clear in this model, i.e., there is unemployment. The tax is assumed imposed in all OECD countries. Tax revenues are recycled in two ways - either the VAT rate is reduced or the income tax is reduced. In the former case GDP is increased by 0.22 per cent in 2005. With income tax reductions GDP increases by 0.18 per cent. Hence, there are double dividends in both these cases. One explanation is that the tax swap decreases unemployment and thus increases production. CO_2 emissions in the UK are reduced by 12 per cent in both scenarios.

In Barker (1997) the MDM model has been extended to include more industries (i.e. 49 sectors). The proposed EC tax discussed by Barker et al. (1993a) is analysed, although it is extended to $20.4 per barrel of oil in 2005, imposed unilaterally in the UK, and the revenues are recycled through reductions in employers' National Insurance Compensation (NIC). Moreover, an energy conservation programme (similar to the one presented by Barker and Johnstone (1993), see chapter 4) is also included here. The MDM model includes a detailed modelling of employment demand in each sector. Switching the tax burden from labour to energy use leads to more labour demand in each sector and more demand for labour-intensive commodities. The latter effect is due to the fact that energy intensive industries are more capital intensive than other industries. The impact on GDP is almost negligible, whereas the inflation rate rises by 0.3 percentage points. CO_2 emissions in the UK are reduced by 16.6 per cent in 2005.

The proposed EC tax is also analysed for Ireland, by Fitz Gerald and McCoy (1992). When the tax revenue is recycled via reduction in social insurance contribution, GDP increases by 0.4 per cent and employment by 0.7 per cent in the year 2000. CO_2

emissions decrease by 3.4 per cent. Again, strong double dividends appear. As a comparison, when the tax revenues instead are used to finance a repayment of debt, GDP falls by 1 per cent. Moreover, CO_2 emissions are reduced by merely 2.7 per cent. This clearly confirms the importance of how the extra tax revenues are used.

We conclude from the review in this subsection that using tax (or auction) revenues to reduce other distortionary taxes may significantly reduce the overall mitigation costs, see Figure 1. The studies that have analysed both lump sum transfers and tax reductions using the same model and reference scenario find that the welfare (or GDP) loss is reduced by up to one percentage point. As expected, the magnitude of this cost reduction increases with larger emission reductions. Moreover, strong double dividends occur in several studies. Actually, welfare (or GDP) changes are small in all these studies (except for the Honkatukia (1997) study that find higher welfare and emissions), ranging from a loss of 0.3 per cent to a gain of 0.4 per cent with only 3 out of 9 studies showing losses. The ratio between relative GDP loss and relative emission reduction varies between 0.03 and -0.12.

As with lump sum recycling, it is difficult to find differences between the countries, as the number of studies in each country is few. Also, the expected differences do not occur. However, the single Swedish study here is the one with the largest welfare loss, whereas the single Irish study has the largest gain (in GDP). In comparison, intertemporal general equilibrium analyses of green tax reforms for the US economy, such as Jorgenson and Wilcoxen (1993) and Goulder (1995a), indicate a welfare loss from switching between labour taxes to taxes on CO_2 emissions. This is partly explained by lower level of labour income tax in the US. Recently, the Energy Journal had a special edition on the costs of the Kyoto Protocol, comparing different global models, see Weyant (1999). Most of the studies were much more pessimistic about mitigation costs than the studies surveyed in this paper. The main reasons for this is that global models are more aggregated than national models, different revenue recycling schemes are usually not considered in international analysis, and that the existing tax wedges are higher in the countries surveyed here (particularly Scandinavian countries) than in other countries that have signed the Kyoto Protocol.

Four studies with other use of tax revenues are also depicted in Figure 1. Two studies give rise to strong (but small) double dividends; these are recycling tax revenues through VAT reductions. One study gets very high costs compared to the emission reduction. Here debt repayment is used. The fourth study, reducing indirect and income taxes, arrives at very small effects on both GDP and emissions. With such a small number of studies it is difficult to draw conclusions. However, it seems that using the extra tax revenues to reduce other taxes than labour taxes is superior to using lump sum transfers, but that labour tax reductions are even better.

2.2 Tax exemptions and grandfathered permits

Now we turn to investigate the impact of tax exemptions or differentiation, and of offering free permits. In all countries where CO_2 taxes have been introduced, some sectors have been exempted from the tax, or the tax is differentiated across sectors (see, e.g., ECON, 1997). Typically, households pay the full tax rate, whereas export-oriented industries pay either nothing or a symbolic rate.[10] Most of the studies in this section examine the effects of proportionally increasing the existing carbon taxes, i.e., maintaining the existing exemptions. As several countries are currently considering creating a quota market for greenhouse gas emissions, the question of grandfathered permits is perhaps the most delicate one. Here we want to examine whether such diverse treatment of different emission sources leads to higher social costs of reducing CO_2 emissions. Table 2 presents an overview of the studies discussed in this section.

In Norway CO_2 taxes are differentiated across sectors. Bye and Nyborg (1999) compare this current tax system with two other tax or quota systems that keep CO_2 emissions at the same level as today, using the MSG-6 model. The first alternative is uniform CO_2 taxes, which may also be interpreted as an auction of permits. To keep total tax revenues unchanged, the payroll tax rate is adjusted accordingly. The other alternative is a tradable quota system, where emission permits are issued freely to all previous polluters (this may also be interpreted as a uniform CO_2 tax with lump sum transfers to the polluters). Here, too, the payroll tax rate is adjusted to maintain the total level of tax revenues. Thus, both these two alternatives are superior to the current

[10] Some exceptions occur, of course. For instance, in Norway emissions of CO_2 from oil and gas production have traditionally been charged the maximum rate.

system in the way that marginal abatement costs are equalised. However, the latter case is inferior to the other two cases in that it does not raise revenues. The welfare effects (total discounted utility) are investigated. Uniform taxes lead to 0.03 per cent increase in welfare compared to the current tax system, whereas grandfathered permits reduce welfare by 0.03 per cent. The main reason is that payroll taxes must increase to maintain the budget balance in this case when carbon taxes are not used. Thus, the tax revenue effects seem to be more important than equalising marginal abatement costs in Norway. This also confirms the results from an earlier Norwegian study, see Mathiesen (1996a).

Table 2. CO_2 mitigation costs studies with tax exemptions or grandfathered permits.

Study	Country	Policy	Recycling	Welfare measure	CO_2 reduction (%)	Welfare loss (%)
Bye and Nyborg (1999)	Norway	Uniform taxes vs. tax exemptions	Labour tax	Welfare index	-	-0.01
Bye and Nyborg (1999)	Norway	Grand-fathering vs. tax exemptions	Labour tax	Welfare index	-	0.12
Jensen (1998)	Denmark	Tax exemptions	Lump sum	Welfare index	20	1.9
Jensen (1998)	Denmark	Grandfathering	-	Welfare index	20	1.4
Bergman (1995)	Sweden	Tax exemptions	Lump sum	GNI	37	0.0
Nilsson (1999)	Sweden	Tax exemptions	Lump sum	GDP	16	1.9
Harrison and Kriström (1996,1999)	Sweden	Tax exemptions	Labour tax	Welfare index	0.1	0.3
Brännlund and Gren (1999)	Sweden	Tax exemptions	VAT	Welfare index	2	not reported
Hill (1999)	Sweden	Tax exemptions	Labour tax	Welfare index	10	0.4
Profu (1997)	Sweden	Tax exemptions	Lump sum	GDP	25	1.4
Jerkkola et al. (1993)	Finland	Subsidies	Lump sum	GDP	30	0.3
Pohjola (1999) (gross emissions)	Finland	Tax exemptions	Lump sum	GDP	34	0.9
Barker et al. (1993a)	UK	Tax exemptions	Labour tax	GDP	12	-0.09
Barker et al. (1993a)	UK	Tax exemptions	VAT	GDP	12	-0.17
Barker et al. (1993a)	UK	Tax exemptions	Lump sum	GDP	12	0.37

Jensen (1998) discusses both exemptions and grandfathering of permits in Denmark, in addition to the permit auction scenario presented in section 2.1.1. In one scenario exemptions are given to six production sectors emitting approximately 15 per cent of Denmark's total emissions. In the other scenario, permits are grandfathered in proportion to benchmark emissions, i.e., given away for free. If exemptions apply, the abatement target implies a welfare loss of 1.9 per cent and a carbon tax rate on the non-exempted tax base of approximately DKK 500 ($70) per ton of CO_2. The grandfathering implies a welfare loss of 1.4 per cent and a permit price of approximately DKK 800 ($110) per ton of CO_2. As a comparison, the permit auction scenario presented above lead to a welfare loss of 1.2 per cent. That is, exemptions or grandfathering increases costs by respectively 60 and 15 per cent in this study. Jensen thus concludes that exemptions appear to imply significantly greater welfare costs than grandfathering, contradicting the findings in Bye and Nyborg (1999) above. However, in Jensen's study extra tax revenues are not used to reduce distortionary taxes, but rather distributed in a lump sum manner. Therefore, the potential efficiency gain from revenue recycling in the tax scenarios is not utilised.

Bergman (1995) examines the effects of introducing a differentiated CO_2-tax in Sweden rather than the uniform tax presented in section 2.1.1. The motivation for this is that the costs associated with the structural change in the industry may be large. Thus, the tax rate applicable for the industrial firms is set to one-quarter of the tax rate for non-industrial firms and households, and the tax revenue is distributed lump sum. The GDP loss increases slightly compared to the uniform tax, but is still quite small. However, the GNI loss is significantly reduced, and carbon leakages are also smaller. Consequently, tax differentiation does not seem to have adverse effects in this study. The CO_2-tax is however much higher when it is differentiated. In the case where emissions are reduced from 79 to 50 million tons per year, the CO_2-tax is rising from SEK 330 ($45) to SEK 1270 ($170) per ton of CO_2. In a final scenario, international co-ordination of CO_2-emission polices are studied, i.e., a uniform tax is levied on all CO_2 emissions in all countries. A striking result is that the impacts on the Swedish economy are very similar to the impacts with a differentiated carbon tax.

Nilsson (1999) also studies the effects of tax exemptions in Sweden, and compare with the effects of uniform taxes (see section 2.1.1). In her study, manufacturing industries only pay 25 per cent of the CO_2 tax, which is fixed at the same level as with uniform taxes. According to her results, tax exemptions diminish the impact on both emission and GDP. CO_2 emissions are now reduced by 16 per cent (vs. 21), whereas GDP is reduced by 1.9 per cent (vs. 2.5). That is, the ratio between GDP loss and emission reduction is about the same. Export-oriented industries are negatively affected in this scenario, too, but not as much as with uniform taxes.

Harrison and Kriström (1996, 1999) present general equilibrium effects of increasing carbon taxes in Sweden, by using a CGE model. In the main scenario, the existing carbon taxes are increased by 100 per cent, maintaining the existing exemptions from carbon taxes, while labour taxes are reduced to maintain constant government revenue. The study presents welfare effects for various households (see chapter 4). Adding up the detailed welfare impacts using a simple utilitarian social welfare function, gives an aggregate loss in income of 4 billion SEK ($0.5 billion) per year, or 0.3 per cent reduction in welfare. The tax increase gives a reduction in domestic CO_2 emissions by only 0.1 per cent, and a carbon leakage around 10 per cent. The reason for the modest impact on emissions is that some sectors will emit more carbon when the carbon tax is introduced because they are less dirty and/or more labour intensive than competing sectors. Alternative ways of revenue recycling are also studied, but in none of the cases is there any double dividend in the strong form (no net welfare gain). Actually, with lump sum transfers welfare loss is merely 15 per cent higher, while emission reductions are 85 per cent higher. With restrictions on the production of nuclear power, carbon tax increases give higher emission reductions, due to a decline in energy-intensive production in Sweden following from higher energy prices. Despite an increase in the aggregate welfare cost, nuclear constraints lower the average welfare cost of carbon reductions. It also gives a substantial restructuring of the Swedish industry.

Similar carbon tax scenarios are studied using a partial equilibrium model in Brännlund and Gren (1999). In contrast to Harrison and Kriström (1996, 1999), this is a *short run analysis* as capital stocks are fixed, and the data used only includes consumption of non-durable goods. If the existing carbon taxes are increased by 100 per cent with a revenue neutral reduction in the value-added tax (VAT), the private income is almost unchanged, cancelling the income effect of taxation. As the income effect in this study is relatively important compared to the price effect, taxes can be raised without altering consumer behaviour in any considerable way. Thus, ambitious environmental targets call for very high taxes. The welfare costs (compensation variation minus the change in tax revenues) of the tax scenario without tax replacement will be approximately SEK 250 per capita per year ($30).[11] This gives a reduction in emissions by approximately 2 per cent. If a reduction of 6 per cent is wanted, a 270 per cent tax increase will suffice. Then the welfare costs in monetary terms will be SEK 730 per capita ($100).

Hill (1999) finds much higher costs of CO_2 emission reductions in Sweden with tax exemptions compared to uniform taxes (see section 2.1.2). In both scenarios, tax revenues are recycled through reductions in the payroll tax. Using the benchmark exemptions, total welfare costs of reducing emissions by 10 per cent are more than 2.5 times higher with exemptions than without. In section 2.1.2 we commented that welfare costs of non-revenue raising instruments were only slightly higher than the welfare costs of carbon taxes. Thus, contrary to the Norwegian findings by Bye and Nyborg (1999) above, Hill finds that different marginal costs across emitters (through exemptions) are more costly than using non-revenue raising instruments. One reason may be that the Norwegian system for carbon taxation puts a higher tax on activities that are not very elastic in supply such as the petroleum sector.

Konjunkturinstitutet (1999) examines the effects of restricting Swedish CO_2 emissions in 2015 to 4 per cent above 1990 level, which is the same as the Kyoto target for Sweden (for all greenhouse gases in 2008-12). This restriction corresponds to a reduction in CO_2 emissions by 14 per cent from the baseline level. The policy measure that is investigated is an increase in the existing carbon taxes (i.e., maintaining tax exemptions), with tax revenues distributed to households in a lump sum manner. A static CGE-model called EMEC with 17 industries is used. Labour supply is fixed and fully employed, but in one scenario wage rigidities are implemented resulting in unemployment. In the main scenario the carbon tax is

[11] The percentage change in welfare is not reported.

increased by a factor of 2.5 to SEK 910 ($120) per ton CO_2, and GDP drops by 0.3 per cent. The authors emphasise that adjustment costs are not taken into account in the model. When wages are not allowed to fall, the GDP loss increases to 0.7 per cent.

Profu (1997) uses the model MARKAL-MACRO to study the effects on energy use and economic costs of the current energy tax system (1996) in Sweden compared to the tax system in 1990. The main difference between 1990 and 1996 is that a CO_2 tax of about $50 per ton CO_2 has been introduced, with the industry paying only 25 per cent of the tax. In addition a SO_2 tax has been introduced, energy taxes have been changed and some investment subsidies to renewable energy sources have been established. Tax revenues (net of investment subsidies) are redistributed to the economy through lump sum transfers. The model is mainly based on the bottom-up model MARKAL, with detailed modelling of the technical energy system. An aggregated macroeconomic module has been linked to MARKAL in order to include the general equilibrium effects of price changes. The baseyear of the model is 1990, and the different tax systems are imposed after the baseyear. CO_2 emissions are reduced by 20 to 30 per cent in the period 2000-2030 with the new tax system. One important reduction takes place through a shift from coal to bio-fuels in heat production. The annual GDP growth rate falls by 0.05 per cent, which means that the GDP loss in 2010 is 1.4 per cent.

In section 2.1.1 we presented the study by Jerkkola *et al.* (1993), which focus on stabilising CO_2 emissions in Finland using CO_2 taxes. They further investigate how CO_2 taxes combined with subsidies to the chemical and metal industry may change the outcome of the stabilisation requirement (which is a 30 per cent reduction compared to baseline). The subsidies are given per unit of production in order to maintain competitiveness in the world market. In both model versions they apply, the GDP loss is slightly increased, i.e., from 0.1 to 0.3 per cent in the basic model and from 0.3 to 0.4 per cent in the alternative model. Other sectors are forced to reduce their emissions more than in the case without subsidies. Thus, allowing for subsidies raises CO_2 taxes by about 90 and 40 per cent.

Pohjola (1999) presents a recursively dynamic computable general equilibrium model for Finland where the existing forest is introduced as a *carbon sink*. Thus, the model can distinguish between gross and net emissions of CO_2, where *gross emissions* are emissions from fossil fuel combustion. *Net emissions* are calculated by adding emissions from timber, and subtracting the carbon sequestrated in forest during that period. Two scenarios are analysed, where the emissions targets are adopted unilaterally: In the first scenario, gross emissions are stabilised at 1990 level by 2010, while in the second scenario net emissions are stabilised instead. Carbon taxes are used as policy instruments, and the tax revenues are redistributed lump sum. The manufacture of iron and steel is exempted from the carbon tax according to current practice. The results show that when stabilising net emissions, nearly half of the emission reduction is achieved by increasing the carbon sink. While the marginal abatement cost curve for fossil fuel emission reductions are relatively steep, the corresponding curve for emissions from wood is relatively flat. Thus, for small emission reductions, it is efficient to reduce emissions from fossil fuels only. The carbon tax that is needed to achieve the net emission stabilisation is clearly lower than the tax needed to stabilise gross emissions. However, there is only a minor difference between the welfare losses associated with stabilising net and gross emissions. This is mainly due to larger emission reductions when net emissions are stabilised, due to faster growth in the reference scenario. In most cases, however, the net emission limit is more advantageous than the gross emission limit.[12]

The British study by Barker et al. (1993a) presents a tax scenario with exemptions in addition to the uniform tax scenario discussed in section 2.1.2. In this new scenario the proposed EC tax is introduced in the EC area rather than in all OECD countries. Energy intensive industries are exempted from the tax, but are assumed to take part in voluntary agreements so that their fuel consumption is reduced as if they had to pay the tax. As before, tax revenues are recycled in two ways - either the VAT rate is reduced or the income tax is reduced. The effects on GDP are still positive, but slightly smaller than with uniform taxes. Therefore, even with tax exemptions strong double dividends are feasible. As indicated in section 2.1.2, one important explanation for this result is that the tax reform reduces unemployment, which is endogenous in the MDM model. With no revenue recycling, GDP is reduced by 0.37 per cent, which means that the question of revenue recycling is more important than the question of

[12] For another study on forestation as a policy instrument in the climate policy, see Mathiesen (1996b).

exemptions. This has probably to do with the type of model used in Barker et al. (1993a). With endogenous labour use, it is easier to stimulate production by choosing the appropriate object of taxation.

None of the Irish studies available present analyses with tax exemptions or grandfathered permits.

The studies reviewed in this section indicate that tax exemptions or grandfathering of emissions in most cases increases the overall mitigation costs. However, there are large differences across the studies. Some studies find that exemptions give significantly higher costs, whereas other studies find that the cost difference is small. In fact, some studies find positive effects of exemptions. There are also differences across the studies with respect to how important exemptions are compared to revenue recycling. Some conclude that the existence and redistribution of tax revenues are more important than whether or not different emission sources are treated differently. Other studies conclude in the opposite way. The results depend on the existing tax wedges in the economy, the ability of the CO_2 tax to create a tax revenue, how the tax revenue is used, and to what degree a differentiated system strengthen existing imperfections in the economy.

Summing up the whole chapter, mitigation costs in the Nordic countries, the UK and Ireland are mostly in the range between -0.4 and 1.2 per cent for emission reductions up to 20-30 per cent, according to Figure 1. These relatively small costs are also confirmed by the studies reviewed in section 2.2, which are not displayed in the figure. Moreover, choosing the most efficient tax reform, i.e., uniform taxes with tax revenues used to reduce distortionary taxes, reduces the costs compared to lump sum recycling. The costs may be small and possibly negative. On the other hand, other political considerations may impede the most efficient outcome, either by allowing for tax exemptions or issuing free permits, or by using extra revenues for other purposes. Studies on these alternatives give very different results.

3. Fossil fuel prices and revenues

So far we have focused on the macroeconomic implications of national policies to reduce CO_2 emissions. For most countries this will also be the main impact of international treaties to reduce emissions of CO_2. However, for countries with major export of fossil fuels, the most significant impact may come through the effects on the international energy markets. Of the countries in focus in our survey, this relates mainly to Norway. United Kingdom is also a major producer of oil and gas, but consumes almost all their supply domestically.

As a large oil and gas producer, the overall future costs for Norway of an international climate treaty will depend critically on the impacts on fossil fuel prices. Lower current and future prices reduce the value of the petroleum resources (the petroleum wealth). This means lower future consumption possibilities. Berg *et al.* (1997) study the impacts of an international carbon tax equivalent to $10 per barrel of oil using a global intertemporal equilibrium model for the fossil fuel markets with market power in the oil market (the Petro model). This tax reduces global CO_2 emissions compared to a reference scenario by 21 per cent in 2000 and 2050. The impacts on the oil wealth differ for the different oil producer groups. Oil wealth is reduced by 23 per cent for OPEC and by 8 per cent for the competitive fringe (non-OPEC). The Norwegian petroleum wealth is roughly about the same size as its GDP (1996). Therefore, for Norway as an average fringe producer in the model, the future loss from lower fossil fuel prices of this specific international agreement amounts to a once for all loss of about 8 per cent of its current GDP level.[13] In a more recent study based on the same model, Kverndokk *et al.* (2000) demonstrates how important the baseline assumptions and emission constraints are for the impact on oil producers. Here, the change in non-OPEC's oil wealth varies between a loss of 22 per cent and a gain of 22 per cent.

Holtsmark (1998) uses a partial equilibrium model for the fossil fuel markets to investigate the effects of fulfilling the Kyoto Protocol under different assumptions

[13] When using a discount rate of 7 per cent (as in Berg *et al.*) this amounts to a permanent income loss of 0.56 per cent of current GDP, which seems to be in the range of the losses presented in chapter 2.

about trade in emissions between regions. Abatement cost curves are used to estimate the costs of emission reductions in each region. Each of the Nordic countries is an individual region in the model. Including terms of trade effects in the cost calculations, Holtsmark finds that Norway experiences much higher costs relative to GDP than other regions, i.e., 1.2-1.4 per cent under the various trading schemes. The explanation for this is mainly price reductions in oil and gas markets (2-8 per cent).

An interesting study by Hagem (1994) focuses on climate policies related to both the macroeconomy and the fossil fuel market. She compares two different ways Norway unilaterally can reduce global CO_2 emissions; reduction in oil production or introducing uniform taxes on fossil fuel consumption. The main conclusion is that a cost-effective climate policy implies a *reduction of oil production* rather than taxing CO_2 emissions. Stabilising national emissions at 1989 level in 2000 requires a reduction of CO_2 emissions of 10 million tons. The carbon-leakage rate of domestic mitigation policies is calculated to be 26 per cent, thus this gives a global reduction of CO_2 emissions of 7.4 million tons. The abatement cost of uniform CO_2 taxes is taken from the Environmental Tax Committee (1992), and are calculated using the medium term macro model MODAG to be 2.2 per cent of GDP. On the other hand, reducing oil and gas production increases fossil fuel prices and, therefore, reduces international demand of fossil fuels and thus CO_2 emissions. A global CO_2 emissions reduction similar to 7.4 million tons requires reduction in oil production at a cost of only 0.7 per cent of GDP. The result, however, is sensitive to price elasticicities. Moreover, the preceding section suggests that the macroeconomic costs could be significantly smaller and even negative if tax revenues were used to reduce distortionary taxes. Also, the study ignores the secondary benefits connected to domestic abatement.

4. Distributional effects

Not only the total costs, but also the distribution of the costs is important for the overall evaluation of climate policies. A policy that leads to an efficiency gain may not be overall welfare improving if some people are made worse off, and vice versa. Notably, the effect on the income distribution should be taken into account in the assessment.

Two other aspects of distribution not dealt with here, are the industry sector impacts and the regional effects of the carbon policy. For instance, a CO_2 tax will obviously lead to very different effects in energy and fossil fuel intensive industries than in sectors producing labour intensive services. Another distributional matter is how the environmental damage, or the environmental benefits from the policy, affects different countries or regions.

Two of the Norwegian studies referred in chapter 2 have studied the distributional effects of introducing carbon taxes without reducing other taxes. Aasness *et al.* (1996) find that poor households are less favourably affected than rich households. This is due to smaller budget shares of consumer goods implying relatively high CO_2 emissions for the rich households. On the other hand, Brendemoen and Vennemo (1994) conclude that the distributional differences across income will not be affected much by their policy experiment.

The Danish study by Jensen (1998) (see chapter 2) finds that when CO_2 emission permits are auctioned and when revenues are distributed equally to all household, the positive effects of transfers dominate the negative effects of emission permits for low-income households. All the high-income household categories experience a welfare loss as the transfer amount to a lower share of these groups' income compared to the low-income groups. This result is also confirmed by Gørtz *et al.* (1999) (see chapter 2). That is, when tax revenues are distributed in a lump sum manner with an equal amount to each household, low income households are better off, whereas high income households are worse off measured in economic welfare. However, if tax revenues are recycled through labour income tax reductions, the distributional impacts are completely turned around (except for the very richest households that still lose). In this case welfare falls by 4 per cent in the lowest income group, and increases by 1.5 per cent in the second highest income group. With VAT reductions, the distributional impact is still in disfavour of the poorest households, but not as much as with income tax reductions.

Harrison and Kriström (1996, 1999) (see chapter 2) investigate how households are affected by increasing carbon taxes in Sweden and recycling revenues through reduced labour taxes. In general all households will lose from the tax increase.

However, for the single-adult household the cost is relatively modest. The costs become more substantial for all other households, especially those with children. Married households with no children experience slightly higher costs than single households with no children. In general richer households within any group tend to bear higher actual costs, reflecting the greater carbon-intensity of their expenditure patterns and their higher initial incomes. Redistributing tax revenues equally to all household implies that low-income groups neither lose nor win from the tax change (see Ministry of Finance, 1997). Economic welfare for other households is reduced.

Several European studies find that carbon taxes have more regressive impacts in the UK and Ireland than in EU countries on the continent (e.g., Barker and Köhler, 1998; Smith, 1992,1998). Below we review single-country studies from these two countries.

Two British studies have looked at the distributional effects of climate policies. Barker and Johnstone (1993) use the same model and the same tax scenario as in Barker *et al.* (1993a) (see chapter 2) to investigate the distributional effects of a carbon/energy tax. In this particular study revenues are however recycled through an energy efficiency program[14] and compared to lump sum transfers. Barker and Johnstone argue that the burden of a carbon/energy tax falls most heavily on low-income groups. At the same time low-income groups are further away from the post-tax optimum, and therefore potential gains to be realised by increasing energy efficiency are higher. In the analyses, each income quintile is assumed to consume the same share of total use of each fuel as before the tax. When the carbon/energy tax is combined with the energy efficiency programme, the low-income group experiences a net increase in disposable income of £725 million by 2005. Under the lump sum scheme, compensation of £560 million is necessary if the low-income group is assumed to receive direct subsidies equal to the price effects of the tax.

Symons *et al.* (1994) investigate the distributional effects of a carbon tax in the UK under various assumptions of revenue recycling. They employ an input-output framework for final and intermediate demand to capture the indirect effects on

[14] That is, a £1.1 (1992) billion once-and-for-all programme of conversation measures that save annual energy consumption valued at £175 million (i.e., a payback of 6-7 years).

consumer expenditures through price changes on all commodity groups. Moreover, they use a detailed demand system for various consumer groups (the SPIT model) to include expenditure changes based on, e.g., price changes. They find that introducing a carbon tax without recycling or with recycling through VAT rate or petrol excise duty reductions is significantly regressive. On the other hand, recycling the carbon tax by a combination of VAT rate reductions and benefits reforms directed towards poorer households has favourable distributive effects.

There are also two Irish studies on income distribution. Fitz Gerald and McCoy (1992), which was presented in chapter 2, modelled the effects on low-income households of the carbon/energy tax proposed by the (then) EC. Revenues were recycled through debt payment or reduced distortionary taxes. The tax proposal was found to be regressive as low-income households spend proportionally more on energy, and since the fuels they buy have a higher carbon content. A similar conclusion was found in O'Donoghue (1997) who studies the distributional effects of introducing a carbon tax. An input-output framework, distinguishing between imported and domestically produced goods, is used to capture the price effects on all sorts of commodities. Moreover, changes in consumption patterns due to price changes are estimated using a demand system for the UK (the SPIT model - see e.g. Symons et al., 1994). When there is no recycling, carbon taxation is generally regressive, unless the tax is levied on industry inputs only (and not on household demand). When the carbon tax is levied on all carbon emissions and tax revenues are recycled through a fixed basic income for all individuals, the distributional effects become almost neutral.

To sum up, the distributional effects of a carbon tax appear to be regressive unless the tax revenues are used either directly or indirectly in favour of the low-income groups. This conclusion seems to hold whether or not tax revenues are used to reduce distortionary taxes. However, lump sum transfers with equal amounts to all households generally have progressive effects.

5. Ancillary benefits of climate policies

So far we have concentrated on the traditional economic impacts of climate policies, and not discussed the environmental benefits from the policies. The notion 'climate policy' signals that the aim of the policy is to reduce emissions of greenhouse gases. The benefits from reducing such emissions are however both very difficult to estimate and accrue to the global community without special benefits to the abatement country. Thus, it is difficult to compare the economic impacts with the environmental benefits, e.g., in some sort of cost-benefit analysis.

Policies aimed at reducing CO_2 emissions do bring about other environmental benefits as well, since emissions of pollutants like NO_x, SO_2 and small particles are closely related to CO_2 emissions: All pollutants are mainly emitted through combustion of fossil fuels. These other pollutants are important contributors to health and environmental damages. Reductions in these damages due to climate policies are often denoted ancillary or secondary benefits of the policy. Although such damages are also difficult to estimate, there is more consensus in this field than in climate research. Several of the ancillary benefits studies also include the benefits from reduction in non-environmental traffic-externalities, e.g., accidents and noise. Since taxes on CO_2 emissions normally lead to reduced road traffic, these externalities may also be reduced.

There are several ways to evaluate the ancillary benefits of climate policies. One is to compare these benefits with the gross mitigation costs of the policy in the same study. However, since the mitigation costs vary significantly with respect to policy choice and modelling tool (see chapter 2), the evaluation may be more attributable to these factors than to the ancillary benefits itself.[15] Another way is to measure the ancillary benefits per ton reduction in CO_2 emissions caused by the climate policy. Then this fraction may be compared to the range of mitigation costs reported in the literature.

Most studies of ancillary benefits have been conducted in Norway or the UK. Moreover, different studies have often used the same background information when it

[15] The ancillary benefits may also depend on the policy choice to reduce greenhouse gases.

comes to damage estimation of emissions. Consequently, comparable results in different studies cannot be taken as evidence of consensus in this matter. Furthermore, most studies have used very simplistic tools in their damage assessments, and often-used benefits transfer or other rough methods rather than transferring dose-response functions.[16] Accordingly, the resulting ancillary benefits must be viewed as very crude estimates. For instance, the calculations of ancillary benefits in most Norwegian studies have been based on specific expert judgements of various damage costs, not on established dose-response functions. Moreover, the benefits calculations have been based on reductions in national emissions, ignoring the difference between emissions in, e.g., urban and rural areas (except for some adjustment of the aggregate damage costs according to the proportion of national emissions coming from the largest cities).

In Figure 2 we have plotted the ancillary benefits per ton reduction in CO_2 emissions in different studies. Note that this measure was not attainable in all studies reported in this section. Moreover, as explained in the text below, not all potential benefits from reduced air pollution and traffic externalities are evaluated in most studies.

Ekins (1996) reviews estimates of the size of secondary benefits in different studies from the early 1990's.[17] All studies included are undertaken in Norway and the UK. For the UK, a great majority of the secondary benefits comes from reductions in SO_2 and NO_x emissions. Also, a majority of the damage from these emissions is derived from damage to buildings. For Norway, the highest damages are related to traffic externalities and health effects, as power production is non-polluting. Although the estimates are few and uncertain, their mid-range suggests that the secondary benefits for Norway and the UK lie within a narrow range, \$250-400 per ton of carbon reduced. The secondary benefits are of the same order of magnitude as the mitigation costs reported in the literature of medium to high levels of CO_2 abatement (at least up to 70 per cent reduction in CO_2 emissions). Thus, Ekins concludes that there is a

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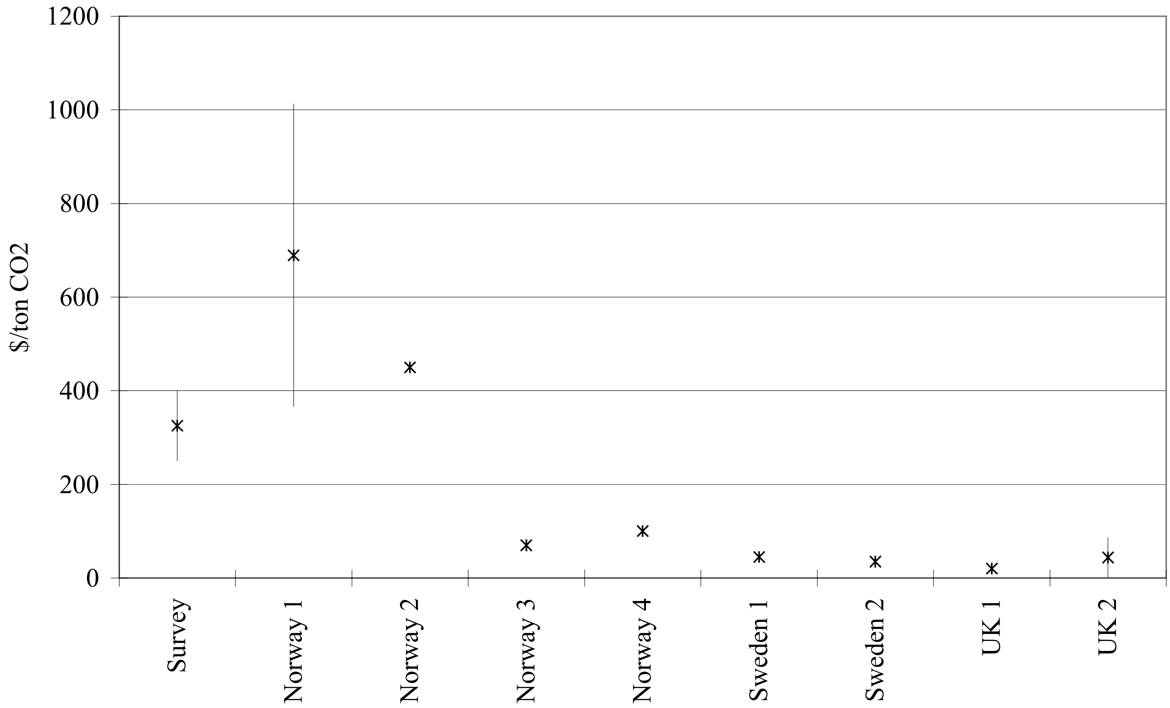
[16] Benefits transfer means that the damage cost of, e.g., a ton SO_2 emissions found in one country/city is directly transferred to another country/city. Dose-response functions describe the quantitative relationship between the concentration of air pollutants and various health effects.

[17] All but one study (Alfsen *et al.*, 1995) are from 1991-93.

strong economic case for reducing the consumption of fossil fuels irrespective of the threat of global warming.

Figure 2. Ancillary benefits of carbon taxes due to reduced air pollution and traffic externalities, per ton reduction in CO_2 emissions.



Note: Survey: Ekins (1996); Norway 1: Aaserud (1996); Norway 2: Brendemoen and Vennemo (1994); Norway 3: Johnsen et al. (1996); Norway 4: Glomsrød et al. (1996); Sweden 1: Nilsson and Huhtala (2000); Sweden 2: Bergman (1995); UK 1: Barker et al. (1993b); UK 2: Ekins (1996).

Aaserud (1996) reviews the results from 10 secondary benefits studies in Statistics Norway around 1990, using either the MSG or the MODAG model. According to his survey, secondary benefits are between \$126 and \$3,056 per ton carbon reduced. Excluding the highest and lowest figure, the range narrows down to \$366-1,012. Moreover, ignoring the traffic-related externalities, the environmental secondary benefits amount to \$138-306 per ton carbon reduced.

Two Norwegian studies not reported in Ekins (1996) or Aaserud (1996), are Brendemoen and Vennemo (1994) and Johnsen *et al.* (1996). However, they both use more or less the same submodule for calculations of emissions, environmental

[18] All but one study (Alfsen *et al.*, 1995) are from 1991-93.

damages and traffic externalities in Norway, as the Norwegian studies reviewed by Ekins. The submodules cover environmental damages related to health, acidification, material corrosion etc., and various traffic externalities. The two studies examine the impacts of carbon taxes (see chapter 2). Brendemoen and Vennemo find that secondary benefits make up about 50 per cent of the loss in private consumption and almost all the GDP loss. They do not report the benefits per ton carbon reduced, but other numbers and figures in the paper indicate that the fraction lies slightly above 3,000 1990-NOK (i.e., around $450) per ton carbon. This is somewhat above the findings in Ekins (1996). On the other hand, in Johnsen *et al.* ancillary benefits are tentatively estimated to be in the order of only 20 per cent of the GDP loss. The benefits amount to around 500 1988-NOK (i.e., about $70) per ton carbon reduced, which is far below the results reported by Ekins. As these two Norwegian studies use almost the same model, with identical environmental submodule, the large differences in results seem surprising. However, in Johnsen *et al.* the major part of emission reduction takes part through reduced gas power production, whereas in Brendemoen and Vennemo private households reduce their demand for fossil fuels significantly. The ancillary benefits of the latter reduction are much higher than the benefits of reduced emissions from gas power plants.

Another Norwegian study presented in chapter 2 was Håkonsen and Mathiesen (1997). They distinguish between ancillary benefits that have productive impact in the economic model, and benefits that have direct impact on utility. Taking into account the first sort of benefits, the carbon tax scenario becomes welfare improving for a larger range of CO_2 emission reductions than before (up to 30 per cent). Adding subjective disutility factors, such as traffic-related noise and health costs other than labour-losses and resource use in medical treatment, computed outside the model, increases welfare even more. As an example, the difference in the welfare index between the reference scenario and the scenario including the subjective disutility factors is 2 percentage points; a 1 per cent loss in the reference scenario is turned to a 1 per cent gain.[19] Thus, they conclude that the possibility of a welfare gain hinges on

[19] It is not possible to calculate the ancillary benefits per ton carbon reduced from the information given in the paper.

inefficiencies in the tax system and the handling of externalities from local pollution. Due to these, CO_2 mitigation may be a “no-regrets” policy.

As opposed to the above mentioned studies, Glomsrød *et al.* (1996) use international dose-response functions and calculates concentration levels of several pollutants within a CGE model for Norway (MSG-EE).[20] Health and environmental impacts are partly linked to the input of the model, and partly valued outside the model. Traffic injuries are also fully integrated in the model, whereas other traffic-related effects are roughly estimated at the end. The study finds that the secondary benefits integrated in the model amount to 16 per cent of the GDP loss, half of it coming from traffic injuries. This is equivalent to about 700 NOK (i.e., $100) per ton carbon reduced. The assessment of other traffic-related benefits indicates a doubling of the secondary benefits. Still, the result is below the range reported by Ekins (1996). One reason is that the emissions of particulate matter in towns, being the main contributor of health damages, are not affected very much by the carbon tax.

The Norwegian studies have in general found that traffic related costs, especially accidents, are dominating the ancillary benefits. Thus, Glomsrød *et al.* (1998) wanted to study the impacts of traffic injuries on labour supply and public health expenditures in the MSG-EE model. The welfare loss associated with individual suffering from health standard is not included here. In a scenario to stabilise CO_2 emissions on 1989 level in 2020, the GDP loss in 2020 is 0.47 per cent without taking account of the traffic-related costs, but reduced to 0.44 per cent when these costs are taken into account. Thus, the reduction is not large. One reason is that the decrease in labour supply due to traffic accidents increases the wage rate to clear the labour market, giving a substitution against other input factors among them transport fuels, accompanied by an increase in the number of traffic accidents. This outweighs some of the first order cost reductions.

In Bergman's (1995) study for Sweden (see chapter 2), an environmental quality adjusted national income is calculated. He takes into account the secondary benefits

[20] The study is in Norwegian, but a brief presentation in English is given in Alfsen and Rosendahl (1996). The modelling approach is presented in detail in Rosendahl (1998).

of reduced SO_2 emissions through economic welfare for households in addition to the feedback effects on production in the forest industry already incorporated in the model. With differentiated CO_2-taxes, a unilateral taxation may actually be a "no regret policy" for all the policy objectives investigated, i.e., the loss of GNI is more than fully compensated by environmental quality gains. This may also be true with uniform CO_2-taxes. The ancillary benefits per ton CO_2 emission reduction are not stated directly, but can be approximately calculated to between SEK 210 and 300, i.e., around $30-40 per ton CO_2.

Hill (1999) points to an interesting feature about the effect of exemptions on the ancillary benefits of a CO_2 tax. The current CO_2 tax system in Sweden and other countries generally put higher taxes on transportation and private households, which are large emitters of NO_x, than on industries. Thus, keeping the benchmark tax exemptions when increasing the CO_2 tax may give rise to higher ancillary benefits compared to uniform taxes especially when traffic-related externalities are considered. Monetary estimates for SO_2 and NO_x damages, taken from damage costs studies in Sweden, are used to calculate welfare effects including environmental benefits. Hill finds that a unilateral CO_2 tax increase could yield a welfare improvement if valuation of CO_2 emission reduction exceeds 300 SEK (about $40) per ton CO_2. It is difficult to translate his results into ancillary benefits per ton CO_2 reduced.

Another Swedish study is Nilsson and Huhtala (2000) which discuss ancillary benefits under different assumptions about emissions trading under the Kyoto protocol. They point out that including the benefits from reduced NO_x and SO_2 emissions may alter the profitability of engaging in international emission trading. A static CGE model called EMEC is used, where emissions of CO_2, NO_x and SO_2 are linked to energy use in the different sectors. No abatement measures other than reducing energy use are implemented in the model. The marginal damage costs of NO_x and SO_2 emissions are simply set equal to the tax rates of these emissions. They compare a scenario with no international trade in emission permits with two scenarios with trade. The international permit price is assumed to be respectively $50 and $100 per ton CO_2 in the trade scenarios. The GDP loss is respectively 80 and 3 per cent higher in the no-trade scenario than in the two trade scenarios. Changes in NO_x and SO_2 damage costs are then added to these GDP changes, where costs of changes in NO_x emissions constitute about 90 per cent. Then the no-trade scenario is only marginally inferior to the \$50 trade scenario, and slightly superior to the \$100 trade scenario. In both cases the ancillary benefits are about SEK 350 (\$45) per ton CO_2 reduced. Of course, objections may be raised against using existing tax rates to value emission. However, the NO_x tax rate is almost the same as the estimates used by Hill (1999), that are based on damage costs studies from Sweden.

Barker *et al.* (1993b) use the results generated by the MDM model presented in Barker *et al.* (1993a) (see chapter 2) to study some secondary benefits of a carbon/energy tax. These benefits are reductions in traffic-related externalities such as congestion, accidents, noise and road surface damage. The MDM model finds that the petrol consumption in 2005 is only reduced by 1.2 per cent in the tax scenario (compared to baseline), even though CO_2 emissions are reduced by 12 per cent. The authors assume that traffic flow is reduced in proportion with petrol consumption, but recognise that this may overstate the real traffic-related benefits. They find the traffic-related secondary benefits to be 0.05 per cent of 1990 GDP. The authors do not state the reduction in CO_2 emissions, but based on Barker et al. (1993a) one can calculate the benefits to around £13 per ton of carbon abated. This is an order of magnitude below the results in Ekins. The explanation for this is the very small effect on petrol consumption, in addition to the fact that benefits of reduced air pollution are not included in the assessment.

Ekins (1996) also includes an interesting comparison of two ways of calculating ancillary benefits of climate policies. The UK and other countries in Europe have obliged themselves to limit their SO_2 emissions through the Second Sulphur Protocol (SSP).[21] Thus, either it can be assumed that the SO_2 reduction coming from climate policies is incorporated in the overall sulphur reduction plan, in which case the secondary benefits are the avoided costs of these abatement measures. Otherwise, it can be assumed that the SO_2 reduction from CO_2 abatement will be additional to it (this is the usual way of measuring ancillary benefits). In the first case, estimates are in the range of \$1.7-58 per ton carbon, while in the second case they are in the range of \$8.5-86. However, these are the benefits for the UK only, and up to three-quarters

[21] In December 1999 a new protocol was signed with limits for the year 2010.

of UK emissions are being deposited abroad. Thus, total benefits in the second case would be greater than those reported here. Generally, the secondary benefits of SO_2 reductions are substantially less with the implementation of the SSP than before it. The reason is that less SO_2 is reduced per ton reduction in carbon emissions either as a result of cleaning SO_2 or by a substitution from, e.g., coal to gas. Moreover, the marginal damage from SO_2 is likely to be greater at higher emission levels. Still, Ekins conclude that even under the SSP, up to 15 per cent of CO_2 emissions could be abated at negative cost due to the secondary benefits of SO_2 reduction.

To sum up this chapter, ancillary benefits are vital to include in an overall assessment of climate policies. Although the size of these benefits varies a lot (see Figure 2), we have seen that they usually are at least on the same order as the gross mitigation costs of climate policies. Thus, even if uncertainties about the marginal damage costs of CO_2 emissions prevail, the ancillary benefits imply that fairly high marginal costs of CO_2 abatement may be justified. This is of course not to say that CO_2 taxes are the best way of dealing with local or regional pollution. Other policies are probably more cost-efficient as they may be targeted directly toward the pollutant in question (e.g., through introducing cleaner technologies or restricting emissions in urban areas). However, if cost-efficient measures against other pollutants are not feasible, managing both environmental problems simultaneously may imply higher CO_2 taxes than if CO_2 emissions were the only target. The extent of this depends very much on where the CO_2 cutback is located; reduction in CO_2 emissions in urban areas are expected to give rise to more ancillary benefits than reduction in rural emissions.

6. Joint mitigation effort by the Nordic countries

Many international studies have been initiated to examine the outcome of joint mitigation of CO_2 emissions across countries (e.g., on the global level, the Annex B level or the EU level). In this chapter we review some studies focusing on joint mitigation effort in the Nordic countries. Even if these countries are similar in a number of respects, they are quite different with respect to energy structure and CO_2 emission intensities. Consequently, abatement costs will typically vary between them, giving opportunities for efficiency gains by joint mitigation.

One experimental study is Bohm (1997). Here, all countries were committed to reduce their individual carbon emissions to 1990 level in 2000; however, bilateral trade in emission quotas was allowed. The negotiation groups were experts appointed by their respective Energy Ministers. They provided information on their business as usual (BAU) emissions in 2000, and social abatement cost curves taking into consideration the real-world political constraints, e.g., employment and distribution effects. Existing CO_2 taxes were supposed to remain unchanged. The negotiations took place over three days, and were done bilaterally via bids and offers. The different negotiation groups knew their own abatement cost curves but not the ones of the other countries. However, as all countries had published abatement cost studies for their own economy, general knowledge of each country's technical costs was widespread among all of them.

Seven contracts were established, six with Finland and one with Denmark as sellers, five with Norway and two with Sweden as buyers. Total trade amounted to almost one third of the total emission reductions required. Joint implementation implied that Finland reduced CO_2 emissions by 5 million tons (Mt) and Denmark by 0.5 Mt more, and Norway by 3.5 Mt and Sweden by 2 Mt less than their 1990 emission levels. Total abatement costs for the year 2000 were reduced by almost 50 per cent. Actually, 97 per cent of the potential net gains from trade were realised, which is a striking result.[22] Reasons for the high gains in the experiment may have been that the technical costs were to a certain degree common knowledge, transaction costs were zero, and the abatement levels for the BAU scenarios were taken as given by the countries. Another interesting aspect was that the presumed roles of Denmark and Finland were interchanged in that Finland instead of Denmark became the dominating seller and Denmark was close to be a non-trader.

The Danish Economic Council (1997) compares the outcome of a joint implementation effort to reduce CO_2 emissions in Denmark and Norway with unilateral reductions, using the simulation model ELEPHANT (Electricity, Liberalisation, Equilibrium, Production, Heterogeneity and Nordic Transmission),

[22] Actual trading in the United States has resulted in realised gains from trade on the order of about 50 per cent, see Hahn and Stavins (1991).

constructed for the Nordic energy market. The model covers Denmark, Norway, Sweden and Finland, where each country is divided into several sectors. In addition to energy, the sectors also demand a macro good. The carbon intensity in power production is considerably higher in Denmark compared to the other countries, due to the large use of coal. Norway has the cleanest power production as the Norwegian production is based on hydropower. If Denmark and Norway agree to reduce total CO_2-emissions by 28 million tons in 1995, the optimal distribution will be 20 million in Denmark and 8 million in Norway. Compared to an equal absolute reduction and an equal percentage reduction, this will reduce total welfare costs by more than 40 per cent and 15 per cent respectively. The reason is that Norway does not have the same possibility as Denmark to reduce emissions by changing the technology of power production.

Hauch (1999) also uses ELEPHANT to analyse impacts of the Kyoto target in the four Nordic countries. Marginal abatement cost functions for all countries were constructed for 1995. The curves reflect the different energy systems, where substitution towards less polluting technologies is possible in the electricity and district heating production, but not in other parts of the economy. Thus, input substitution is the only option in households and other production sectors. The possibilities of reducing national emissions by importing electricity is not studied in constructing the curves, i.e., there is no electricity trade. In Norway, electricity is based on hydropower only, and there is no potential for reducing emissions from electricity production, only by input substitution in other sectors. Therefore, the marginal abatement cost curve is rapidly increasing. Denmark has a potential for substituting from coal use towards use of natural gas in electricity and district heating production, and the cost curve is, therefore, flatter and lower than the Norwegian. However, the cheapest way to make small Danish emission reductions is by input substitution in households and industry. In Sweden, electricity production is primarily based on hydro and nuclear power, and the Swedish marginal cost curve is similar to the Norwegian curve. The Finnish marginal cost curve is similar to the Danish in the sense that it is composed of increasing and horizontal segments, due to polluting technologies in electricity production.

Allowing for electricity trade will reduce abatement costs. For instance, Norway can increase its production of hydropower without increasing CO_2 emissions. If Denmark imports electricity from Norway, Danish emissions will be reduced. Thus, constructing a marginal abatement cost curve for the four countries together gives lower total costs at a common target. According to the curve, 85 million tons of CO_2 can be reduced at a marginal abatement cost of DKK 500 ($65). Imposing a similar carbon tax in all countries without allowing for electricity trade will reduce emissions only by 72.5 million tons totally.

The Kyoto agreement and the proposed implementation in EU give different emission targets to the Nordic countries compared to their 1990 levels. Denmark has agreed to reduce emissions by 21 per cent. Finland has agreed to keep emissions constant, while Sweden and Norway have agreed not to increase emissions by more than 4 and 1 per cent respectively. Two scenarios were analysed, one with emission quota trade within the four countries, and one where emission trading is not allowed. Existing emission taxes are removed in both scenarios. The emission targets are assumed to adjust linearly from the base year up to the Kyoto requirements in 2010, and stay unchanged from 2010 to 2020. Total emissions in BAU are 28 per cent higher than the Kyoto target in 2010 and 53 per cent higher in 2020. With quota trade, the permit price increases through most of the period and is DKK 350 ($45) per ton CO_2 in 2010. Finland will be selling large amounts of emission permits. Denmark and Norway will be importing permits in the long run, while Sweden will be selling some permits. Thus, the trading pattern indicates that the Kyoto Protocol and its implementation in EU have given Finland a very good bargain, Denmark and Norway bad bargains, while Sweden has got a slightly good bargain. The electricity trade is also affected by the agreement, with lower trade from Finland to Sweden, and Denmark being a net importer through the whole period. Norway will export electricity and Sweden will import electricity. With no quota trade, the national emission quota prices differ significantly with the Norwegian price reaching DKK 1600 ($210) in 2020. The Danish quota price is lower than the Norwegian, but still high, while the lowest quota prices are in Finland and Sweden. Thus, Norway and Denmark would gain from buying quotas from Sweden and Finland. The Swedish and Finnish permit prices are relatively equal and develop similarly through the whole period. This is due to the changed electricity trade between Sweden and Finland. Thus, electricity trade can work as a substitute to quota trading and equalise marginal abatement costs.

Summing up this chapter, we observe that emission trading or other kinds of joint implementation may give major cost reductions even between a small number of neighbouring countries. The condition seems to be that the countries have dissimilar structure with respect to energy production or energy use, so that the marginal abatement cost curves have different shapes.

7. Concluding remarks

The social costs of mitigating CO_2 emissions depend on a number of factors. First, restricting the use of fossil fuels through taxes or other measures against CO_2 emissions has a direct cost to society. Moreover, the costs may be intensified as increasing the price of fossil fuels in general increase the tax distortions in the economy. However, by choosing policy tools that raise extra revenues (e.g., CO_2 taxes or permit auctions), the government may be in a position to reduce distortionary taxes, giving a positive effect on the economy. An important discussion in the literature is exactly how big the net impact of these tax distortions is.

Our review of the numerical, macroeconomic studies in the Nordic countries, the UK and Ireland indicates that the overall welfare effects of CO_2 taxes are generally small in these countries, i.e., below 1.5 per cent for 20-30 per cent reduction in CO_2 emissions. Moreover, when the most efficient policy is chosen, i.e., uniform taxes and revenue recycling through labour tax reductions, the tax distortions seem to leave room for strong double dividends, i.e., the net mitigation costs may be negative. Our review further demonstrates that there is a clear welfare gain from recycling tax revenues by reducing distortionary taxes rather than giving lump sum transfers. Moreover, using tax exemptions seem to have a negative impact on welfare in most cases, but in some studies the conclusion is the reverse.

An important question is of course why an efficient climate policy has not been implemented already. Is it because there are political controversies with some elements of such a tax swap?

One important element is the distributional impact. The studies reviewed in our survey indicate that unless the CO_2 tax revenues are aimed specifically at the lower income households, the income effect of the mitigation policy will be regressive. In particular, using extra tax revenues to reduce other distortionary taxes seem to increase the income inequality in the society. Consequently, there may be a trade-off between choosing an efficient green tax reform and a tax reform that does not have negative effects on the income distribution.

Another significant point for some countries is related to international market effects. If the mitigation is part of a co-ordinated effort throughout the world to reduce CO_2 emissions (e.g., the Kyoto Protocol), there will probably be a considerable impact on the fossil fuel markets. This will have major bearings on the total costs of fossil fuel exporting countries like Norway. Our survey suggests that lost income from this export is in the same range as the possible domestic mitigation costs of complying with the emission targets.

In case domestic CO_2 mitigation is not cost free, joint mitigation effort between countries may drastically reduce the overall costs of complying with the Kyoto Protocol or another specified emission target. Our survey of emission trade between the Nordic countries indicates that the cost savings are so high that the extra savings of introducing joint effort in all OECD countries may be small in comparison.

Finally, bringing in the environmental benefits by valuing reductions in CO_2 emissions is difficult, both from a scientific point of view and from a narrow-minded country perspective. However, policies aimed at reducing CO_2 emissions also bring about emission reductions for other pollutants, which have damaging impact on health, eco-systems etc. Therefore, such policies have ancillary benefits that must be accounted for. According to our survey, these benefits are of the same order of magnitude as the gross mitigation costs,and therefore significantly reduce the net social costs (or increase the benefits) of reducing CO_2 emissions.

Assuming that enough parties ratify the Kyoto Protocol, the richer part of the world will have to reduce its emissions of greenhouse gases. Our survey seems to indicate that this will not lead to major welfare losses for the populations in the Nordic countries, the UK and Ireland. Moreover, the survey has given valuable information about how the losses may be minimised, and even possibly turned to a gain without regarding the climate benefits. If this turns out to be real, not only in these six countries but in the industrial world as a whole, the prospects for further global agreements beyond Kyoto may be brighter than they seem today.

References

Aaserud, M., 1996: Costs and Benefits of Climate Policies: An Integrated Economy-Energy-Environment Model Approach for Norway. In B. Madsen, C. Jensen-Butler, J.B. Mortensen, A.M. Bruun Christensen (eds.): *Modelling the Economy and the Environment*, Springer, Berlin.

Aasness, J., T. Bye, and H. T. Mysen, 1996: Welfare effects of emission taxes in Norway. *Energy Economics*, **18**(4), 335-46.

Alfsen, K., H. Birkelund and M. Aaserud, 1995.: Impacts of an EC carbon/energy tax and deregulating thermal power supply on CO_2, SO2 and NO_x emissions. *Environmental and Resource Economics* **5**, 165-89.

Alfsen, K. H., T. Bye, and E. Holmøy (eds.), 1996: *MSG-EE: An Applied General Equilibrium Model for Energy and Environmental Analyses*. Social and Economic Studies 96, Statistics Norway.

Alfsen, K. and K. E. Rosendahl, 1996: Economic Damage of Air Pollution. Documents 96/17, Statistics Norway.

Andersen, F. M., H. K. Jacobsen, P. E Morthorst, A. Olsen, M. Rasmussen, T. Thomsen, and P. Trier, 1998: EMMA: En energi- og miljørelateret satellitmodel til ADAM (EMMA an energy an environmental related satellite model to ADAM). *Nationaløkonomisk Tidsskrift*, **136**(3), 333-349.

Barker, T., 1997: Taxing pollution instead of jobs: Towards more employment without more inflation through fiscal reform in the UK. In T. O'Riordan (ed.): *Ecotaxation*, Earthscan, 1997.

Barker, T., S. Baylis and P. Madsen, 1993a: A UK carbon/energy tax. The macroeconomic effects. *Energy Policy* **21**, No. 3, March 1993, 296-308.

Barker, T., N. Johnstone and T. O'Shea, 1993b: The CEC carbon/energy tax and secondary transport-related benefits. Energy-Environment-Economy Modelling Discussion Paper No. 5, Department of Applied Economics, University of Cambridge, UK.

Barker, T. and N. Johnstone, 1993: Equity and efficiency in policies to reduce carbon emissions in the domestic sector. *Energy&Environment* **4**, No. 4, 335-361.

Barker, T. and J. Köhler, 1998: Equity and ecotax reform in the EU: Achieving a 10% reduction in CO_2 emissions using excise duties. Environmental Fiscal Reform Working Paper No. 10, University of Cambridge.

Barker, T. and K. E. Rosendahl, 2000: Ancillary Benefits of GHG Mitigation in Europe: SO_2, NO_x and PM_{10} reductions from policies to meet Kyoto targets using the E3ME model and EXTERNE valuations. Proceedings of Expert workshop on assessing the ancillary benefits and costs of greenhouse gas mitigation strategies, 27th-29th March 2000, Washington DC.

Berg, E., S. Kverndokk, and K. E. Rosendahl, 1997: Market power, international CO_2 taxation and petroleum wealth. *The Energy Journal,* **18**(4), 33-71.

Bergman, L., 1991: General Equilibrium Effects of Environmental Policy: A CGE-Modeling Approach. *Environmental and Resource Economics*, **1**(1): 43-61.

Bergman, L., 1995: Sectoral Differentiation as a Substitute for International Coordination of Carbon Taxes: A Case Study of Sweden. In J. Braden and T. Ulen (eds.): *Environmental Policy with Political and Economic Integration*, Edward Elgar, Cheltenham.

Bohm, P., 1997: *Joint Implementation as Emission Quota Trade: An Experiment Among Four Nordic Countries*. Nord 1997:4, Nordic Council of Ministers.

Bovenberg, A. L. and R. de Mooij, 1994: Environmental Levies and Distortionary Taxation. *American Economic Review* **84**(4), 1085-89.

Bovenberg, A. L. and F. Van der Ploeg, 1998: Consequences of Environmental Tax Reform for Unemployment and Welfare. *Environmental and Resource Economics,* **12**(2): 137-150.

Brekke, K. A. and H. A. Gravingsmyhr, 1994: Adjusting NNP for instrumental or defensive expenditure. Discussion Papers 134, Statistics Norway.

Brendemoen, A. and H. Vennemo, 1994: A Climate Treaty and the Norwegian Economy: A CGE Assessment. *The Energy Journal*, **15**(1), 77-93.

Brendemoen, A., S. Glomsrød, and M. Aaserud, 1992: *Miljøkostnader i makroperspektiv (Environmental costs in a macro perspective)*. Reports 92/17, Statistics Norway.

Brännlund, R. and I.-M. Gren, 1999: Green Taxes in Sweden: A Partial Equilibrium Analysis of the Carbon Tax and the Tax on Nitrogen in Fertilizers. In R. Brännlund and I.-M. Gren, (eds.): *Green Taxes – Economic Theory and Empirical Evidence from Scandinavia*, Edward Elgar, Cheltenham.

Bye, B., 1999: Environmental Tax Reform and Producer Forsight: An Intertemporal Computable General Equilibrium Analysis. *Journal of Policy Modeling*, forthcoming.

Bye, B. and K. Nyborg, 1999: The Welfare Effects of Carbon Policies: Grandfathered Quotas versus Differentiated Taxes. Discussion Papers 261 (revised version), Statistics Norway.

Bye, B., T. Bye and L. Lorentsen, 1989: SIMEN. Studies of Industry, Environment and Energy towards 2000. Discussion Paper 44, Statistics Norway.

Danish Economic Council, 1997: *Dansk økonomi, efterår 1997 (Danish Economy, autumn 1997).* Danish Economic Council, Copenhagen.

Dean, A. and P. Hoeller, 1992: *Costs of reducing CO_2 emissions. Evidence from six global models*. OECD Economics Department Working Papers No. 122, OECD, Paris.

ECON, 1997: *Avgiftenes rolle i klimapolitikken (The role of taxes in the climate policy)*. ECON-rapport nr. 60/97, ECON.

Ekins, P., 1996: How large a carbon tax is justified by the secondary benefits of CO_2 abatement?. *Resource and Energy Economics*, **18**(2), 161-187.

Environmental Tax Committee, 1992: *Mot en mer kostnadseffektiv miljøpolitikk i 1990-årene (Towards a more cost-effective environmental policy in the 1990's).* NOU 1992:3, Ministry of Finance, Oslo, Norway.

Fitz Gerald, J. and D. McCoy, 1992: The Macroeconomic Implications for Ireland. Chapter 5 in J. Fitz Gerald and D. McCoy (eds.): *The Economic Effects of Carbon Taxes*. Policy Research Series, Paper no. 14, Economic and Social Research Institute, Dublin.

Frandsen, S. E., J. V. Hansen, and P. Trier, 1995: *GESMEC - En generel ligevægtsmodel for Danmark. Dokumentation og anvendelser (GESMEC – An applied general equilibrium model for Denmark – Documentation and applications)*. The Secretariat of the Economic Council, Copenhagen.

Frandsen, S. E., J. V. Hansen, and P. Trier, 1996: En generel ligevægtsmodel for Danmark og beregnede virkninger af CO_2-afgifter (A general equilibrium model for Denmark and calculated impacts of CO_2 taxes). *Nationaløkonomisk Tidsskrift*, **134**, 272-289.

Glomsrød, S., A. C. Hansen, and K. E. Rosendahl, 1996: *Integrering av miljøkostnader i makroøkonomiske modeller (Integrating environmental costs into macroeconomic models)*. Rapporter 96/23, Statistics Norway.

Glomsrød, S., R. Nesbakken, and M. Aaserud, 1998: Modelling impacts of traffic injuries on labour supply and public health expenditures. In K. E. Rosendahl (ed.): *Social Costs of Air Pollution and Fossil Fuel Use – A Macroeconomic Approach*, Social and Economic Studies 99, Statistics Norway.

Goulder, L. H., 1995a: Effects of carbon taxes in an economy with prior tax distortions: An intertemporal general equilibrium analysis. *Journal of Environmental Economics and Management*, **29**, 271-297.

Goulder, L. H., 1995b: Environmental taxation and the double dividend: A reader's guide. *International Tax and Public Finance*, **2,** 157-183.

Gørtz, M. and J.V. Hansen, 1999: Regulation of Danish Energy Markets with Imperfect Competition. Working Paper 1999:2, Danish Economic Council.

Gørtz, M., J.V. Hansen and M. Larsen, 1999: CO_2-skatter, dobbelt-dividende og konkurrence i energisektoren: Anvendelser af den danske AGL-model ECOSMEC (CO_2 taxes, double dividend and competition in the energy sector: Applications of the Danish CGE model ECOSMEC). Arbejdpapir 1999:1, Danish Economic Council.

Hagem, C., 1994: Cost-Effective Climate Control in a Small Country. *The Energy Journal*, **15**(4), 119-39.

Hall, A. and L. A. Clements, 1998: The Viking CGE Model, Working Paper Series, W98:03, Institute of Economic Studies, University of Iceland.

Hahn, R and R. Stavins, 1991: Incentive-Based Environmental Regulation: A new era from an old idea? *Ecology Law Quarterly*, **18**.

Harrison, G. W. and B. Kriström, 1996: Effekter av olika skattväxlingsalternativ enligt en allmän jämviktsmodell (Effects of different green tax alternatives using a general equilibrium model). In *Expertrapporter från skatteväxlingskommittén.* SOU 1996:117, Fritzes förlag, Stockholm.

Harrison, G. W. and B. Kriström, 1999: General equilibrium effects of increasing carbon taxes in Sweden. In R. Brännlund and I-M. Gren (eds.): *Green Taxes - Economic Theory and Empirical Evidence from Scandinavia*., Edward Elgar, Cheltenham.

Hauch, J., 1999: *Elephant – A Simulation Model for Environmental Regulation at Nordic Energy Markets.* Ph.D thesis, Danish Economic Council, Copenhagen.

Hill, M., 1999: Green Tax Reforms in Sweden: The Second Dividend and the Cost of Tax Exemptions. Beijer Discussion Paper Series No. 119, Beijer Institute of Ecological Economics, The Royal Swedish Academy of Sciences, Stockholm.

Holtsmark, B., 1998: From the Kyoto Protocol to the fossil fuel market. Working Paper 1998:9, CICERO, Oslo.

Honkatukia, J., 1997: Are there double dividends in Finland?. Helsinki School of Economics and Business Administration, Helsinki.

Håkonsen, L. and L. Mathiesen, 1997: CO_2-Stabilization May Be a 'No-Regrets' Policy. *Environmental and Resource Economics*, **9**(2), 171-98.

IPCC, 1996: *Climate Change 1995 – Economic and Social Dimensions of Climate Change*. Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press.

Jacobsen, H. K., 1998: Integrating the bottom-up and top-down approach to energy-economy modelling: the case of Denmark. *Energy Economics*, **20,** 443-461.

Jensen, J., 1998: *Carbon Abatement Policies with Assistance to Energy Intensive Industry.* Working paper No 2/98, The MobiDK Project, The Ministry of Business and Industry, Copenhagen.

Jensen, J. and T. N. Rasmussen, 1998: *Allocation of CO_2 Emission Permits: A General Equilibrium Analysis of Policy Instruments.* The MobiDK Project, The Ministry of Business and Industry, Copenhagen.

Jerkkola, J., J. Kinnunen and J. Pohjola, 1993: A CGE Model for Finnish Environmental and Energy Policy Analysis: Effects of Stabilizing CO_2 Emissions. Discussion papers No. 5, Helsinki School of Economics, Helsinki.

Johnsen, T. A., B. M. Larsen, and H. T. Mysen, 1996: Economic impacts of a CO_2 tax. In K. H. Alfsen, T. Bye, and E. Holmøy, (eds.): *MSG-EE: An Applied General Equilibrium Model for Energy and Environmental Analyses*, Social and Economic Studies 96, Statistics Norway.

Jorgenson, D. W. and P. J. Wilcoxen, 1993: Reducing U.S. carbon emissions: An econometric general equilibrium assessment. *Resource and Energy Economics*, **15**, 7-25.

Konjunkturinstitutet, 1999: *Miljö och ekonomi - scenarier fram till år 2015. Bilaga 2 till Långtidsutredningen 1999 (Environment and economy - scenarios towards 2015. Annex 2 to the Long term report 1999)*. Ministry of Finance, Sweden.

Kverndokk, S., L. Lindholt and K. E. Rosendahl, 2000: Stabilisation of CO_2 concentrations: Mitigation scenarios using the Petro model. *Environmental Economics and Policy Studies*, forthcoming.

Mathiesen, L., 1996a: Grønn Skattereform: Beregning av noen konsekvenser (Green Taxreform: Calculations of some consequences). SNF-Rapport 30/96.

Mathiesen, L., 1996b: Skog og skogproduksjon som virkemiddel for å binde klimagasser: En CGE-analyse (Forest and forest production as means to bind greenhouse gases: A CGE analysis). *Sosialøkonomen*, 5:29-37.

Mathiesen, L., 1999: Regulering av norske klimagassutslipp. En oppsummering av resultater fra SNFs CO_2-modell (Regulation of Norwegian greenhouse gas emissions. A survey of results from SNF's CO_2 model). SNF Arbeidsnotat nr. 41/1999.

Meyer, H., P. E. Morthorst, L. Schleisner, N. I. Meyer, P. S. Nielsen, and V. Nielsen, 1994: *Omkostningsopgørelse for miljøeksternaliteter i forbindelse med energiproduktion (An assessment of external environmental costs related to energy production).* Risø National Laboratory, Roskilde.

Ministry of Finance, 1997: *Taxation, environment, and employment. A report from the Swedish Green Tax Commission*. Fritzes, Stockholm.

Nilsson, C., 1999: Unilateral versus Multilateral Carbon Dioxide Tax Implementations - a numerical analysis with the European model - GEM-E3. Preliminary version, National Institute of Economic Research, Stockholm.

Nilsson, C. and A. Huhtala, 2000: Is CO_2 trading always beneficial? A CGE-model analysis on secondary environmental benefits. Draft version, National Institute of Economic Research, Stockholm.

O'Donoghue, C., 1997: Carbon dioxide, energy taxes and household income. Working paper 90, The Economic and Social Research Institute, Dublin, Ireland.

Parry, I. W. H. (1997): Environmental Taxes and Quotas in the Presence of Distorting Taxes in Factor Markets. *Resource and Energy Economics*, **19**: 203-220.

Pohjola, J., 1999: Economywide Effects of Reducing CO_2 Emissions: A Comparison between Net and Gross Emissions. *Journal of Forest Economics*, **5**(1): 139-168.

Profu, 1997: Styrmedlens inverkan på koldioxidutsläppen. Beräkningar med MARKAL-MACRO modellen (Governmental impact on CO_2 emissions. Analyses based on the MARKAL-MACRO model). NUTEK R 1997:39, Stockholm.

Rosendahl, K. E. (ed.), 1998: *Social Costs of Air Pollution and Fossil Fuel Use – A Macroeconomic Approach.* Social and Economic Studies 99, Statistics Norway.

Schleisner, L. and P. S. Nielsen, 1997: *External Costs Related to Power Production Technologies – ExternE National Implementation for Denmark.* Risø National Laboratory, Roskilde.

Smith, S., 1992: *The Distributional Consequences of Taxes on Energy and the Carbon Content of Fuels*. European Economy, Special Edition No.1, The Economics of Limiting CO_2 Emissions. Commission of the European Communities, Brussels.

Smith, S., 1998: Distibutional incidence of environmental taxes on energy and carbon: a review of policy issues. Paper presented at Colloque du Ministere de l'Environnnement et de l'Amenagement du Territoire, Toulouse, 13 May.

Symons, E., J. Proops and P. Gay, 1994: Carbon taxes, consumer demand and carbon dioxide emissions: A simulation analysis for the UK. *Fiscal Studies*, **15**, No.2, 19-43.

Weyant, J. P. (ed.), 1999: *The costs of the Kyoto Protocol: A multi-model evaluation*. *The Energy Journal*, special edition.