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DIRECT AND INDIRECT EFFECTS OF REDUCING SO_2 EMISSIONS: EXPERIMENTAL CALCULATIONS ON THE MSG-4E MODEL.

BY

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ABSTRACT

Preliminery estimates of impacts of regulating SO_2 emissions from manufacturing sectors are made. Only emissions pertaining to fuel use are included in the regulation. Direct and indirect effects are considered and it is shown that indirect (general equilibrium) effects on the reduction of emissions are neglectible. Indirect costs of the control policy are, however, not neglectible.

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1. Introduction.

1.1 Background.

Some areas of Norway are heavily damaged by acid rain. Acid rain is mainly caused by emissions of sulphur dioxide (SO_2) to air. Acidification has killed off fish populations in numerous lakes and rivers in the southern part of Norway, and acid rain has led to increased concentration of heavy metals in the drinking water. The related health effects are still uncertain, but preliminary investigations indicate that they might be serious[1]. In addition, release of aluminum from the ground is known to increase under acid conditions, and high concentration of aluminum in drinking water is a suspected cause of Alzheimer's disease (Vogt (1986)). Sulphur dioxide and other related elements in the atmosphere can cause health damages, mainly manifested through increases in respiratory illnesses. Increased rates of corrosion on buildings and other exposed structures due to sulphur dioxide emissions are likely to cause large losses to society through increased maintenance costs and a shorter lifetime of capital equipment. Corrosion losses in the 9 southern counties of Norway were estimated to be approximately 1.5 billion 1983-NOK in 1979 (Henriksen et al. (1981)). This represented approximately 3% of the depreciation of the total fixed capital stock in Norway that year.

Approximately 90% of all sulphur deposited in Norway comes from sources abroad. It might therefore seem futile to regulate domestic emissions of SO_2. However, Norway hopes to influence other countries which export acidic discharges to reduce their SO_2 emissions through collective actions. Furthermore, the consentration level of SO_2 in air above urban regions in Norway is mainly determined by local sources.

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1. See for instance SFT report no. 38: Luftforurensning: Virkninger på helse og miljø (Air pollution: Effects on health and the environment), Oslo 1982.

Norway, together with some twenty other countries, signed the "Protocol to the 1979 convention on long-range transboundary air pollution on the reduction of sulphur emissions or their transboundary fluxes by at least 30 per cent" (ECE (1985))(the so called Helsinki treaty) in June 1985. The treaty has as basic provision that "The parties shall reduce their national annual sulphur emissions or their transboundary fluxes by at least 30 per cent as soon as possible and at the latest by 1993, using 1980 levels as the basis for calculation of reductions". Recent estimates (Glomsrød and Vigerust (1985), (1986), Alfsen and Glomsrød (1986a), and Alfsen et al. (1986a)) seem to indicate that the goal stated in the treaty may be difficult to achieve in Norway without an active regulatory policy against emissions of SO_2 to air. This serves as a motivation for the present study of the economic impact of alternative regulatory measures aiming at a reduction in SO_2 emissions from the manufacturing sectors in Norway.

In Norway estimates show that about 45% of SO_2 emissions result from fuel oil combustion (the remaining 55% are related to other industrial processes, e.g. copper smelters etc.). Reductions of the fuel related emissions can be achieved by several means, two of which are:

- Firms can install "top of pipe" cleaning equipment to reduce the content of sulphur dioxide in the emissions.

- Alternatively, they can switch to more expensive, but lower sulphur fuel oil.

Either direct regulation through legislation or economic incentives through taxation can be applied to lower emissions in these ways.

Some regulations have already been introduced in Norway. First, a preliminary regulation was implemented for new industrial plants established after 1 January 1977, restricting the sulphur content of heating oils to 1% or lower in regions along the southern coast of Norway. Then, from 1 January 1986, this regulation was

extended to cover all existing industry in the entire southern part of the country. More stringent standards were made for two of the larger cities where the upper limit is 0.8% sulphur in heating oils. The rest of the country is allowed to use oil with sulphur content up to 2.5%. These restrictions were implemented as regulatory measures without any economic incentives. However, a modest tax based on sulphur content of fuel oils has also been in effect. Furthermore, over the last decade a government supported clean-up program for manufacturing sectors has been carried out. A large fraction of the most polluting firms has therefore already installed equipment for cleaning of SO_2 emissions.

1.2 The aim of the report.

Two of the questions that naturally occur in connection with introducing an emission control policy are: by how much are emissions reduced? And at what costs to the society? As we shall see, these are highly non-trivial questions.

This report seeks to answer these questions for a family of closely related control policies, all of which are aimed at reducing SO_2 emissions by reducing the sulphur content of the heavy oil used in the manufacturing sectors. (Preliminary results have been published in the proceedings of the Eighth IAEE International Conference (Alfsen et al. (1986b))). The effects of these policies are measured against a scenario with an average sulphur content of heavy oil of 2.15% as measured by weight. The difficult question concerning the benefits of the control measures are only briefly discussed at the end of this paper.

The control policies considered in this study are:

1. Legislation prohibiting the use of heavy fuel oils with a sulphur content above 1% in the manufacturing sectors. This policy will be denoted 1R (policy 1, implemented by direct regulation).

2. Legislation prohibiting the use of heavy fuel oils with a sulphur content above 0.7% in manufacturing firms lacking equipment for cleaning of SO_2 emissions. Firms with such equipment are allowd to use heavy oil with a sulphur content below 1%. This policy is denoted 2R.

3. Taxing the SO_2 emissions from manufacturing sectors with a rate equal to 2300 NOK per ton SO_2 emitted. This policy is denoted 1T (Policy 1 implemented with a tax).

4. Taxing the SO_2 emissions from manufacturing sectors with a rate equal to 5000 NOK per ton SO_2 emitted. This policy is referred to as policy 2T.

The control policies affect the manufacturing sectors in all regions of the country. The cost minimizing responses of these sectors to control policies 1T and 2T, i.e. the policies based on taxation of emissions, are constructed so as to be identical to the responses to policy 1R and 2R, respectively. This is discussed further in Appendix A. The tax will then induce a change from heavy oil with a high sulphur content to oil with lower sulphur content. In particular, it is assumed that no additional cleaning of emissions takes place beyond that induced by the emission tax. The reason for this assumption is the recently finished clean-up program in Norway, where cleaning equipment was installed in almost every major plant emitting large quantities of SO_2. Thus, further cleaning in the manufacturing sectors is a priori assumed to be uneconomical compared to the option of switching fuel.

To the companies the main difference represented by the two classes of control policies, i.e. quantity and tax regulations, can then be viewed as a difference in the effective price of oil. In addition to paying a premium on low sulphur oil, taxes will have to be paid on remaining emissions under control policy 1T and 2T. This effectively means a higher price on oil under these control policies than under the corresponding quantity regulations (policy 1R and 2R). See also the discussion in Appendix A.

Both emission reduction effects and social costs associated with the control policies can be considered as consisting of two parts; direct and indirect effects.

Direct effects of the control policies are in this report taken to be consequences that are directly related to the fuel switch from oil with high to oil with low sulphur content, disregarding economic repercussions on the production structure within a single sector or among sectors. Thus, under the assumptions discussed above, the direct effects on emissions are only due to the lower emission coefficients associated with the use of oil with a low sulphur content. The fact that firms will tend to use less heavy oil when the price of oil increase, is not included in the direct effects. Similarily, the direct private cost to the manufacturing sectors of the control policies is the added cost of purchasing the same amount of the more expensive oil with a reduced sulphur content. The direct social cost is the direct private cost to manufacturing sectors adjusted for taxes paid, since taxes are not considered to be a cost to the society, but simply a redistribution of income.

Over and above the direct effects, there will be two responses, called indirect effects[2] in this report, associated with the implementation of a control policy. One is due to readjustments that will take place within a regulated sector when the effective price of oil increases. Where possible, electricity will be substituted for oil, and other input factors like labour and materials will be substituted for energy. The other part of the total (i.e. direct plus indirect) effects is the reallocation that will take place among sectors when the increased cost of production is reflected in the prices on their products. This adjustment will affect all sectors of the economy, not only those directly influenced by the control policies. The indirect effects

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2. In the economic literature, direct effects are often defined so as to include the first of the two responses we have labeled indirect effects in this report. As it turns out, this part of the total effects of the control policies is very small. The main conclusions of the report are therefore not affected by a reinterpretation of direct and indirect effects along the lines common in economic literature.

on emissions are due to adjusted demand for fuel oil with adjusted emission coefficients. The total cost to the manufacturing sectors and to the society is more difficult to define precisely. Changes in gross output, GDP and consumption are some of the indicators that will be used in this paper.

The distinction between direct and indirect effects on emissions can perhaps be illustrated by defining μ to be the emission coefficient (e.g. kg SO_2 per ton fuel oil) and F to be the demand for fuel oil in one sector before regulation. After implementing the control policy the emission coefficient will change to μ^* and fuel oil demand to F*. Total emission will then be chamged by an amount given by

$$U = \mu^*F^* - \mu F = \mu^*(F^* - F) + F(\mu^* - \mu) \qquad (1.1)$$

Here, the term $F(\mu^* - \mu)$ represents the direct effect of the regulation, while $\mu^*(F^* - F)$ represents the indirect effect.

A major aim of this report is to determine the order of magnitude of the direct and indirect effects, both on emissions and on the overall cost of the policies. In particular, the relative size of the two types of effects are of interest. If direct effects can be shown to dominate, the assessment of the control policies discussed in this report, or similar ones, become a relatively trivial calculation. However, if the indirect effects are found to be important, the repercussions of the control policies on the economy will have to be analyzed and taken into consideration before such policies are pursued.

The direct effects of all four control policies are determined in this report. However, the total effects, i.e. direct plus indirect effects, are only calculated for control policy 2T. The reason for concentrating on this scenario is of course that it represents the most extreme alternative among the family of control measures included in the report.

The study of the economic effects of taxing SO_2 emissions relies on the use of a disaggregated general equilibrium growth model

called MSG-4E (Bjerkholt et al. (1983), Longva et al. (1985)). This model is utilized by the Ministry of Finance in Norway in its long-term planning of the national economy and the Ministry of Petroleum and Energy for energy planning purposes. The opportunity thus exists for a closer link between environmental, economic and energy planning. In fact, the reference scenario in this paper is based on one of the official forecasts of the economy, as described in the Government's Long-Term Programme for the years 1986 to 1989. The scenario describes one likely growth path for a twenty year time period, taking 1983 as the base year. Other assumptions made in this forecast are discussed in more detail in section 3.

Basing our analysis on a general equilibrium model, we accomplish two objectives, both essential in a study of impacts of regulatory measures against air pollution. From a theoretical point of view a general equilibrium model of the economy provides the means of analyzing the interrelationships between the sectors of the economy in a coherent setting. From an application point of view, it provides a method for determining the indirect general equilibrium effects of economic "disturbances" due to, for instance, environmental measures like taxes on emissions of SO_2. When choosing among alternative control policies, the total effects must be calculated and compared. The total social costs of reducing emissions must then be weighted against the benefits of achieving a better environment.

Not surprisingly, this study shows that the indirect effects on the emissions are rather small. The reason is that by switching fuel, emission coefficients are reduced by more than 50%, while readjustments in the economy are of a far smaller magnitude. Hence, good estimates of the total effects of a control policy on future emissions can be obtained by restricting the analysis to the direct effects only. However, the total social cost (measured as production foregone due to the control policy), are found to be relatively large compared to the direct social costs, and might be of major concern when the policy of taxing emissions is to be assessed. For policy 2T, we estimate a per capita total social cost in year 2000 two and a half time greater than the

direct social cost. Clearly this difference is significant when the policy of taxing emissions is to be assessed. A discussion of this point, in view of the fact that emission taxes are often recommended as superior to other regulations, will be given later.

1.3 Structure of the report.

As a background for the study, a short history of SO_2 emissions in Norway is presented in section 2 (see also Vigerust (1986)), together with a discussion of sources of emissions and likely development in future emissions (without the additional control measures). Section 3 briefly describes the MSG-4E model and how the emission tax is implemented in the model. (The model was slightly modified for this study to allow for sector dependent increases in taxes on fuel oil usage). Section 4 describes the direct effects of the control policies on future emissions of SO_2, while section 5 describes the indirect effects on emissions and important economic variables of policy 2T. A discussion of the results, in view of the literature on tax approaches vs. emission regulations, completes section 5. In section 6, we briefly mention some modelling issues that are not treated adequately, or not at all, in the present analysis, and point out possible directions for further research. Finally, section 7 summarizes the paper.

There are two appendices to this report. Appendix A discusses the marginal control cost curves and the impact of SO_2 cleaning on control costs. The cost minimizing behaviour of firms subjected to regulation or taxation of SO_2 emissions are discussed. Appendix B contains emission data for the reference and the policy scenarios as well as data on the policy costs. Although the results should be considered preliminary due to the uncertainties in some of the key assumptions, the methodology for calculating emissions and policy costs is clearly stated in Appendix B.

2. SO_2 emissions in Norway.

2.1 Historic emissions.

As shown in table 2.1, the SO_2 emission level in Norway has decreased considerably after 1980. This is in spite of a (relatively weak) general economic growth which, by itself, would be expected to increase the emission level. There are several reasons for this trend, and chief among them is probably the price shocks on oil products experienced during the 1970's. As a consequence, the demand for oil products has declined and combustion related emissions have been reduced. Also, in the early eighties cheap hydro-electric surplus power was in abbundant supply. In addition, Norway experienced a substantial growth in its oil and gas production during this period. As a consequence, services and public and private consumption have grown at a faster rate than traditional manufacturing, thus reducing the macro energy coefficients of the economy. Finally, the Norwegian government introduced a modest set of regulations of maximum sulphur content in heating oils in the seventies.

The sector distribution of the SO_2 emissions are shown in the lower half of the table. The decline in the emissions from pulp and paper production is particularly sharp. This sector has been one of the main beneficiaries of the abbundant supply of surplus hydro-power in the last few years.

The sources of SO_2 emissions in 1983 are shown in table 2.2. Approximately 73% of all SO_2 emitted comes from manufacturing sectors. More than half of total SO_2 emission is due to industrial processes, while approximately 18% comes from combustion of oil within these sectors.

TABLE 2.1. EMISSION OF SO_2 IN NORWAY. THOUSAND METRIC TONS.

Year	1976	1977	1978	1979	1980	1981	1982	1983	1984[1]
Total emissions	147	146	142	144	141	127	113	105	95
Agriculture/ Fishing	6	6	6	6	5	4	4	5	4
Pulp and paper	33	34	30	25	26	20	13	7	5
Power intensive industries	45	45	46	53	54	53	53	47	50
Other industries/ mining	36	34	34	33	29	24	23	23	17
Construction	2	2	2	2	2	2	2	1	1
Trade, services	9	8	7	8	7	7	4	6	4
Transport	10	10	11	11	11	11	12	12	10
Private househ.	7	6	6	7	6	6	5	4	4

1) Preliminary.
Source: Central Bureau of Statistics of Norway.

TABLE 2.2. SOURCES OF SO_2 EMISSIONS. 1983. PERCENT.

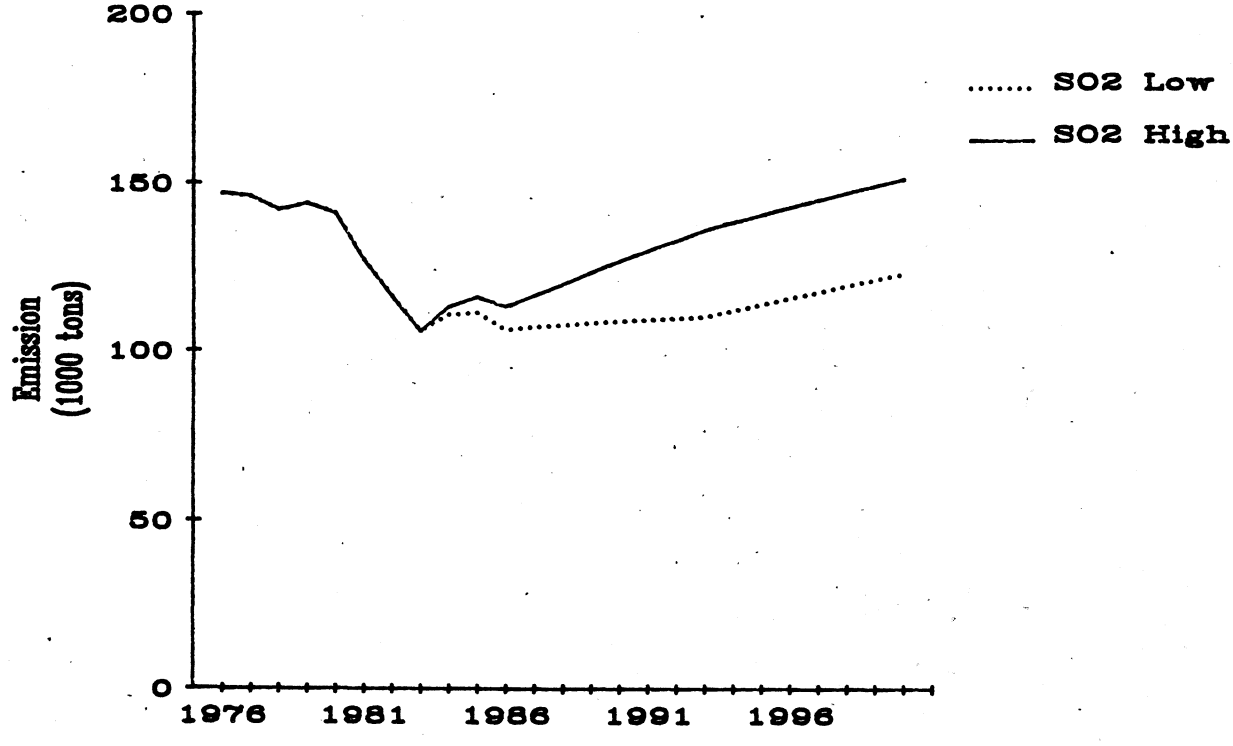
Manufacturing	73	
Of which due to:		
Combustion of oil		18
Industrial processes		55
Transport	18	
Other	9	
Total	100	

2.2 Future emissions.

Factors that led to a decrease in SO_2 emissions during the past decade will probably diminish in importance in the years ahead. Figure 2.1 shows projections of future SO_2 emissions for the period from 1983 to year 2000 together with historical data.

The SO_2 projections shown in the figure are based on one high and one low economic growth path that bracket the growth alternative chosen as the reference scenario in this paper. They include effects of planned regulations of maximum sulphur content of oil. The MSG-4E model, described in the next section, is the core model employed in making these forecasts. For further discussion of assumptions and forecasts of emissions of other pollutants we refer to previously published works by Glomsrød and Vigerust (1985,1986), Alfsen and Glomsrød (1986a) and Alfsen et al. (1986a).

Figure 2.1. Historical data on SO_2 emissions 1976-1983, and projections towards year 2000 based on two economic scenarios.



If Norway is going to fulfil the Helsinki treaty, SO_2 emissions must be below 100 thousand tons in 1993. From figure 2.1 we see that this is almost fulfilled in the scenario with low economic growth (1.4% annual growth in GDP). Judging this scenario to be relatively pessimistic, it is likely that further regulations are needed in order to meet the Helsinki obligation. The recent decline seen in the price of oil is also likely to boost the growth in combustion related emissions (see Alfsen and Glomsrød (1986b)). Thus, the forecasts serves as motivation for studying the policies which seek to induce a maximum sulphur content of heating oil equal to 1.0% or 0.7%.

3. The core model, emission coefficients and taxation.

3.1 The MSG-4E model.

MSG-4E is a disaggregated general equilibrium model employed by the Ministry of Finance in Norway for long-term economic planning and by the Ministry of Petroleum and Energy for energy planning purposes. The production X in 33 sectors is described by a function of four input factors; capital K, labour L, materials M, and energy U

$$X = \exp(\gamma t)\ f(K,L,M,U) \qquad (3.1)$$

(In some sectors, e.g. public-, primary-, and oil and gas sectors, production is exogenously given). The mix of input factors in each sector is determined by relative prices, using a Generalized Leontief cost function to represent production. γ represents a sector dependent exogenous rate of factor neutral technical change. Energy U is a composite of electricity E and fuels F

$$U = g(E,F) \qquad (3.2)$$

F is composed of two commodities; gasoline G and fuel oils H, in fixed proportions in each sector. The proportions are determined

from base year (1983) data. Relative prices determine the fuel and electricity shares within the energy commodity.

Total labour supply, wage rates, return to capital, and technical change are some of the most important exogenous supply side variables in the model. Prices on materials are determined by production costs. The cost minimizing allocation of production between sectors is determined within an input-output framework. Some final demand categories like exports and government consumption are exogenous variables. Private consumption expenditures are derived residuallyso as to ensure full capacity utilization. The commodity composition of private consumption is calculated from total expenditure and relative prices, using a complete demand system. Imports are determined by commodity and sector specific import shares. Among the exogenous variables, export volumes play an important role. About 40% of SO_2 emissions stem from production for export. Consequently the indirect effects on total SO_2 emissions of introducing an emission tax are limited by this export demand rigidity - unless relaxed by the model user.

The structure of the MSG-4E model will of course influence the calculated impact of an emission tax. In a long-term equilibrium model, which always ensures full capacity utilization along the growth path, a change in exogenous prices can mainly lead to a reallocation of production and inputs of energy, materials, labour and capital. The total availability of labour is given, while the accumulation of capital depends on an exogenously given rate of return on capital. Thus, capital is determined by the distribution of production among sectors with varying degrees of capital intensity and technical change as well as the price of capital. As a consequence the effects of changes in exogenous prices on the general activity level are reallocation gains or losses, combined with changes in capital availability.

The sectors in MSG-4E are listed in table 3.1. Manufacturing sectors directly affected by the emission tax are marked by an asterisk (*) in the table.

TABLE 3.1. SECTOR LIST. MSG-4E.

1	Agriculture	18	Electricity distribution
2	Forestry	19	Construction
3	Fishing and hunting	20	Wholesale & retail trade
4	*Mining and quarrying	21	Drilling for oil and gas
5	*Manufacture of food	22	Production of oil and gas
6	*Beverages and tobacco	23	Ocean transport
7	*Textiles, wearing apparel	24	Domestic transport
8	*Wood products	25	Financing, insurance
9	*Paper and pulp	26	Housing services
10	*Industrial chemicals	27	Repair
11	Refineries	28	Other private services
12	*Chemicals and minerals	29	Public administration
13	*Metals	30	Defence
14	*Metal products, machinery	31	Education and research
15	*Construction of ships etc	32	Health and social service
16	*Printing and publishing	33	Other public services
17	Electricity production		Private households

3.2 Reference scenario.

The reference scenario is based on the medium alternative for economic growth presented in the government's long-term programme 1986 - 1989 (Governmental report no. 83, 1984/85). Average annual real GDP growth in this alternative is 1.9% for the years 1983-2000. This is rather low seen in a historic perspective; the average annual growth rate for the period 1963 - 1983 was 4.0%. However, excluding off-shore oil activity, the growth was on average 2.2% per year. The aggregate sector composition of the economic growth in the reference scenario is indicated in table 3.2. In this table Manufacturing is an aggregate over sector no. 4-16 in table 3.1, Services corresponds to sector no. 20 and 25-33, Transport corresponds to sector no. 23 and 24, while Other sectors consists of the residual of the list in table 3.1.

TABLE 3.2. AVERAGE ANNUAL GROWTH RATES IN PRODUCTION, CONSUMPTION AND GDP 1983 - 2000, AND SHARE OF TOTAL PRODUCTION BY AGGREGATED SECTORS. PERCENT.

	Average annual growth.	Share of total production.	
	1983-2000	1983	2000
Manufacturing	1.7	30.9	29.8
Services	2.4	29.4	31.9
Transport	2.1	10.5	10.9
Other sectors	1.5	29.2	27.4
Private consumption	2.8	26.8	31.4
GDP	1.9	56.0	57.0

The scenario assumes a constant 1983 real price of crude oil (approximately USD 29 per barrel), a 0.3% annual increase in labour supply (hours worked), and an (implicit) average increase in real capital of 2.7% per year. The relative price of electricity with respect to the price of oil increases by 1.6% per year. These estimates of the future development in key economic variables are of course uncertain, cfr. the latest development in oil prices, and not too much weight should be put on the actual numbers of the reference path. However, we are comparing two growth paths (with and without a tax on emissions, respectively). What is important is that our results should be robust against moderate changes in the reference path.

3.3 Emission coefficients.

The emission forecasts presented in the previous section are post calculations to the MSG-4E model run. The model calculates future demand for fuel oils and gasoline in the production sectors and private households. Future emission from combustion is related to future demand for oil products, while emission from industrial processes is assumed proportional to demand for materials. The

emission coefficients are determined in the base year (1983). In the projections presented in section 2 the base year emission coefficients were adjusted for known future environmental regulation when appropriate. However, in the reference scenario as defined in this study, we employ the base year emission coefficients unadjusted. Hence, no additional emission policy measures beyond 1983 are included in the reference case.

The calculation of fuel oil related emission coefficients takes into account estimates of average cleaning of emissions in each sector. For details, we refer to Appendix B. Table 3.3 presents the calculated fuel oil use and the related SO_2 emissions in the base year and in the year 2000 from the economic reference scenario.

3.4 Tax rate.

Based on a (rough estimate of a) sulphur content/fuel price curve, figure 3.1, the cost per ton reduction in SO_2 emissions by means of fuel switching has been calculated (cfr. Appendix A). The marginal cost of lowering SO_2 emissions by switching from 2.15% to 1% sulphur oil is estimated to be 2 300 NOK/ton SO_2. The additional switch to 0.7% sulphur oil is estimated to have a marginal cost of 5000 NOK/ton SO_2. In these estimates we have assumed that the prices on the various types of oil products remain fixed despite the shift in market demand.

The tax rates for policies 1T and 2T (NOK 2 300 and 5 000 per ton SO_2 emitted, respectively) are chosen so that implementing them has the same effect on emission control in manufacturing sectors as the corresponding regulatory policy (1R and 2R, respectively). The tax will induce a (cost minimizing) change to fuel oil with approximately 1% sulphur in firms with cleaning facilities under policy 2, assuming a cleaning fraction of 0.40 in sectors where cleaning takes place and a variable costs of cleaning sulphur emissions of NOK 2300/ton SO_2 removed. Due to previous cleaning programs, new cleaning facilities are assumed to be less cost effective than switching of fuel.

TABLE 3.3. OIL USE AND SO_2 FROM OIL USE IN REFERENCE SCENARIO. EMISSION COEFFICIENTS.

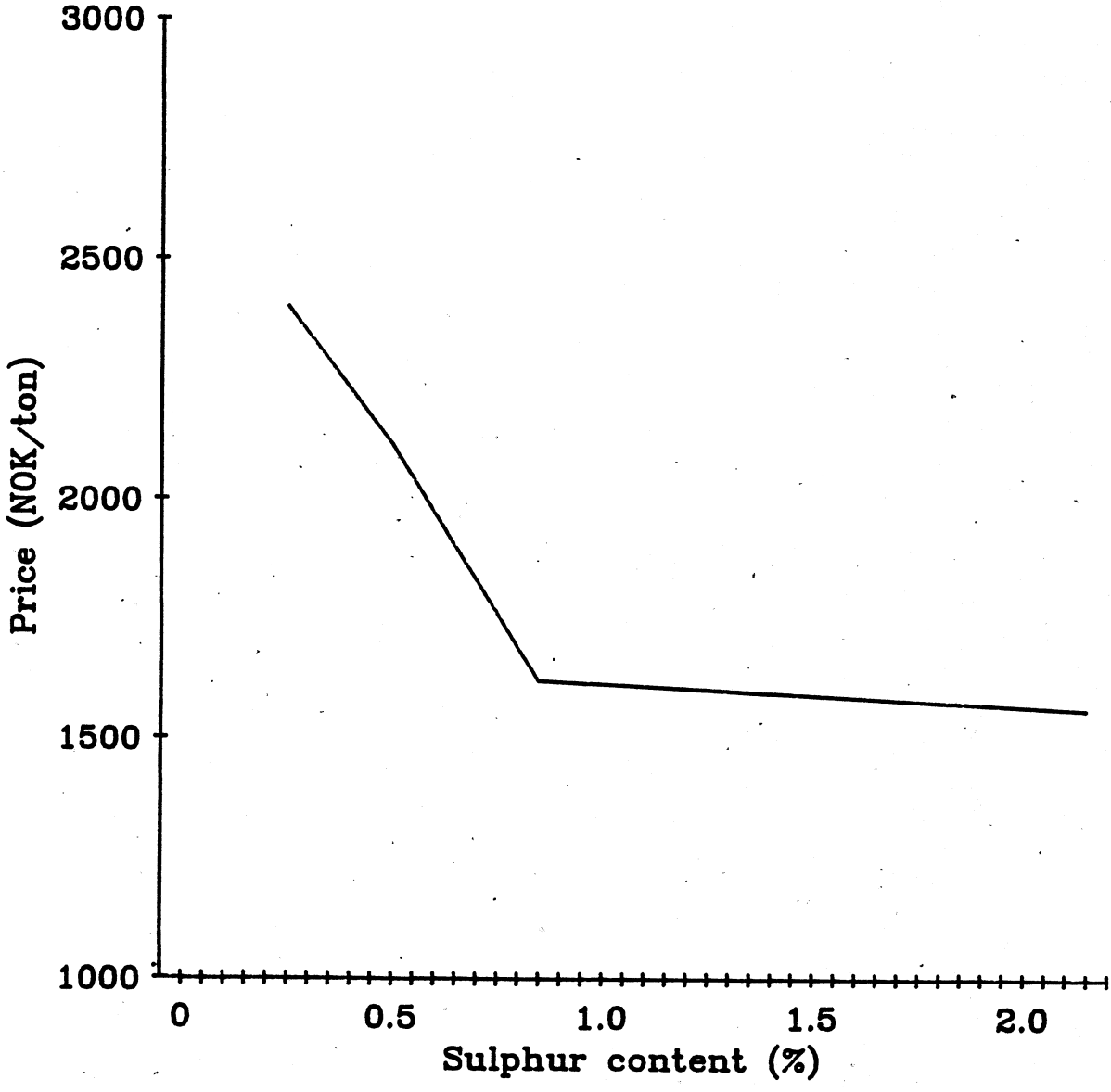
#	Sector	FUEL OIL USE		SO_2 FROM FUEL OIL	EMISSION COEFF.	SO_2 FROM FUEL OIL
		1983 (1000 tons)	2000 (1000 tons)	1983 (Tons)	1983 (10^{-3})	2000 (Tons)
11	Agriculture	147.00	142.00	1425.00	9.69	1376.53
12	Forestry	11.00	15.00	66.00	6.00	90.00
13	Fishing and hunting	383.00	642.00	2668.00	6.97	4472.21
31	Mining and quarrying	63.00	68.00	1601.00	25.41	1728.06
16	Manufacture of food	183.00	238.00	7176.00	39.21	9332.72
17	Beverages and tobacco	15.00	20.00	507.00	33.80	676.00
18	Textiles, wearing apparel	17.00	17.00	418.00	24.59	418.00
26	Wood products	36.00	42.00	908.00	25.22	1059.33
34	Paper and pulp	113.00	120.00	3197.20	28.29	3395.26
37	Industrial chemicals	211.00	208.00	1886.60	8.94	1859.78
40	Refineries	0.00	0.00	0.00	N/A	0.00
27	Chemicals and minerals	138.00	247.00	3247.00	23.53	5811.66
43	Metals	118.00	141.00	2854.00	24.19	3410.29
45	Metal products, machinery	66.00	118.00	1093.00	16.56	1954.15
50	Construction of ships etc	33.00	30.00	329.00	9.97	299.09
28	Printing and publishing	7.00	9.00	56.00	8.00	72.00
72	Electricity production	6.20	7.00	0.00	0.00	0.00
73	Electricity distribution	3.80	5.00	0.00	0.00	0.00
55	Construction	151.00	204.00	978.00	6.48	1321.27
81	Wholesale & retail trade	189.00	378.00	1297.00	6.86	2594.00
64	Drilling for oil and gas	64.00	85.00	0.00	0.00	0.00
68	Production of oil and gas	184.00	255.00	0.00	0.00	0.00
60	Ocean transport	244.00	294.00	0.00	0.00	0.00
74	Domestic transport	967.00	1522.00	11537.00	11.93	18158.54
82	Financing, insurance	0.00	0.00	0.00	N/A	0.00
83	Housing services	0.00	0.00	0.00	N/A	0.00
79	Repair	16.00	16.00	112.00	7.00	112.00
84	Other private services	113.00	234.00	774.00	6.85	1602.80
91	Public administration	12.00	14.00	77.00	6.42	89.83
92	Defence	100.00	104.00	826.00	8.26	859.04
93	Education and research	56.00	66.00	364.00	6.50	429.00
94	Health and social service	71.00	110.00	465.00	6.55	720.42
95	Other public services	19.00	23.00	104.00	5.47	125.89
	Private households	517.00	1012.18	3004.00	5.81	5881.22
	Total	4254.00	6386.18	46969.80		67849.10
	Manufacturing[1] (-refining)	1000.00	1258.00	23272.80		30016.34

1) Manufacturing sectors are defined in table 3.1.

Increased emissions from refineries due to higher production of low sulphur oil and cost or revenue from disposal of surplus sulphur is not included in this study.

The SO_2 emission from combustion in a sector is directly related to the sulphur content of the fuel oil used in that sector. To tax SO_2 emissions is then equivalent to taxing fuel oil usage by sulphur content adjusted for cleaning of emissions and already existing taxes on fuel oil. The calculation of this sector dependent equivalent oil tax is described in Appendix B. Implicitly, we assume that the sulphur tax rate escalates at the same rate as fuel oil prices.

Figure 3.1. Fuel oil price as function of sulphur content.



4. Policy impacts: Direct effects.

Introducing a tax on SO_2 emissions or regulating the maximal sulphur content of fuel oils, leads to substitution from high sulphur oil to low sulphur oil and an increased cost for fuel. The direct effects of this substitution on emissions is limited to reductions associated with changes in emission coefficients. The quantity of fuel is by assumption the same as in the reference case. Similarily, the direct cost is the associated increase in the fuel bill.

4.1 Direct effects on SO_2 emissions.

The direct effects on emissions are calculated by employing reduced emission coefficients with the same factor demands as in the reference scenario. Whether the control policies are implemented by direct regulation or as "voluntary" actions with incentives of emission taxes does not matter for the calculation of direct SO_2 emission effects.

Detailed sectoral results for the affected manufacturing sectors for the year 2000 are given in table 4.1. Note that the emission figures in this table for the reference scenario do not correspond to those shown in figure 2.1, since the latter refers to other economic growth paths and includes direct regulations of maximum sulphur content in heating oils. (See table B.8 and B.9 in Appendix B for data on the direct effects of policy 1 and 2 in the base year).

The gross reduction in the total SO_2 emissions, calculated as the difference between column 3 (5) and 2 under policy 1 (2) and aggregated over all sectors, is 14.0 (16.7) thousand tons of SO_2 in year 2000, see table 4.2 in the next sub-section. Table 4.1 reports the percentage reduction in sectoral SO_2 emissions in year 2000 under the two control policies.

TABLE 4.1. POLICY IMPACTS ON SO_2 FORECAST FOR THE MANUFACTURING SECTORS: DIRECT EFFECTS, YEAR 2000.

#	Sector	TOTAL SO_2 EMISSIONS 1983 (Tons)	TOTAL SO_2 EMISSIONS REFERENCE 2000 (Tons)	TOTAL SO_2 EMISSIONS POLICY 1 2000 (Tons)	REDUCTION SO_2 EMIS. POLICY 1 2000 (Percent)	TOTAL SO_2 EMISSIONS POLICY 2 2000 (Tons)	REDUCTION SO_2 EMIS. POLICY 2 2000 (Percent)
31	Mining and quarrying	1602.00	1729.42	978.52	43.42	773.77	55.26
16	Manufacture of food	7244.00	9419.57	4958.18	47.36	3741.41	60.28
17	Beverages and tobacco	508.00	677.16	362.23	46.51	276.31	59.20
18	Textiles, wearing apparel	421.00	421.03	230.43	45.27	178.41	57.62
26	Wood products	909.00	1060.33	594.60	43.92	467.62	55.90
34	Paper and pulp	7036.00	7578.44	5818.87	23.22	5683.70	25.00
37	Industrial chemicals	6243.00	6290.57	5391.81	14.29	5322.10	15.40
27	Chemicals and minerals	10969.00	17250.48	14648.92	15.08	14143.39	18.01
43	Metals	33066.00	36706.83	35052.08	4.51	34936.67	4.82
45	Metal products, machinery	1098.00	1962.55	1216.29	38.02	1012.68	48.40
50	Construction of ships etc	332.00	302.65	207.02	31.60	180.89	40.23
28	Printing and publishing	57.00	73.00	60.40	17.26	56.85	22.12
	Total	103078.00	134830.89	120878.20	10.35	118132.67	12.38
	Manufacturing (-refining)	69485.00	83472.04	69519.35	16.72	66773.82	20.00

4.2 Direct costs and tax revenue.

In section 3 and Appendix A the marginal cost of switching to oils with 1% sulphur content is calculated to be 2 300 NOK/ton SO_2 in 1983, while the additional reduction of sulphur content to 0.7% is estimated to have a marginal cost of 5 000 NOK/ton SO_2 in 1983.

The SO_2 reductions obtained by switching to 1% sulphur oil, is estimated to be 14.0 thousand tons by year 2000, cfr. table 4.1. The direct cost of this is thus 32.1 million (1983) NOK. The further reduction of sulphur content to 0.7% gives a reduction in SO_2 emissions of 2.7 thousand tons in year 2000. This marginal reduction times 5 000 NOK per ton yields an additional direct cost of about 13.7 million NOK. The total direct cost due to increased prices on fuel oils from the implementation of policy 2 aggregated over manufacturing sectors is thus 45.8 million NOK in year 2000, measured in 1983 currency. If the policies are implemented with the tax approach, the tax revenue from the remaining emissions due to combustion of heavy oil, is estimated

to be 37.0 million NOK and 66.6 million NOK under policy 1T and 2T, respectively, in year 2000. This tax payment added to the increased cost of fuel oil yields a total direct cost to the manufacturing sectors of 69.0 million NOK and 112.4 million NOK in year 2000 for the two policies. This is summarized in table 4.2 below, where the cost data have been adjusted for the (small) difference that exists between the inflation rate and the increase in oil price. Also shown in the table is cost effectiveness numbers, i.e. 1983-NOK per ton SO_2 removed under the various policy options as well as cost per capita.

TABLE 4.2. DIRECT EFFECTS IN MANUFACTURING SECTORS (-REFINERIES). YEAR 2000.

	REF.	POL.1R	POL.1T	POL.2R	POL.2T
Total SO_2 emissions (1000 tons)	83.5	69.5	69.5	66.8	66.8
SO_2 emissions from oil (1000 tons)	30.0	16.1	16.1	13.3	13.3
SO_2 reductions (1000 tons)		14.0	14.0	16.7	16.7
Cost+tax (Mill.NOK/yr)	-	30.1	64.8	43.0	105.6
(Cost+tax)/SO_2 red. (NOK/ton/yr)		2160	4647	2577	6322
(Cost+tax)/capita (NOK/cap/yr)		7.0	15.0	9.9	24.4

It should be noted that the direct costs shown in table 4.2 for the policies implemented by taxing emissions, i.e. policy 1T and 2T, are the cost to the manufacturing sectors, and includes taxes paid on remaining emissions. These taxes should not be counted as a social cost. Rather, the direct social cost should reflect the fact that the economy uses more resources to produce heavy oil with low sulphur content than oil with a higher sulphur content.

This is mirrored in the prices of the various oil qualities. Thus, the direct social cost associated with policy 1T and 2T are equal to the costs cited for policy 1R and 2R, respectively, and consists of the cost added to the fuel bill due to the fuel switch only. In particular, the direct social cost of policy 2T is, from table 4.2, equal to 43 million (1983) NOK in year 2000, corresponding to NOK 2577 per ton SO removed, or approximately NOK 10 per capita. In the next section we are going to compare the direct costs and emission reductions of this policy with the total effects, taking the general equilibrium or reallocation effects into account.

5. Policy impacts: Indirect effects of policy 2T.

The direct effects of taxing SO_2 emissions were discussed in the previous section, assuming fixed sectoral fuel consumption. However, the control policy increases the effective price of fuel oil in the manufacturing sectors. These sectors are therefore expected to reduce their fuel consumption, if the factor use is price elastic. Other energy commodities (e.g. electricity) are substituted against oil. This lower the SO_2 emissions over and above the reductions associated with the direct effect of switching to a lower sulphur fuel oil. However, the chain of effects does not end with lower fuel consumption. Other factors of production, like labour, are substituted for energy. Also the costs of pollution control are passed on to the consumers in the form of higher product prices, thus changing the mix of consumer goods, material input to production sectors, investment levels, etc, in the economy. As a result of these adjustments, sector output shifts by varying amounts. The question is whether these sectoral shifts are significant, i.e whether their contributions to the total reduction in SO_2 emissions and the total social cost of the control policy, are of importance compared to the direct effects. In section 5.1 we report on the general equilibrium effects on SO_2 emissions of implementing control policy 2T, while section 5.2 is concerned with the economic impacts of this policy.

5.1 General equilibrium effects on emissions.

Incorporating an emission tax in the MSG-4E model yields an alternative economic growth path to the reference scenario. The next two tables show the total (i.e. direct plus indirect) effects on SO_2 emissions in year 2000 of policy 2T. Table 5.1 shows the total effects of this control policy on SO_2 emissions from combustion of oil alone in the year 2000 and compares these with the direct effects. Table 5.2 shows sectoral effects on total SO_2 emissions including effects of policy 2T on SO_2 emissions from industrial processes and combustion of gasoline. These are of course purely indirect effects, since emissions from combustion of gasoline and industrial processes are not subjects of the control measures, i.e. are not taxed. In general, changes in emissions from sectors not directly affected by the control policy are found to be small. Finally, table 5.3 summarizes the overall reductions in SO_2 emissions due to the introduction of policy 2T and compares these with the direct effects.

From table 5.3 it is clear that the total effect on emissions from the control policy is almost entirely accounted for by the direct effects (change in emission coefficients with fixed fuel consumption). In other words, there are only small overall reductions in the use of fuel oil. In addition, total process emissions are almost unchanged by the regulation (table 5.2). Hence, expected emission reductions due to taxation of emissions from combustion of fuel oil, are only marginally larger than expected reductions from a similar direct regulation of the emission levels.

TABLE 5.1. TOTAL EFFECTS OF POLICY 2T ON SO_2 EMISSIONS FROM OIL IN YEAR 2000.

#	Sector	SO_2 FROM OIL REFERENCE (Tons)	SO_2 FROM OIL POL.2T (Tons)	TOTAL REDUCTION (Percent)	DIRECT REDUCTION (Percent)	DIFFERENCE TOTAL-DIR. REDUCTION (Percent)
11	Agriculture	1376.53	1376.53	0.00	0.00	0.00
12	Forestry	90.00	89.91	.10	0.00	.10
13	Fishing and hunting	4472.21	4472.21	0.00	0.00	0.00
31	Mining and quarrying	1728.06	770.10	55.44	55.30	.13
16	Manufacture of food	9332.72	3577.82	61.66	60.84	.82
17	Beverages and tobacco	676.00	269.64	60.11	59.30	.81
18	Textiles, wearing apparel	418.00	172.75	58.67	58.04	.63
26	Wood products	1059.33	452.15	57.32	55.95	1.36
34	Paper and pulp	3395.26	1485.51	56.25	55.80	.44
37	Industrial chemicals	1859.78	889.53	52.17	52.07	.10
40	Refineries	0.00	0.00	N/A	N/A	N/A
27	Chemicals and minerals	5811.66	2672.11	54.02	53.46	.56
43	Metals	3410.29	1631.93	52.15	51.91	.24
45	Metal products, machinery	1954.15	995.25	49.07	48.61	.46
50	Construction of ships etc	299.09	176.26	41.07	40.71	.36
28	Printing and publishing	72.00	55.85	22.43	22.43	.00
72	Electricity production	0.00	0.00	N/A	N/A	N/A
73	Electricity distribution	0.00	0.00	N/A	N/A	N/A
55	Construction	1321.27	1319.95	.10	0.00	.10
81	Wholesale & retail trade	2594.00	2591.41	.10	0.00	.10
64	Drilling for oil and gas	0.00	0.00	N/A	N/A	N/A
68	Production of oil and gas	0.00	0.00	N/A	N/A	N/A
60	Ocean transport	0.00	0.00	N/A	N/A	N/A
74	Domestic transport	18158.54	18158.54	0.00	0.00	.00
82	Financing, insurance	0.00	0.00	N/A	N/A	N/A
83	Housing services	0.00	0.00	N/A	N/A	N/A
79	Repair	112.00	112.11	-.10	0.00	-.10
84	Other private services	1602.80	1602.80	0.00	0.00	0.00
91	Public administration	89.83	89.83	0.00	0.00	0.00
92	Defence	859.04	859.04	0.00	0.00	0.00
93	Education and research	429.00	429.00	0.00	0.00	0.00
94	Health and social service	720.42	720.42	0.00	0.00	0.00
95	Other public services	125.89	125.89	0.00	0.00	0.00
	Private households	5881.22	5875.04	.10	0.00	.10
	Total	67849.10	50971.60	24.88	24.61	.26
	Manufacturing (-refining)	30016.34	13148.91	56.19	55.63	.56

TABLE 5.2. TOTAL EFFECTS ON SO_2 EMISSIONS IN YEAR 2000.

#	Sector	SO_2 FROM PROC.+GAS. REFERENCE (Tons)	SO_2 FROM PROC.+GAS. POL.2T (Tons)	REDUCTION SO_2 FROM PROC.+GAS. (Percent)	TOTAL SO_2 REFERENCE (Tons)	TOTAL SO_2 POL.2T (Tons)	REDUCTION TOTAL SO_2 (Percent)
11	Agriculture	75.70	75.69	.02	1452.24	1452.22	.00
12	Forestry	2.67	2.66	.10	92.67	92.57	.10
13	Fishing and hunting	0.00	0.00	N/A	4472.21	4472.21	0.00
31	Mining and quarrying	1.35	1.36	-.06	1729.42	771.46	55.39
16	Manufacture of food	86.85	86.73	.14	9419.57	3664.54	61.10
17	Beverages and tobacco	1.16	1.16	.07	677.16	271.36	59.93
18	Textiles, wearing apparel	3.03	3.03	.09	421.03	175.78	58.25
26	Wood products	1.00	.97	3.00	1060.33	453.59	57.22
34	Paper and pulp	4183.18	4177.62	.13	7578.44	5651.13	25.43
37	Industrial chemicals	4430.79	4429.47	.03	6290.57	5319.00	15.44
40	Refineries	10821.09	10809.66	.10	10821.09	10809.66	.10
27	Chemicals and minerals	11438.82	11430.21	.02	17250.48	14102.32	18.25
43	Metals	33296.54	33275.63	.06	36706.83	34907.57	4.90
45	Metal products, machinery	8.40	8.36	.40	1962.55	1003.61	48.86
50	Construction of ships etc	3.56	3.55	.22	302.65	179.82	40.59
28	Printing and publishing	1.00	1.00	.00	73.00	56.85	22.12
72	Electricity production	0.00	0.00	N/A	0.00	0.00	N/A
73	Electricity distribution	0.00	0.00	N/A	0.00	0.00	N/A
55	Construction	4.00	4.00	.10	1325.27	1323.95	.10
81	Wholesale & retail trade	178.00	177.82	.10	2772.00	2769.23	.10
64	Drilling for oil and gas	0.00	0.00	N/A	0.00	0.00	N/A
68	Production of oil and gas	0.00	0.00	N/A	0.00	0.00	N/A
60	Ocean transport	0.00	0.00	N/A	0.00	0.00	N/A
74	Domestic transport	54.72	54.72	0.00	18213.26	18213.26	0.00
82	Financing, insurance	6.00	6.00	0.00	6.00	6.00	0.00
83	Housing services	0.00	0.00	N/A	0.00	0.00	N/A
79	Repair	6.00	6.01	-.10	118.00	118.12	-.10
84	Other private services	42.75	42.75	0.00	1645.55	1645.55	0.00
91	Public administration	22.00	22.00	0.00	111.83	111.83	0.00
92	Defence	1.60	1.60	0.00	860.64	860.64	0.00
93	Education and research	0.00	0.00	N/A	429.00	429.00	0.00
94	Health and social service	0.00	0.00	N/A	720.42	720.42	0.00
95	Other public services	0.00	0.00	N/A	125.89	125.89	0.00
	Private households	2311.55	2309.60	.08	8192.76	8184.69	.10
	Total	66981.78	66931.60	.07	134830.89	117903.20	12.55
	Manufacturing (-refining)	53455.70	53419.09	.07	83472.04	66568.01	20.25

TABLE 5.3. SUMMARY OF TOTAL EFFECTS ON SO_2 EMISSIONS IN YEAR 2000.

	Ref.scen. SO_2 emiss. (1000 tons)	Pol.scen. SO_2 emiss. (1000 tons)	Total reduction (Per cent)	Direct reduction (Per cent)
Total SO_2 emissions				
Manufacturing	83.5	66.6	20.2	20.0
All sectors	134.8	117.9	12.6	12.4
SO_2 emissions from fuel oil				
Manufacturing	30.0	13.1	56.2	55.6
All sectors	67.8	51.0	24.9	24.6

5.2 Aggregate economic impacts.

Varying one exogenous variable in a simultaneous model, e.g. the tax rate of fuel oil in manufacturing sectors, will generally lead to adjustments in all endogenous variables. Some of the exogenous variables will also normally have to be modified. In the MSG-4E model import shares and export volumes of traded commodities are exogenously determined. In the present study they are, however, not adjusted for effects of the control policy, i.e. they are the same as in the reference scenario. One way to interpret this is to assume that a similar emission tax is introduced more or less simultaneously in all countries trading with Norway. This is discussed further in a later subsection, where some possible effects of the control policy on export demand and emissions from the exporting sectors are estimated.

Below is summarized some of the more important economic changes following the introduction of control policy 2T. Generally, the changes are small relative to most macroeconomic aggregates (typically less than a tenth of a percentage), but they are nevertheless important when the cost of the control policy is to be assessed. There are two main reasons for this. One is that,

although small in macroeconomic terms, the total social cost of the control policy, measured for instance by the calculated impact on GDP of the policy, represents a large environmental investment compared with other environmental programs in Norway. The other reason is that the size of the total social cost is found to be considerably higher than the direct cost associated with the policy. Hence, the social cost of the control policy can not be estimated from the direct costs alone. An understanding of macroeconomic effects is mandatory.

First the impacts of the control policy on some of the more important macroeconomic variables are reported, before allocation and model effects on a more detailed sector level are discussed.

5.2.1 Impacts on some macroeconomic variables.

A possible definition of the total social cost of a control policy is the change in real GDP following the implementation of the policy. The magnitude of this change is shown in table 5.4 for the year 2000 together with various other macroeconomic variables.

TABLE 5.4. IMPACTS ON MACROECONOMIC VARIABLES. YEAR 2000. MILLION (1983) NOK.

	REFERENCE CASE	POLICY CASE	REDUCTION	REDUCTION PER CENT
Gross Production	986 689	986 284	406	0.041
GDP	562 103	561 990	113	0.020
Imports	256 672	256 512	160	0.062
Exports	253 188	253 188	0	0.0
Domestic use	565 587	565 314	273	0.048
Of which:				
Private consumption	309 571	309 365	206	0.067
Public consumption	119 003	119 008	-5	-0.004
Investments	136 428	136 356	72	0.053
Stock changes	585	585	0	0.0

TABLE 5.5. IMPACTS ON THE GDP DEFLATOR. YEAR 2000.

	Reference Case	Policy Case	Increase	Increase Per Cent
GDP deflator	176.854	176.921	0.067	0.038

The reduction in GDP due to the control policy is seen to be 113 million (1983) NOK, corresponding to a cost of 6 686 NOK/ton SO_2 removed or a cost per capita of approximately NOK 26 in year 2000. Although small, this loss of income is about two and a half times the direct social cost as defined in section 4 (i.e. direct costs to the manufacturing sectors excluding taxes paid, cfr. table 4.2). Thus indirect costs of the policy are certainly significant when compared with the direct social costs of fuel switching. The main reason for this (to be discussed in more detail below) is the reduced capital stock found in the policy scenario relative to the reference secenario. A decrease in investments of 72 million NOK (corresponding to a reduction of 0.053%) is found in the policy scenario when compared with the reference alternative in year 2000 (table 5.4).

Real consumer spending goes down by 206 million NOK or 0.067%, corresponding to a reduction per capita of NOK 48. This reflects less final goods available in the economy, since both GDP and imports are down. In the MSG-4E model private consumption is a residual demand category. Hence, some of the reduction in consumption reflects increased savings due to an implied improved trade balance.

As explained above, imports are determined in the MSG-4E model by import shares exogenously specified by commodity and receiving sector. When material usage declines in manufacturing sectors due to increased prices and decreased sectoral output, imports decrease also. Column 4 in table 5.4 shows an impact of 160 million NOK.

Exports, on the other hand, are exogenously determined and left unchanged in the policy scenario. The realism of this and a discussion of possible trade effects of the control policy are presented in sub-section 5.2.3.

5.2.2 Intertemporal aspects.

The adjustments described above refer to the year 2000. It is, however, important to recognize that the whole path of economic growth is shifted by the control policy.

The reduction in capital stock was found to be a major reason for the decline in labour productivity and reductions in the output of the economy. This long run reduction in consumption and production is, however, accompanied by a short run increase in consumption, since the economy invests less in the policy scenario. This is shown in figure 5.1 and table 5.6 which reports results as projected by the MSG-4E model. Short term adjustments are not expected to be well described by the MSG-model, but the results nevertheless point out the considerable shifts that take place in investment and consumption over time relative to the development in the reference scenario.

Figure 5.1. Intertemporal development of some key economic variables. Million 1983-NOK. 1984-2000.

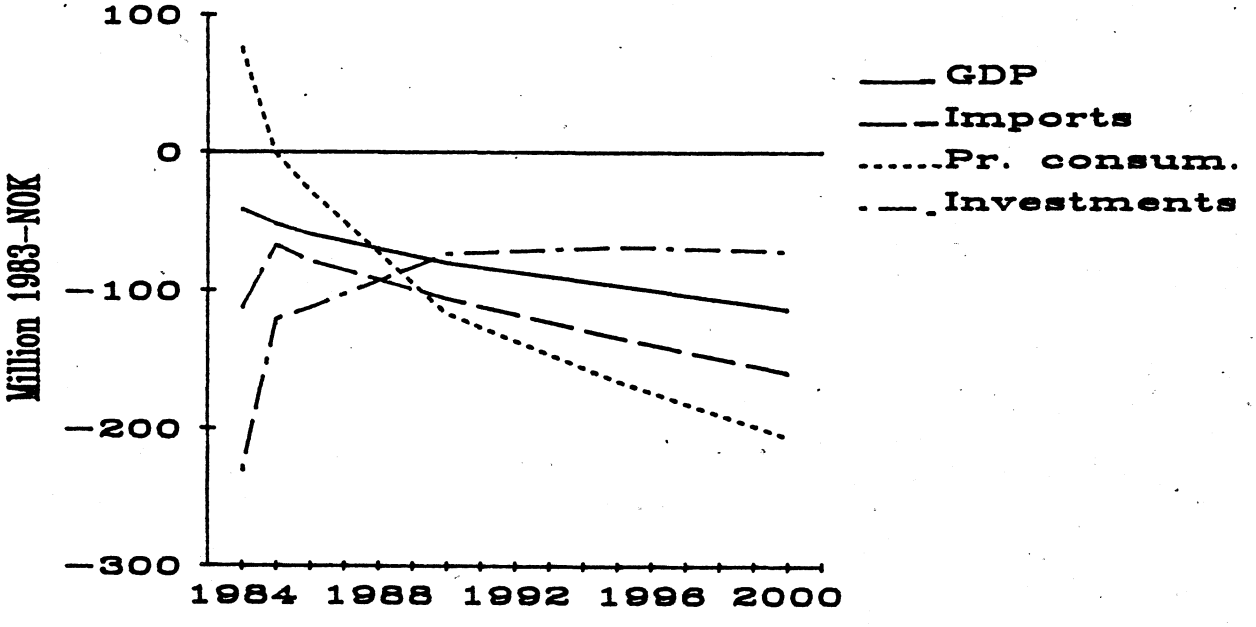


TABLE 5.6. DEVIATIONS FROM THE TIME PATH OF THE REFERNCE CASE. MILLION (1983) NOK.

YEAR	CHANGE IN GDP	CHANGE IN IMPORTS	CHANGE IN TOTAL DOM. USE	CHANGE IN PRIVATE CONSUMPTION	CHANGE IN GOVERNMENT SPENDING	CHANGE IN GROSS INVESTMENTS
1984	- 42.2	-112.4	-154.7	75.7	0.4	-230.7
1985	- 52.6	- 67.5	-120.1	- 1.1	1.3	-120.3
1986	- 59.7	- 79.1	-138.8	- 28.5	1.7	-112.1
1990	- 80.7	-106.1	-186.9	-116.5	3.1	- 73.5
1995	- 96.5	-133.6	-230.1	-165.7	4.0	- 68.4
2000	-113.6	-159.5	-273.1	-206.1	4.8	- 71.8

Investments decrease substantially in 1984, the first year affected by the policy in the simulation. This is due to immediate reduction in capital stock, as calculated in the model under general equilibrium conditions. Note that changes in GDP plus changes in imports make up the change in total domestic use, which is then distributed among change in private consumption, change in government spending, and change in gross investments.

5.2.3. Effects on export demand.

As mentioned previously, exports are exogenously determined and left unchanged in the policy scenario. This is perhaps a reasonable approach if all trading partners introduce similar regulatory measures against emissions of SO_2. If this is not the case, we must expect reductions in the export volume due to increased costs. Based on historic price elasticities for the main exporting sectors in Norway (Bergan and Olsen (1985)), estimates of the order of magnitude of this reduction and the associated decrease in SO_2 emissions can be found. Not surprisingly, the reductions in the level of SO_2 emissions are neglectable compared with the direct effect of the control policy. Reductions in export volumes are also small in absolute terms and less than 0.2% for most sectors, but tend to be of the same order of magnitude or larger than the reduction in output due to the

control policy. (Overall reduction in export relative to sectoral output in export industries, exclusive of oil and gas export, is of the order of 0.06%, while the reduction relative to all sectoral output is approximately 0.01%).

5.2.4. Effects on factor prices.

Increasing the price of fuel oil leads to a higher price of the fuel commodity (PF). The price increase depends on the share of gasoline in F. As a consequence of a higher fuel price, the factor price of energy (PU) increases. Higher costs are passed on by producers to prices on products. These products also serve as input factors. Hence, user cost of capital (PK)[3] and materials (PM) also increase. Exogenous wage rates and import prices are of course unaffected. Relative factor prices will change, and the exogenous price of labour (PL) will decrease relative to prices of other factors. Inflation, measured by the consumer price index or the GDP deflator, is found to be only slightly affected by the control policy. While the GDP price deflator is 176.854 in year 2000 in the reference scenario, it is increased to 176.921 in the policy scenario (cfr. table 5.5)

5.2.5 Substitution effects.

Substitution effects deal with how factor input shift in the production when factor prices change. Tables 5.7 and 5.8 below show relative changes in input factors and factor intensities (input factors per unit output) by MSG sectors.

As reported in table 5.4, aggregate output (X_i) is down by approximately 0.04%. Interestingly, the reduction is fairly balanced across sectors. Sectors with large reductions, i.e. greater than 0.07%, are the following:

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[3] In our simulation the user cost of capital is only marginally increased compared to the reference scenario.

Forestry (12), Wood products (26), Refineries (40), Electricity production (72), Trade (81) and Housing services (83).

Only one of these sectors (Wood products, sector no. 26) is taxed in our analysis. However, the higher price of wood products due to this tax, affects the demand for housing services, and thereby indirectly the demand for electricity. Demand for forestry is of course also reduced when demand for wood products is decreased.

TABLE 5.7. PERCENT CHANGE IN OUTPUT AND INPUT FACTORS RELATIVE TO THE REFERENCE SCEANRIO. YEAR: 2000.

#	Sector	X	M	K	L	E	F
11	Agriculture	0.00	0.00	-.02	.08	0.00	0.00
12	Forestry	-.09	-.10	-.12	0.00		0.00
13	Fishing and hunting	0.00	0.00	-.02	0.00	0.00	0.00
31	Mining and quarrying	0.00	.08	-.11	1.11	-.14	-.30
16	Manufacture of food	-.03	-.01	-.15	.16	.95	-2.06
17	Beverages and tobacco	-.07	-.04	-.30	0.00	1.48	-2.05
18	Textiles, wearing apparel	-.05	-.08	.08	0.00	.60	-1.59
26	Wood products	-.08	-.10	-.09	0.00	-.57	-3.10
34	Paper and pulp	-.03	-.09	.21	0.00	.22	-1.02
37	Industrial chemicals	-.01	-.05	-.06	0.00	-.09	-.25
40	Refineries	-.10	-.10	-.10	0.00	0.00	
27	Chemicals and minerals	-.04	-.04	-.33	.38	-.34	-1.22
43	Metals	-.00	.02	-.10	.29	-.34	-.53
45	Metal products, machinery	-.04	-.05	-.09	0.00	.35	-.90
50	Construction of ships etc	-.02	-.04	-.03	0.00	.25	-.50
28	Printing and publishing	-.06	-.06	-.06	0.00	-.13	-.09
72	Electricity production	-.08	-.08	-.09			0.00
73	Electricity distribution	-.02	-.02	-.01	0.00	-.02	0.00
55	Construction	-.06	-.09	-.12	.05	0.00	-.06
81	Wholesale & retail trade	-.07	-.09	-.09	-.04		-.08
64	Drilling for oil and gas	0.00	0.00	0.00	0.00		0.00
68	Production of oil and gas	0.00	0.00	0.00	0.00		0.00
60	Ocean transport	-.00	-.00	0.00	0.00		0.00
74	Domestic transport	-.04	-.06	-.05	-.03	-.03	-.04
82	Financing, insurance	-.05	-.05	-.08	-.12	0.00	-.03
83	Housing services	-.07	-.07	-.07	0.00		-.41
79	Repair	-.07	-.09	-.08	0.00	0.00	0.00
84	Other private services	-.04	-.04	-.06	-.02	-.05	-.04
91	Public administration	-.05	0.00	0.00	0.00	0.00	0.00
92	Defence	-.03	0.00		0.00	0.00	0.00
93	Education and research	-.06	0.00	0.00	0.00	0.00	0.00
94	Health and social service	-.03	0.00	0.00	0.00	0.00	0.00
95	Other public services	-.05	0.00	0.00	0.00	0.00	0.00
	Private households						
	Total	-.04	-.05	-.05	.00	-.03	-.29
	Manufacturing (-refining)	-.04	-.04	-.10	.10	-.04	-1.14

TABLE 5.8. PERCENT CHANGE IN FACTOR INTENSITIES RELATIVE TO THE REFERENCE SCENARIO. YEAR 2000.

#	Sector	Z_M	Z_K	Z_L	Z_E	Z_F
11	Agriculture	0.00	-.02	.08	0.00	0.00
12	Forestry	-.01	-.02	.09		.09
13	Fishing and hunting	0.00	-.02	0.00	0.00	0.00
31	Mining and quarrying	.08	-.11	1.11	-.14	-.30
16	Manufacture of food	.02	-.12	.18	.98	-2.04
17	Beverages and tobacco	.03	-.24	.07	1.55	-1.98
18	Textiles, wearing apparel	-.03	.13	.05	.65	-1.55
26	Wood products	-.01	-.01	.08	-.49	-3.01
34	Paper and pulp	-.05	.24	.03	.25	-.98
37	Industrial chemicals	-.04	-.05	.01	-.08	-.24
40	Refineries	-.00	-.00	.10	.10	
27	Chemicals and minerals	.01	-.28	.42	-.30	-1.18
43	Metals	.02	-.09	.29	-.33	-.53
45	Metal products, machinery	-.01	-.05	.04	.39	-.86
50	Construction of ships etc	-.02	-.01	.02	.26	-.49
28	Printing and publishing	.00	.00	.06	-.07	-.03
72	Electricity production	.00	-.00			.08
73	Electricity distribution	.00	.00	.02	-.00	.02
55	Construction	-.03	-.06	.11	.06	.00
81	Wholesale & retail trade	-.02	-.02	.03		-.01
64	Drilling for oil and gas	0.00	0.00	0.00		0.00
68	Production of oil and gas	0.00	0.00	0.00		0.00
60	Ocean transport	-.00	.00	.00		.00
74	Domestic transport	-.02	-.01	.01	.01	.00
82	Financing, insurance	-.00	-.03	-.07	.05	.01
83	Housing services	-.00	-.00	.07		-.34
79	Repair	-.02	-.02	.07	.07	.07
84	Other private services	-.01	-.02	.01	-.01	-.00
91	Public administration	.05	.05	.05	.05	.05
92	Defence	.03		.03	.03	.03
93	Education and research	.06	.06	.06	.06	.06
94	Health and social service	.03	.03	.03	.03	.03
95	Other public services	.05	.05	.05	.05	.05
	Private households					
	Total	-.00	-.00	.05	.01	-.25
	Manufacturing (-refining)	-.00	-.06	.13	-.01	-1.11

Sectors with small reductions in output, i.e. less than 0.02%, are the following:

Industrial chemicals (37), Metals (43), Construction of ships etc. (50), Electricity distribution (73) and Ocean transport (60).

Two of the sectors above (37 and 43) are taxed in our analysis. Both of these sectors export a relative large share of their production (60.5% and 80%, respectively, in 1983), and, hence, demand for their output is to a large degree exogenously determined and kept fixed in this study.

Material usage for the most part tends to follow output. That is, the percentage change in material usage per unit output (Z_M) is small - cfr. table 5.8. The direction of change in Z_M is ambiguous because (i) the increase in material prices (PM) will decrease Z_M, while (ii) materials may be a substitute for energy or capital, thus tending to increase Z_M.

The decrease in the desired capital stock (by 0.1% in manufacturing sectors, and 0.05% averaged over all sectors) plays a key role in explaining the reduction in sectoral outputs. What we observe is energy-capital complementarity on a macro level.[4] This is also shown in table 5.8, where in most sectors the capital per unit output, Z_K, decreases when we introduce the control policy. There are a few exceptions where Z_K increases, such as Textiles (18), Pulp and paper (34), and Printing (28). However, in Printing (28), total capital decreases because the reduction in sector output offsets the increase in capital intensity.

Labour productivity ($1/Z_L$) decreases as a result of less capital[5]. Labour is generally a substitute for energy, materials and capital. Therefore, as other factor prices rise, labour intensity, Z_L, also rises and labour productivity falls. However, employment in the MSG-4E model is exogenously given at its full employment level at each point in time. Thus,

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[4] Our model is more complex than the pure microeconomic energy-capital relations studied for example by Berndt and Wood (1979) involving only changes in the price of energy with other factor prices held fixed (Allen partial elasticities of substitution). In our simulation we observe aggregate energy-capital complementarity when both material and capital prices are allowed to vary, taking the price of labour as our numeraire.

[5] The functional relationship between labour productivity and capital is explicit in a production function approach and implicit in a cost function approach. The latter is used in the MSG model.

$$L_j = Z_{Lj}X_j = L \qquad (5.1)$$

is given exogenously and not changed by the control policy. Z_{Lj} is the factor input coefficient or factor intensity for labour in sector j, i.e. labour use per unit output. From (5.1) follows

$$W_j(dZ_{Lj}/Z_{Lj}) = - W_j(dX_j/X_j), \qquad W_j = L_j/L. \qquad (5.2)$$

Hence, in the MSG-4E model the weighted average percentage increase in the labour factor intensity Z_L in a sector must equal the weighted average percentage decrease in output X. It can also be noted from table 5.8 that Z_L tends to increase more in the manufacturing sectors where the energy price rises due to the emission tax. In non-manufacturing sectors the rise in Z_L is mainly due to the rise in material prices, reflecting an increase in the general price level in the economy. As consumer prices increase, the real wage rate declines. Labour becomes less expensice and is employed on the margin in less productive ways.

The existence of value taxes cause capital and labour productivity and sectoral output to decrease more than they otherwise would. The reason is that demand for capital and labour are functions of all factor prices including energy and material prices. When the price of energy rises, material prices rise also. The simultaneous equation description of production, where material prices in one sector are based on unit costs in other sectors, causes material prises to rise to a new higher equilibrium. Proportional value added taxes cause material prices to increase by a greater absolute amount than they would have done without taxes. Since taxes can create economic allocation distortions, there will be additional dead weight losses. Specifically, since Z_K and Z_L are functions of material prices, there will be excess loss of capital and labour productivity resulting in reduced sectoral output.

There are two types of <u>energy demand</u> in the MSG-model: fuels and electricity. The demand for fuel, F, decreases in all sectors which are taxed (see table 5.7). However, fuel demand may

increase in other sectors if fuel is a substitute for materials. Facing a higher price of fuels, firms will tend to substitute electricity for fuels when covering their energy demand. Total demand for electricity is reduced by 96 GWh (approximately 0.1%) in this study, while demand for electricity in manufacturing sectors, excluding power intensive industries, increases by 16 GWh, corresponding to a growth of approximately 0.2%. Electricity demand per unit output, Z_E, may either increase or decrease in manufacturing. Electricity is a substitute for fuel oil, but a total decrease in demand for energy offsets this in some sectors (see table 5.8).

5.2.6. Effects on income.

Due to fixed nominal wages and increased inflation, real wages decline. On the other hand, public revenues increase. Decreased imports and unchanged export will increase Norway's financial savings. An improved terms-of-trade in the long run is a consequence of the model specification of the export activities, and is clearly one of the more unrealistic model results.

5.3 Economic comparison of taxes versus regulations.

This paper has shown that an emission tax approach to the problem of emissions to air can cause considerably larger economic losses than an environmentally equivalent regulation of the emissions. This might seem counterintuitive given the potential efficiency of pollution taxes. However, the results must be interpreted in the context of the simulation design; specifically, the investment function employed in the MSG-4E model requires a fixed rate of return to the capital. Furthermore, value added taxes on materials was found to increase the price of this input factor above the efficient price level. In order to harvest the full benefit of a tax approach to pollution problems, at least two other types of policy changes should be included: (1) macroeconomic stimulation of investment and (2) reduction in alternative taxes.

The first policy may be needed to counteract the capital - energy complementarity observed here. That is, if the required return to capital remains fixed (as is assumed in our calculations), higher effective energy prices reduce the capital stock and lower sectoral output.

The second policy consideration pertains to microeconomic efficiency. It was suggested above that the existing tax structure (e.g. value added taxes) worsens the impact of higher energy prices by causing material prices to rise in excess of their base case levels. If these distorting taxes could be lowered in response to the increased revenue from the pollution tax, there is a potential for an efficiency gain.

If it were feasible to make these macro- and microeconomic policy adjustments, then an emission tax has the potential for efficiency improvements over regulations of emissions standards. This potential advantage of emission taxes is well known to economists (see for instance Baumol and Oates (1975)). That is, it is efficient to treat an externality, such as air pollution, by imposing a tax to reduce it to a desired lower level. Then commodity prices will reflect the real social costs and the demand for commodities from firms and consumers will be based on appropriate prices. This study has shown, however, that these potential advantages of emission taxes may be difficult to attain because macroeconomic and general taxation policies may also need to be adjusted. A further study of this topic will be published elsewhere (Hanson and Alfsen (1986)).

6. Modelling issues.

Several crucial assumptions were made in the course of this study. Some concern exogenous variables[6], like the future price

[6] Note, however, that in this study two economic growth paths are compared. Uncertainties in exogenous variables that are kept fixed in the two scenarios are then probably of less importance for the results. An exception is the prescription of exogenous export levels, since these levels will change in

of crude oil, export levels, and the cleaning fraction of emissions from various manufacturing sectors, while others stem from the structure of the MSG-4E model itself. The weakest point in this regard is perhaps the simplified treatment of the exporting sectors. The uncertainties associated with these assumptions are of course transfered to the results, but have not been treated explicitly in this work. Hence, a general warning against interpreting the results too literally should be issued. Nevertheless, an undertaking like this, built upon the use of a general equilibrium model, is useful in that it uncovers some of the main mechanisms and paths of impacts that are likely to be of importance in a situation where one considers the potential effects of control measures against air pollution.

Furthermore, topics worthy of further study are discovered. Among these are the possibility of reducing SO_2 emissions from industrial processes and coal combustion. Also the scope could be expanded to include SO_2 reductions in non-manufacturing sectors, in particular Refineries should be included. The real cost and increased emissions of refining lower sulphur fuel should be investigated. The tax approach - allowing for various compensating payments financed by the increased tax revenue - should be compared in detail with other approaches, e.g. direct regulations. Also the allowed responses of firms to an emission tax should be broadened to include other options than fuel switching (e.g. more cleaning).

Impacts on other pollutants than SO_2 should be investigated. Possibly, one will have to weight reductions in the emission level of one pollutant against increases in the emissions of other components as the production structure shifts due to sector specific control measures. In Norway SO_2 emissions stem mainly from manufacturing sectors, while the service sectors are the main sources of NO_x emissions. Hence, a reduction in sulphur emission is suspected to be accompanied by an increase in NO_x emission levels.

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response to the control policy if it is introduced unilaterally by Norway.

The benefits of the control policy have not been considered in this paper. However, as mentioned in the introduction, several potentially important benefits can readily be identified. The one most easy to quantify is probably the reduction in corrosion damages on capital equipment that would follow from a reduction in acid emissions. More difficult to assess are benefits associated with an improved opportunity for wildlife and fishing activities following from a reduction in acid precipitation and deposition. It is doubtful whether "dead" lakes can be revived through a rather modest reduction in domestic SO_2 emissions. It is difficult to determine the value of such a revival in money terms. Finally, there are potential benefits from the reduction in health damages due to SO_2 emissions and the associated acid environment. Both health damages caused by polluted air and secondary effects from, for instance, acidification of drinking water might be of measurable macroeconomic importance - reducing labour productivity and increasing medical costs. Even moderate improvements with respect to health and productivity effects might make the net benefit of the control policies considered in this report positive.

7. Summary.

The report gives preliminary estimates of impacts of regulating or taxing SO_2 emissions from manufacturing sectors. Only emissions from fuel use in the manufacturing sectors were included in the emission control policies.

Total social cost and total reduction in SO_2 emissions were decomposed into two parts: direct and indirect effects. The direct reduction in SO_2 emissions was calculated assuming unchanged consumption of fuel oil, but a reduced emission coefficient due to a switch to fuel oil with a lower sulphur content. Similarily, the direct social cost was set equal to the increase in the fuel bills of the manufacturing sectors due to the fuel switch, keeping the fuel consumption fixed. However, introducing a tax on SO_2 emissions will necessarily change the

demand for input factors in a sector and the levels of production in all sectors of the economy. The total response of the economy was modelled with the general equilibrium model MSG-4E. The difference between the total and direct reduction in emissions of SO_2 was designated indirect reductions. Similarily, the difference between the total social cost of the control policy, measured by the reduction in GDP, and the direct social cost, was called the indirect social cost of the control policy.

Comparing the direct and indirect effects it was shown that indirect effects on reductions of emissions were neglectable compared to the direct consequences of fuel switching. This was as expected, since the fuel switch reduced the emission coefficients by more than 50%. This was then the order of magnitude of the direct reduction of SO_2 emissions from the manufacturing sectors. The indirect reductions due to economic adjustments can hardly be expected to be of this order of magnitude.

In estimating the indirect social costs of the control policy, it was found that this component of the total cost was important- in fact it dominated the direct social cost of the control policy. The tax payment was found to result in reduced production in the economy. General equilibrium effects which amplified commodity and material price changes and reduced the capital stock, resulted in lower real wages and increased demand for labour. Due to the constraint on the supply of labour in the model, reduced sectoral output and lowered labour productivity resulted in a changed growth path of the economy with a reduced growth in GDP.

By keeping the export levels fixed, as was done in this study, the indirect social cost of the control policy was probably underestimated. On the other hand, by only allowing firms to switch fuel in response to the introduction of the emission tax, the total social cost of the control policy may be biased upwards. In conclusion, it seems reasonable to state that the effects of the control policy on emissions can be estimated by the direct reductions in emissions, while the social cost must be estimated taking the response of the economy as a whole into

account. Direct costs (calculated costs incured by the production sectors with factor use and production levels kept fixed) alone will severely underestimate the real total cost of the control policy.

Social cost per ton SO_2 removed can be viewed as a measure of the cost-effectiveness of the control policy. It was found (table 4.2, 5.3 and 5.4) that direct social cost (increased fuel bill) amounts to NOK 2577 per ton SO_2 removed, but increased to NOK 6686 per ton SO_2 removed when indirect economic impacts were taken into account. (All costs are measured as annual costs in year 2000 in 1983 NOK). Measured per capita, the social costs were found to be approximately NOK 10 and NOK 26 for the direct and total costs, respectively.

In a cost-benefit analysis, the cost of the policy chosen (tax or regulation approach), should be weighted against estimates of benefits such as reduced corrosion, improved health and labour productivity resulting from the control policy. This has not been done in this paper. Rather the aim has been to illustrate the importance of taking reallocation effects into account when estimating the social cost of an environmental protection measure like taxation of SO_2 emissions. A further point has been to show that the optimality of a tax approach when dealing with an externality like air pollution, is not something which is achieved more or less automatically. Compensating policies are usually required to avoid distortions of economic growth.

APPENDIX A: Marginal cost of SO_2 reduction.

This appendix discusses the marginal cost of SO_2 reduction incurred by switching from higher to lower sulphur fuel oils and cost minimizing behaviour of firms when emissions of SO_2 are taxed. Empirical data for assessing the marginal costs associated with a fuel switch are few. We are therefore forced to rely on uncertain estimates and assumptions.

A.1 Marginal cost.

Consider two substitute fuels with price p_i, $i = 1,2$, per ton of fuel and sulphur content S_i expressed as a fraction of weight. Let h_{12} be the theoretical fuel heat content per ton of fuel 1 relative to fuel 2. Then one ton of fuel 1 can be replaced by h_{12} tons of fuel 2. As a result the marginal cost of a switch from fuel 1 to fuel 2 per unit of SO_2 reduction is given by

$$MC_{12} = - \frac{h_{12}p_2 - p_1}{E_2 - E_1} = - \frac{h_{12}p_2 - p_1}{2h_{12}S_2 - 2S_1} .$$

E_i is the amount of sulphur dioxide emitted when burning one unit of fuel i. The factor "2" arises since one ton of sulphur when converted to SO_2 yields approximatly two tons of SO_2.

Data for the estimation of marginal switching costs for Norway is given in table A.1. (See also figure 3.1). They reflect the fact that lower sulphur fuels have higher prices than fuel oils with a lower sulphur content.

TABLE A.1. FUEL PRICE DATA.

Fuel type	Average sulphur content (Percent)	Price* (NOK/ton)	Heating value (TJ/1000 ton)
Heavy Oil #6 Normal sulphur (NS)	2.15	1 560	41.9
Heavy Oil #6 Low sulphur (LS)	0.85	1 619	41.9
Special Distillate #3,4 (SD)	0.5	2 113	42.1
Light oil #2 (LO)	0.25	2 400	42.3

*1984 prices have been converted to 1983 NOK to be consistent with the MSG-4E model.
Sources: Norwegian Petroleum Institute and Norwegian Shell.

The resulting estimates of marginal switching costs are shown in table A.2. The main result is that switching from normal sulphur heavy oil (NS) to low sulphur heavy oil (LS) has a marginal cost of approximatly 2 300 NOK/ton SO_2 removed.

TABLE A.2. MARGINAL COST OF FUEL SWITCHING.

Fuel switch	h_{12}	p_1 (NOK/ton)	$h_{12}p_2$	E_1	E_2	MC (NOK/ton)
NS -> LS	1.0000	1 560	1 619	0.043	0.017	2 300
LS -> SD	0.9956	1 619	2 103	0.017	0.010	69 000
LS -> LO	0.9905	1 619	2 377	0.017	0.005	63 000

NS = Heavy oil with normal (2.15%) sulphur content.
LS = Heavy oil with low (0.85%) sulphur content.
SD = Special distillate.
LO = Light oil.

Table A.2 shows the very high costs associated with a switch from heavy oil to special distillate (SD) or light oil (LO). Clearly,

it is reasonable to assume that these high quality fuels refined for special purposes will not be used in industrial boilers.

For the purpose of this study the following values for marginal costs are assumed:

1. 2 300 NOK/(ton SO_2 removed) for switching from 2.15% to 1% sulphur heavy oil.

2. 5 000 NOK/(ton SO_2 removed) for switching from 1% to 0.7% sulphur heavy oil.

The first number is based on the data in table A.2, whereas the second number is judged to be a reasonable estimate for the marginal cost associated with a switch to an as yet non-existing (i.e. non-marketed) type of heavy oil.

The price of low sulphur oil may drop and the price of high sulphur oil may rise when a switch to lower sulphur oil occurs on a large scale. In this situation the calculation of marginal cost of a SO_2 reduction is more complicated. Essentially, it would require a study of supply costs by refineries when the fuel mix is significantly shifted to lower sulphur oil. Also neglected in this study is the possibility of increased SO_2 emissions from refineries themselves due to the greater demand for fuel oils with reduced sulphur content.

A great deal of uncertainty is connected with the behaviour of refineries and firms facing taxation of SO_2 emissions or regulation of the sulphur content of oil. For the purpose of this study we assume that

- Supply of heavy oil with 2.15% sulphur will stop in Norway.
- Only heavy oils with 1% or 0.7% sulphur will be available.
- Policy 1 implemented by regulation (i.e. policy 1R) requires all firms to switch to heavy oil with 1% sulphur content.

- Policy 2 implemented by regulation (i.e. policy 2R) requires firms without cleaning of emissions to switch to 0.7% sulphur heavy oil, while firms with cleaning of emissions switch to heavy oil with 1% sulphur content.

- Firms show cost minimizing behaviour when policy 1 or 2 are implemented by taxation (i.e. in response to policy 1T and 2T).

In the next section we take a look at the cost minimizing behaviour, taking the cleaning of emissions into account.

A.2 Cost minimization.

Let E be the number of tons SO_2 emitted when combustion of one ton of heavy oil takes place, and let P(E) be the price of heavy oil as a function of sulphur content. Assume a tax on SO_2 emissions with a tax rate equal to T NOK/ton SO_2 emitted. Let the fraction of SO_2 removed due to cleaning of emissions be denoted by c, and assume the variable costs of cleaning to be equal to V NOK/ton SO_2 removed. Under these conditions a firm would use a heavy oil minimizing the following expression:

$$C(E) = E\,[T(1 - c) + cV] + P(E)$$

E would then satisfy (provided P(E) is continuous):

$$-P'(E) = T(1 - c) + cV$$

In firms without cleaning of emissions (c=0) we obviously have

$$-P'(E) = T$$

Thus, from the marginal cost data presented above, policy 1 implemented with a tax (policy 1T) requires a tax rate T_1 = 2 300 NOK/ton SO_2, while policy 2T requires T_2 = 5 000 NOK/ton SO_2.

Unfortunatly, we do not have good information on the variable cost of cleaning SO_2 emissions. We believe, however, that a reasonable value is V = 2300 NOK/ton SO_2 removed. A further reason to chose this value is that the marginal cost of switching to heavy oil with 1% sulphur becomes independent of the fraction

of emitted SO_2 removed by cleaning. The average cleaning fraction for firms reporting to SFT is estimated to be c = 0.4. We can now determine the cost minimizing behavior of these firms.

In table A.3 below the cost minimizing behaviour of firms under different circumstances, i.e. different emission tax regimes, are indicated. Under policy 1 implemented by tax (1T) it is found that firms without cleaning of emissions shift to oil with 1% sulphur, while firms with cleaning will avoid switching from the 2.15% sulphur heavy oil. Under policy 2T firms without cleaning switch to 0.7% sulphur oil, while forms with cleaning have an incentive to switch to heavy oil with 1% sulphur content.

TABLE A.3. COST MINIMIZING BEHAVIOUR OF FIRMS.

Sulphur content of oil (%)	Policy 1T (Tax=2300 NOK/ton SO_2)		Policy 2T (Tax=5000 NOK/ton SO_2)	
	Without cleaning	With cleaning	Without cleaning	With cleaning
2.15		X		
1.0	X			X
0.7			X	

APPENDIX B: Calculation of Base Year SO_2 Emissions and Policy Costs.

B.1 Introduction.

This appendix presents in greater detail the calculation of SO_2 emissions in the base year 1983 from various emission sources, and the estimation of some of the costs associated with the various policy options (regulation or tax, with 1% and 0.7%, as the aims for the the sulphur content of heating oils). The information is organised in 14 tables, each of which clarify one aspect of the procedure followed. The tables are presented at the end of the appendix.

The results are presented by sector - 34 in all - including private households. Also, where appropriate, totals as well as sub-totals for the manufacturing sectors (exclusive refineries) are given. The manufacturing sectors are marked by an asterix in table 3.1 in the main text.

B.2 SO_2 Emissions.

Table B.1 - B.9 presents data on the main sources of SO_2 emissions, such as combustion of gasoline, combustion of coke and coal, other industrial processes than combustion (e.g. coke used as anode material in electrolysis), combustion of light oil, and combustion of heavy oil. In addition, consideration is given to cleaning of emissions of SO_2, which takes place in certain firms in some of the more polluting sectors. Below we briefly comment on the content of each table.

Table B.1 gives SO_2 emissions in tons due to combustion of gasoline, together with gasoline consumption in 1000 tons. Dividing, we obtain emission coefficients measured in kg SO_2 emitted per ton gasoline consumed.

Table B.2 shows emission coefficients associated with emissions from coke, coal and industrial processes, other than combustion.

The first two columns give sector output (X) and material usage (M) in billion NOK. In private households we have put X = M = private consumption. SO_2 emissions from coke, coal and industrial processes other than combustion are given in tons in column 3. (The emission numbers are taken from tables B.5 and B.6 below.) Dividing emissions by X and M, we obtain emission coefficients associated with production and material input as shown in the last two columns. They are expressed in tons SO_2 emitted per billion (1983) NOK production or material input, respectively. For projection purposes, the ratio of process and coal emissions to material input M is considered to be more stable over time, and hence preferable to the X coefficients. Furthermore coal and coke are treated as parts of the material input in the MSG-4E model. Finally, the MSG-4E model incorporates a Hicks' neutral technical change. By relating future SO_2 emissions from coke, coal and industrial processes to material input, we implicitly assume that the technical change also affect future emissions. This seems to be a reasonable assumption.

Table B.3 reports the sector use of various oil types and coke and coal in 1983. All numbers are in 1000 tons. In one sector, industrial chemicals (37), feedstocks account for most of the heavy oil usage. This use of heavy oil is treated separately. Light oil is defined as all fuel oils except heavy oil, specifically, parafine, middle distillate fuel oils, and auto and marine diesel fuels. It is seen that 79% of the heavy oil use is in manufacturing sectors, which is the focus of this study.

To undertake a policy analysis of fuel oil switching, it is necessary to separate the amount of SO_2 emissions due to fuel oil combustion from that which is due to other sources. Furthermore, cleaning of SO_2 emissions must also be taken into account. This decomposition of SO_2 emissions is shown in table B.4, which also illustrates the calculation methodology. The first column gives an estimate of total theoretical SO_2 emissions from combustion of heavy oil measured in tons. The estimate is based on heavy oil usage and average sulphur content of heavy oil in each sector. Specifically, heavy oil with 2.15% sulphur was assumed in all sectors except Trade (81), Defence (92), Health services (94) and

Private households, where 1.6% sulfur was assumed. Column 2 shows data calculated in the same way, but only for larger plants reporting SO_2 emissions to the Norwegian State Pollution Control Authority (abbreviated SFT in Norwegian). Cleaning of emissions to air is assumed to take place within this set of larger plants only. Column 3, calculated as the difference between the two first columns, yields the SO_2 emissions from other plants due to combustion of heavy oil. It is assumed that no cleaning of SO_2 emissions take place in these generally smaller plants. Column 4 provides correction for heavy oil used as feedstock. For feedstock, zero SO_2 emissions is assumed. All consumption of heavy oil as feedstock is allocated to the larger, SFT-reporting plants, and are therefore subtracted from column 2 prior to applying the cleaning factor in column 5 to the emissions from SFT-plants. Within this subclass of plants, the percentage of SO_2 cleaning is set equal to 40% on average. This average includes plants with no cleaning and plants with a cleaning fraction in excess of 0.4. The assumption of 40% SO_2 cleaning on average is rather arbitrary, and should be improved in future studies.

Based on these assumptions, SO_2 emissions from SFT-plants are calculated in column 6. Column 7 reports emissions from light oils, and is based on the mix of light fuel oil consumption and sulphur content of each type of light oil. The emission coefficients for oil are obtained by dividing total SO_2 emissions from oils (column 8) by oil use as reported in table B.3. The unit is kg SO_2 emissions per ton oil use.

Table B.5 shows a similar procedure for emissions from coke and coal. Based on recent data, coal is assumed to have an average sulphur content of 0.8%. Again 40% cleaning is assumed in those plants reporting to SFT, while no cleaning is assumed in other plants. In two industries (sectors number 27 and 43) most of the coal and coke is used as feedstock in processes. Here it is assumed that 80% of the theoretical (uncleaned) SO_2 emissions are removed, which represents an average over coal used in combustion and coke and coal used in processes. This procedure of adjusting the cleaning fraction is used instead of explicitly entering feedstock in column 4, because data on feedstock was unavailable.

Table B.6 deals with process emissions. Almost all process emissions of SO_2 occur in a couple of industrial processes such as smelting of metals and pulp processing to make paper. These industries consists usually of large manufacturing facilities, which report emissions to SFT. Therefore process emissions (column 3) are calculated as the total SO_2 emissions from SFT plants (column 1) minus the calculated emissions from use of oil and coke and coal in those plants (column 2). Table B.6 also presents total SO_2 emissions from stationary sources (column 4), which however includes emissions due to use of auto and marine diesel fuels. Total SO_2 emissions in 1983 (column 5) includes the small amount of SO_2 from combustion of gasoline. All emission numbers are expressed in tons in table B.6.

Table B.7 shows the percentage of total SO_2 emissions in 1983 estimated to be due to combustion of oil, coal, gasoline or other industrial processes. SO_2 from gasoline is less than 1% of total emissions. Combustion of fuel oils accounts for approximatly 46% of total emission of SO_2 and 33% of the total within the manufacturing sectors. These estimates should be considered to be preliminary and are of course based on the assumptions described above. Emissions from refineries are not analysed as part of this study. Hence no attention was given to allocating refinery emissions between categories. Arbitrarily the emissions are placed in the process category.

A final note should be made on the variability of SO_2 emissions, particularily emissions from some of the more polluting manufacturing sectors. The table below reports SO_2 emissions from five sectors in 1982 and 1983 as reported to SFT.

CHANGES IN SO_2 EMISSIONS. 1982-1983.

Sector	1982 (Tons)	1983 (Tons)	Change (Per cent)
34 Paper and pulp	9 686	6 111	-37%
37 Industrial chemicals	6 929	5 602	-19%
40 Refineries	9 625	8 386	-13%
27 Chemical products	4 560	5 370	+18%
43 Metals	32 392	32 138	- 1%
Sum	63 192	57 607	- 9%

Part of the variation is due to changes in activity levels and the amount of cleaning of emissions. Another part of the reduction in SO_2 releases from 1982 to 1983 is probably due to the good supply of cheap surplus hydro power in 1983. In many applications electricity can be substituted for fuel oil, when cheap electricity is available. These variations are of course not taken into account in the forecasting model. Rather they should be looked upon as estimates of emissions in a 'normal' year, i.e. with average economic conditions abroad and at home and with a normal amount of precipitation during the year.

B.3 Policy impacts.

The remainder of the appendix deals with policy impacts on future SO_2 emissions and costs associated with the control measures. As mentioned previously the following options are studied:

Policy 1: Shift from heavy oil with 2.15% sulphur content to heavy oil with 1% sulphur content.

Policy 2: An additional shift to heavy oil with 0.7% sulphur (1% sulphur for firms with cleaning of emissions).

Both policies can be implemented either by direct regulation or by an appropriate tax on SO_2 emissions, and are then denoted policy iR and iT, i= 1,2, respectively. A problem occurs when the behaviour of firms with cleaning of emissions are considered. If

the control policy is implemented by way of taxing the emissions, the firms are supposed to react by minimizing total costs, taking the price of oil, emission tax and variable costs associated with the cleaning into account. Also the availability of different fuel types must be considered. This question is studied in some detail in appendix A. Under the assumptions in appendix A it is found that firms with cleaning will switch to heavy oil with 1% sulphur when a tax is levied on emissions so that firms without cleaning switch to fuel oil with 0.7% sulphur. Policy 2 implemented by direct regulation assumes the same differentiated switch to occur.

B.3.1 Direct effects on emissions.

Table B.8 derives the direct effect on emissions of policy 1 in the base year, i.e. a switch to heavy oil with 1% sulphur content. The direct effects are those associated with the reduction in emission coefficients, thus keeping the fuel consumption fixed. The policy scaling variable of 0.48 in table B.8 reflects the change in sulphur content from 2.15% to 1%. This factor scales emissions from both large plants (reporting to SFT) with some SO_2 cleaning and other plants without cleaning. Column 1 and 3 show emissions after a policy scaling has been applied to the reference case emissions shown in table B.4. Emission coefficients, relating emissions to the use of fuel oil, are also reported. Corresponding emissions coefficients before scaling were shown in table B.4.

Table B.9 is similar to B.8, but relates to policy 2. A summary of the direct effects of both policies is shown below.

SO_2 EMISSIONS REDUCTIONS. DIRECT EFFECTS. YEAR 2000.

Reduction SO_2 emissions: Direct effect 1983.	From oil (percent)	Total (percent)
Policy 1:		
Manufacturing	47	16
All sectors	23	11
Policy 2:		
Manufacturing	56	19
All sectors	28	13

In the calculation above, emissions from gasoline, coal and processes are kept constant.

B.3.2 Direct costs.

The SO_2 emission control policies discussed in this report effectively increase the real price of using fuel commodity F. Let us denote this price by PF. The fuel price in the model is sector specific because its composition between gasoline, fuel oil and trade differs among sectors. Also existing taxes on fuel differs among sectors. The expression for the sector dependent price of the fuel commodity F in MSG-4E is as follows:

$$PF = L41*(1 + TV41*HV41)*B41 + L42*(1 + TV42*HV42)*B42 + L81*B81$$

where the commodities 41, 42 and 81 are gasoline, fuel oil and trade, respectively. The base prices of these commodities are B41, B42 and B81, while HV41 and HV42 are sector specific value added taxes in the base year. The tax parameters TV41 and TV42 are used to implement policies for this study, and are equal to 1 in the reference case.

Total expenditure on fuel oil (H) in year t can be written as follows:

$$ExpH(t) = L42*(1 + HV42)*F(t_0)*B42(t)*H(t)/H(t_0)$$

where all quantities are sector dependent. Here, L42(1 + HV42) represents the share of fuel oil H in the fuel commodity F in the base year t_0. Multiplying by F in the base year yields the expenditure on fuel oil in this year. To obtain the expenditure in year t, we multiply the relative increase in fuel oil consumption by the price index of fuel oil B42(t). Note that B42 = 1 in the base year 1983.

The introduction of a SO_2 emission control policy increases the expenditure on fuel oil with

$$[AC(E - E^*) + TE^*]*B42(t)*H(t)$$

where E and E^* are the emission coefficients before and after the introduction of the control policy, respectively, AC is the average cost of removing one ton of SO_2 due to switching of fuels, and T is the tax rate on SO_2 emissions in the base year. Note that we assume that the cost of fuel switching and the emission tax are indexed based on the inflation in fuel oil H. Variable cost of cleaning is taken into account in the expression for average cost of fuel switching.

Equating the expenditure on fuel oil including the added expenditure due to the emission control policy with

$$L42*(1 + TV42*HV42)*F(t_0)*B42(t)*H(t)/H(t_0)$$

it is possible to solve for the tax parameter TV42 as follows:

$$TV42 = 1 + g*(1 + 1/HV42)$$

where g is the relative increase (growth) in fuel oil expenditure due to the control policy in the base year, i.e.

$$g = \frac{\text{(Cost of fuel switching}(t_0) + \text{Emission tax}(t_0)}{\text{Expenditure on fuel oil } (t_0)}$$

To summarize, an emission control policy which causes the fuel related expenditures to increase by a fraction g in a sector can be implemented in the MSG-4E model by a sector specific change in fuel oil tax rate, with TV42 given by the above formulae.

The next four tables (B.10 - B.13) present cost calculations associated with policy 1 and policy 2 as these are implemented either by regulation or by imposing a tax on SO_2 emissions. Only direct costs, i.e. cost associated with the increased price of oil due to lower sulphur content, are considered. The main purpose of these tables is to compute the MSG-4E variable TV42, which is used to represent policy costs in the model. TV42 is expected to be constant over time once the policy is implemented. Hence TV42 is estimated using base year 1983 data.

Table B.10 presents base year (1983) costs under policy 1 (switch to 1% sulphur heavy oil) as implemented by direct regulation. The cost is computed as the product of SO_2 emissions reductions (column 1) times the cost per ton SO_2 removed. The latter parameter is 2 300 NOK per ton removed for policy 1, as discussed in appendix A and shown at the top of the table. Control costs in column 2 are in thousands of NOK. The percentage change in the price of fuel oil g is shown in column 3. A modest increase below 2% is seen to occur as a consequence of policy 1. The weighted average is 1.19%. The change in the price of the fuel commodity F in MSG-4E (PF) is obtained by multiplying g by the share of fuel oil in the fuel commodity. These shares are reported in table B.14 to be discussed below.

The increase in fuel costs can be represented in MSG-4E as an added tax on fuel oil usage. The existing tax is denoted HV42 (given in table B.14 below). The new tax is TV42*HV42 and is shown in the last column in table B.10. We find that policy 1 increases the weighted average tax on oil in the manufacturing sectors from 1.41% to 2.61% (shown on the bottom line of table B.10).

Table B.11 shows base year (1983) costs of policy 1 as implemented with a tax on SO_2 emissions, i.e. the added costs of taxing the remaining SO_2 emissions at a rate of 2 300 NOK per ton. The weighted average price increase on fuel oil across manufacturing sectors are now 2.55%. In table B.11 as well as table B.13 taxes are also shown on non manufacturing sectors although they are not included in the analysis here.

Table B.12 shows the additional costs associated with policy 2, i.e. the additional switch from 1% to 0.7% sulphur oil in firms without cleaning of emissions. The cost of the additional switch is estimated as 5 000 NOK per ton SO_2 removed. The average control costs are shown in column 5 of the table. Averaged over all manufacturing sectors the total cost is 2732 NOK per ton SO_2 removed.

Table B.13 shows policy 2 costs as implemented with a tax of 5 000 NOK per ton of remaining SO_2 emissions. Here the price increase on fuel oil in the manufacturing sectors associated with the policy is 4.1% on average. The equivalent weigthed average tax on fuel oil becomes 5.6%. A summary of average price increases on fuel oil in the manufacturing sectors and equivalent tax rates on fuel oil associated with the various modes of implementation of policy 1 and 2 is offered in the table below.

PRICE INCREASES ON FUEL OIL. WEIGHTED AVERAGE OVER MANUFACTURING SECTORS. EXISTING TAX ON FUEL OIL (HV42): 1.41%.

	Policy 1R Regulation	Policy 1T Tax	Policy 2R Regulation	Policy 2T Tax
Equivalent tax on fuel oil (TV42*HV42):	2.61%	3.98%	3.11%	5.60%
Increase in price of fuel oil (g):	1.19%	2.55%	1.68%	4.14%

Finally, table B.14 shows data taken from the MSG-4E model. The data are expenditures on the fuel commodity F in 1983 (preliminary estimates are used in the present MSG-4E version), the

base year tax rate for fuel oil (HV42) and the oil share parameter Lambda42. Adjusted for tax effects the fuel oil share of the fuel commodity F is Lamda42*(1 + HV42). The weigthed average fuel share in manufacturing is approximatly 67%. This is higher than in non manufacturing sectors which uses a higher percentage of gasoline. The share parameters allow the expenditure on fuel oil to be calculated from expenditure data on the fuel commodity F. The average price of fuel oil is also calculated in table B.14.

TABLE B.1. SO_2 EMISSIONS FROM GASOLINE COMBUSTION, GASOLINE USAGE AND EMISSION COEFFICIENTS. 1983.

#	Sector	SO_2 FROM GASOLINE (Tons)	GASOLINE USAGE (1000 tons)	EMISSION COEFFICIENT (10^{-3})
11	Agriculture	6.00	14.00	.43
12	Forestry	2.00	3.00	.67
13	Fishing and hunting	0.00	5.00	0.00
31	Mining and quarrying	0.00	1.00	0.00
16	Manufacture of food	2.00	4.00	.50
17	Beverages and tobacco	0.00	1.00	0.00
18	Textiles, wearing apparel	0.00	1.00	0.00
26	Wood products	1.00	2.00	.50
34	Paper and pulp	0.00	0.00	N/A
37	Industrial chemicals	0.00	11.00	0.00
40	Refineries	0.00	0.00	N/A
27	Chemicals and minerals	1.00	3.00	.33
43	Metals	0.00	1.00	0.00
45	Metal products, machinery	2.00	4.00	.50
50	Construction of ships etc	1.00	1.00	1.00
28	Printing and publishing	1.00	2.00	.50
72	Electricity production	0.00	2.00	0.00
73	Electricity distribution	0.00	4.00	0.00
55	Construction	4.00	8.00	.50
81	Wholesale & retail trade	89.00	184.00	.48
64	Drilling for oil and gas	0.00	0.00	N/A
68	Production of oil and gas	0.00	0.00	N/A
60	Ocean transport	0.00	0.00	N/A
74	Domestic transport	35.00	71.00	.49
82	Financing, insurance	5.00	10.00	.50
83	Housing services	0.00	0.00	N/A
79	Repair	6.00	12.00	.50
84	Other private services	27.00	60.00	.45
91	Public administration	2.00	3.00	.67
92	Defence	3.00	88.00	.03
93	Education and research	0.00	0.00	N/A
94	Health and social service	0.00	0.00	N/A
95	Other public services	0.00	0.00	N/A
	Private households	531.00	1062.00	.50
	Total	718.00	1557.00	
	Manufacturing (-refining)	8.00	31.00	

TABLE B.2. GROSS PRODUCTION, MATERIAL USAGE, PROCESS AND COAL EMISSIONS AND EMISSION COEFFICIENTS. 1983.

#	Sector	MSG X^1 PROC.+COAL (Bill.NOK)	MSG M^2 X (Bill.NOK)	SO_2 EM. M (Tons)	EMISSION COEFFICIENTS (Tons./Bill.NOK)	
11	Agriculture	22.98	10.86	80.00	3.48	7.37
12	Forestry	2.74	.31	0.00	0.00	0.00
13	Fishing and hunting	5.95	1.65	0.00	0.00	0.00
31	Mining and quarrying	3.38	1.49	1.00	.30	.67
16	Manufacture of food	46.49	33.96	66.00	1.42	1.94
17	Beverages and tobacco	5.96	1.29	1.00	.17	.77
18	Textiles, wearing apparel	4.63	2.47	3.00	.65	1.21
26	Wood products	16.07	8.96	0.00	0.00	0.00
34	Paper and pulp	11.32	6.93	3838.80	339.22	553.83
37	Industrial chemicals	10.39	6.27	4356.40	419.15	694.72
40	Refineries	14.63	12.93	8386.00	573.10	648.45
27	Chemicals and minerals	18.64	9.96	7721.00	414.31	775.35
43	Metals	18.34	10.54	30212.00	1647.00	2866.39
45	Metal products, machinery	33.22	16.36	3.00	.09	.18
50	Construction of ships etc	24.77	16.64	2.00	.08	.12
28	Printing and publishing	13.64	6.66	0.00	0.00	0.00
72	Electricity production	21.33	11.28	0.00	0.00	0.00
73	Electricity distribution	10.48	1.69	0.00	0.00	0.00
55	Construction	64.61	36.25	0.00	0.00	0.00
81	Wholesale & retail trade	94.53	21.80	0.00	0.00	0.00
64	Drilling for oil and gas	76.26	6.06	0.00	0.00	0.00
68	Production of oil and gas	4.74	1.36	0.00	0.00	0.00
60	Ocean transport	31.26	20.70	0.00	0.00	0.00
74	Domestic transport	44.39	14.92	0.00	0.00	0.00
82	Financing, insurance	24.20	24.24	0.00	0.00	0.00
83	Housing services	19.97	4.89	0.00	0.00	0.00
79	Repair	6.87	1.53	0.00	0.00	0.00
84	Other private services	58.17	17.39	0.00	0.00	0.00
91	Public administration	1.39	4.57	0.00	0.00	0.00
92	Defence	.58	7.43	0.00	0.00	0.00
93	Education and research	.54	3.89	0.00	0.00	0.00
94	Health and social service	2.20	4.60	0.00	0.00	0.00
95	Other public services	2.35	5.54	0.00	0.00	0.00
	Private households	192.50	192.50	720.00	3.74	3.74
	Total	909.54	527.93	55390.20		
	Manufacturing (-refining)	206.86	121.53	46204.20		

1) Gross production.
2) Material usage.

TABLE B.3. OIL, COAL AND COKE USE. 1000 TONS. 1983.

#	Sector	MSG OIL OL42	HEAVY OIL INCL.FEED.	OIL FOR FEEDSTOCK	LIGHT OIL	COAL AND COKE
11	Agriculture	147.00	12.00	0.00	135.00	5.00
12	Forestry	11.00	0.00	0.00	11.00	0.00
13	Fishing and hunting	383.00	0.00	0.00	383.00	0.00
31	Mining and quarrying	63.00	31.62	0.00	31.38	.05
16	Manufacture of food	183.00	155.93	0.00	27.07	4.12
17	Beverages and tobacco	15.00	10.74	0.00	4.26	.07
18	Textiles, wearing apparel	17.00	8.67	0.00	8.33	.17
26	Wood products	36.00	18.14	0.00	17.86	0.00
34	Paper and pulp	113.00	111.38	0.00	1.62	0.00
37	Industrial chemicals	211.00	175.22	114.00	35.78	129.40
40	Refineries	0.00	0.00	0.00	0.00	0.00
27	Chemicals and minerals	138.00	78.74	0.00	59.26	911.34
43	Metals	118.00	94.20	0.00	23.80	1147.83
45	Metal products, machinery	66.00	18.98	0.00	47.02	.22
50	Construction of ships etc	33.00	4.79	0.00	28.21	.10
28	Printing and publishing	7.00	.46	0.00	6.54	0.00
72	Electricity production	6.20	0.00	0.00	6.20	0.00
73	Electricity distribution	3.80	0.00	0.00	3.80	0.00
55	Construction	151.00	1.00	0.00	150.00	0.00
81	Wholesale & retail trade	189.00	7.00	0.00	182.00	0.00
64	Drilling for oil and gas	64.00	0.00	0.00	64.00	0.00
68	Production of oil and gas	184.00	0.00	0.00	184.00	0.00
60	Ocean transport	244.00	0.00	0.00	244.00	0.00
74	Domestic transport	967.00	145.00	0.00	822.00	0.00
82	Financing, insurance	0.00	0.00	0.00	0.00	0.00
83	Housing services	0.00	0.00	0.00	0.00	0.00
79	Repair	16.00	0.00	0.00	16.00	0.00
84	Other private services	113.00	0.00	0.00	113.00	0.00
91	Public administration	12.00	0.00	0.00	12.00	0.00
92	Defence	100.00	5.00	0.00	95.00	0.00
93	Education and research	56.00	0.00	0.00	56.00	0.00
94	Health and social service	71.00	2.00	0.00	69.00	0.00
95	Other public services	19.00	0.00	0.00	19.00	0.00
	Private households	517.00	17.00	0.00	500.00	45.00
	Total	4254.00	897.87	114.00	3356.13	2243.30
	Manufacturing (-refining)	1000.00	708.87	114.00	291.13	2193.30

TABLE B.4. SO_2 EMISSIONS FROM OIL. 1983.

#	Sector	UNCONTROLLED EMISSIONS FROM HEAVY OIL				NON-CLEANED	EMISSIONS			OIL EMISSION
		ALL PLANTS (Tons)	SFT PLANTS (Tons)	NON-SFT PLANTS (Tons)	FEED-STOCK (Tons)	FRACTION OF EMIS.	HEAVY OIL. SFT PLANTS (Tons)	LIGHT OIL (Tons)	TOTAL FROM OIL (Tons)	COEFF. (10^{-3})
11	Agriculture	504.00	0.00	504.00	0.00	.60	0.00	921.00	1425.00	9.69
12	Forestry	0.00	0.00	0.00	0.00	.60	0.00	66.00	66.00	6.00
13	Fishing and hunting	0.00	0.00	0.00	0.00	.60	0.00	2668.00	2668.00	6.97
31	Mining and quarrying	1328.00	0.00	1328.00	0.00	.60	0.00	273.00	1601.00	25.41
16	Manufacture of food	6549.00	0.00	6549.00	0.00	.60	0.00	627.00	7176.00	39.21
17	Beverages and tobacco	451.00	0.00	451.00	0.00	.60	0.00	56.00	507.00	33.80
18	Textiles, wearing apparel	364.00	0.00	364.00	0.00	.60	0.00	54.00	418.00	24.59
26	Wood products	762.00	0.00	762.00	0.00	.60	0.00	146.00	908.00	25.22
34	Paper and pulp	4678.00	3787.00	891.00	0.00	.60	2272.20	34.00	3197.20	28.29
37	Industrial chemicals	7359.00	6864.00	495.00	4788.00	.60	1245.60	146.00	1886.60	8.94
40	Refineries	0.00	0.00	0.00	0.00	.60	0.00	0.00	0.00	N/A
27	Chemicals and minerals	3307.00	1330.00	1977.00	0.00	.60	798.00	472.00	3247.00	23.53
43	Metals	3956.00	3280.00	676.00	0.00	.60	1968.00	210.00	2854.00	24.19
45	Metal products, machinery	797.00	0.00	797.00	0.00	.60	0.00	296.00	1093.00	16.56
50	Construction of ships etc	201.00	0.00	201.00	0.00	.60	0.00	128.00	329.00	9.97
28	Printing and publishing	19.00	0.00	19.00	0.00	.60	0.00	37.00	56.00	8.00
72	Electricity production	0.00	0.00	0.00	0.00	.60	0.00	0.00	0.00	0.00
73	Electricity distribution	0.00	0.00	0.00	0.00	.60	0.00	0.00	0.00	0.00
55	Construction	42.00	0.00	42.00	0.00	.60	0.00	936.00	978.00	6.48
81	Wholesale & retail trade	224.00	0.00	224.00	0.00	.60	0.00	1073.00	1297.00	6.86
64	Drilling for oil and gas	0.00	0.00	0.00	0.00	.60	0.00	0.00	0.00	0.00
68	Production of oil and gas	0.00	0.00	0.00	0.00	.60	0.00	0.00	0.00	0.00
60	Ocean transport	0.00	0.00	0.00	0.00	.60	0.00	0.00	0.00	0.00
74	Domestic transport	6090.00	0.00	6090.00	0.00	.60	0.00	5447.00	11537.00	11.93
82	Financing, insurance	0.00	0.00	0.00	0.00	.60	0.00	0.00	0.00	N/A
83	Housing services	0.00	0.00	0.00	0.00	.60	0.00	0.00	0.00	N/A
79	Repair	0.00	0.00	0.00	0.00	.60	0.00	112.00	112.00	7.00
84	Other private services	0.00	0.00	0.00	0.00	.60	0.00	774.00	774.00	6.85
91	Public administration	0.00	0.00	0.00	0.00	.60	0.00	77.00	77.00	6.42
92	Defence	160.00	0.00	160.00	0.00	.60	0.00	666.00	826.00	8.26
93	Education and research	0.00	0.00	0.00	0.00	.60	0.00	364.00	364.00	6.50
94	Health and social services	64.00	0.00	64.00	0.00	.60	0.00	401.00	465.00	6.55
95	Other public services	0.00	0.00	0.00	0.00	.60	0.00	104.00	104.00	5.47
	Private households	544.00	0.00	544.00	0.00	.60	0.00	2460.00	3004.00	5.81
	Total	37399.00	15261.00	22138.00	4788.00		6283.80	18548.00	46969.80	
	Manufacturing (-ref.)	29771.00	15261.00	14510.00	4788.00		6283.80	2479.00	23272.80	

TABLE B.5. SO_2 EMISSIONS FROM COKE AND COAL. 1983.

#	Sector	EMISSIONS WITHOUT CLEANING				NON-CLEANED	EMISSIONS	
		TOTAL (Tons)	SFT PLANTS (Tons)	NON-SFT PLANTS (Tons)	FEED-STOCK (Tons)	FRACTION SFT PLANTS	SFT PLANTS (Tons)	TOTAL (Tons)
11	Agriculture	80.00	0.00	80.00	0.00	.60	0.00	80.00
12	Forestry	0.00	0.00	0.00	0.00	.60	0.00	0.00
13	Fishing and hunting	0.00	0.00	0.00	0.00	.60	0.00	0.00
31	Mining and quarrying	1.00	0.00	1.00	0.00	.60	0.00	1.00
16	Manufacture of food	66.00	0.00	66.00	0.00	.60	0.00	66.00
17	Beverages and tobacco	1.00	0.00	1.00	0.00	.60	0.00	1.00
18	Textiles, wearing apparel	3.00	0.00	3.00	0.00	.60	0.00	3.00
26	Wood products	0.00	0.00	0.00	0.00	.60	0.00	0.00
34	Paper and pulp	0.00	0.00	0.00	0.00	.60	0.00	0.00
37	Industrial chemicals	2070.00	2070.00	0.00	0.00	.60	1242.00	1242.00
40	Refineries	0.00	0.00	0.00	0.00	.60	0.00	0.00
27	Chemicals and minerals	14581.00	11432.00	3149.00	0.00	.20	2286.40	5435.40
43	Metals	18365.00	18323.00	42.00	0.00	.20	3664.60	3706.60
45	Metal products, machinery	3.00	0.00	3.00	0.00	.60	0.00	3.00
50	Construction of ships etc	2.00	0.00	2.00	0.00	.60	0.00	2.00
28	Printing and publishing	0.00	0.00	0.00	0.00	.60	0.00	0.00
72	Electricity production	0.00	0.00	0.00	0.00	.60	0.00	0.00
73	Electricity distribution	0.00	0.00	0.00	0.00	.60	0.00	0.00
55	Construction	0.00	0.00	0.00	0.00	.60	0.00	0.00
81	Wholesale & retail trade	0.00	0.00	0.00	0.00	.60	0.00	0.00
64	Drilling for oil and gas	0.00	0.00	0.00	0.00	.60	0.00	0.00
68	Production of oil and gas	0.00	0.00	0.00	0.00	.60	0.00	0.00
60	Ocean transport	0.00	0.00	0.00	0.00	.60	0.00	0.00
74	Domestic transport	0.00	0.00	0.00	0.00	.60	0.00	0.00
82	Financing, insurance	0.00	0.00	0.00	0.00	.60	0.00	0.00
83	Housing services	0.00	0.00	0.00	0.00	.60	0.00	0.00
79	Repair	0.00	0.00	0.00	0.00	.60	0.00	0.00
84	Other private services	0.00	0.00	0.00	0.00	.60	0.00	0.00
91	Public administration	0.00	0.00	0.00	0.00	.60	0.00	0.00
92	Defence	0.00	0.00	0.00	0.00	.60	0.00	0.00
93	Education and research	0.00	0.00	0.00	0.00	.60	0.00	0.00
94	Health and social service	0.00	0.00	0.00	0.00	.60	0.00	0.00
95	Other public services	0.00	0.00	0.00	0.00	.60	0.00	0.00
	Private households	720.00	0.00	720.00	0.00	.60	0.00	720.00
	Total	35892.00	31825.00	4067.00	0.00		7193.00	11260.00
	Manufacturing (-refining)	35092.00	31825.00	3267.00	0.00		7193.00	10460.00

TABLE B.6. PROCESSES AND TOTAL SO_2 EMISSIONS. TONS. 1983.

#	Sector	TOTAL EM. SFT PLANTS	OIL+COAL EM. FROM SFT PLANTS	PROCESS EM. FROM SFT PLANTS	TOTAL EM. STATIONARY SOURCES	TOTAL EMISSIONS (INCL.GAS.)
11	Agriculture	0.00	0.00	0.00	1505.00	1511.00
12	Forestry	0.00	0.00	0.00	66.00	68.00
13	Fishing and hunting	0.00	0.00	0.00	2668.00	2668.00
31	Mining and quarrying	0.00	0.00	0.00	1602.00	1602.00
16	Manufacture of food	0.00	0.00	0.00	7242.00	7244.00
17	Beverages and tobacco	0.00	0.00	0.00	508.00	508.00
18	Textiles, wearing apparel	0.00	0.00	0.00	421.00	421.00
26	Wood products	0.00	0.00	0.00	908.00	909.00
34	Paper and pulp	6111.00	2272.20	3838.80	7036.00	7036.00
37	Industrial chemicals	5602.00	2487.60	3114.40	6243.00	6243.00
40	Refineries	8386.00	0.00	8386.00	8386.00	8386.00
27	Chemicals and minerals	5370.00	3084.40	2285.60	10968.00	10969.00
43	Metals	32138.00	5632.60	26505.40	33066.00	33066.00
45	Metal products, machinery	0.00	0.00	0.00	1096.00	1098.00
50	Construction of ships etc	0.00	0.00	0.00	331.00	332.00
28	Printing and publishing	0.00	0.00	0.00	56.00	57.00
72	Electricity production	0.00	0.00	0.00	0.00	0.00
73	Electricity distribution	0.00	0.00	0.00	0.00	0.00
55	Construction	0.00	0.00	0.00	978.00	982.00
81	Wholesale & retail trade	0.00	0.00	0.00	1297.00	1386.00
64	Drilling for oil and gas	0.00	0.00	0.00	0.00	0.00
68	Production of oil and gas	0.00	0.00	0.00	0.00	0.00
60	Ocean transport	0.00	0.00	0.00	0.00	0.00
74	Domestic transport	0.00	0.00	0.00	11537.00	11572.00
82	Financing, insurance	0.00	0.00	0.00	0.00	5.00
83	Housing services	0.00	0.00	0.00	0.00	0.00
79	Repair	0.00	0.00	0.00	112.00	118.00
84	Other private services	0.00	0.00	0.00	774.00	801.00
91	Public administration	0.00	0.00	0.00	77.00	79.00
92	Defence	0.00	0.00	0.00	826.00	829.00
93	Education and research	0.00	0.00	0.00	364.00	364.00
94	Health and social service	0.00	0.00	0.00	465.00	465.00
95	Other public services	0.00	0.00	0.00	104.00	104.00
	Private households	0.00	0.00	0.00	3724.00	4255.00
	Total	57607.00	13476.80	44130.20	102360.00	103078.00
	Manufacturing (-refining)	49221.00	13476.80	35744.20	69477.00	69485.00

TABLE B.7. PERCENT SO_2 EMISSIONS BY SOURCE CATEGORY. 1983.

#	Sector	OIL	COAL	PROCESS	GASOLINE
11	Agriculture	94.31	5.29	0.00	.40
12	Forestry	97.06	0.00	0.00	2.94
13	Fishing and hunting	100.00	0.00	0.00	0.00
31	Mining and quarrying	99.94	.06	0.00	0.00
16	Manufacture of food	99.06	.91	0.00	.03
17	Beverages and tobacco	99.80	.20	0.00	0.00
18	Textiles, wearing apparel	99.29	.71	0.00	0.00
26	Wood products	99.89	0.00	0.00	.11
34	Paper and pulp	45.44	0.00	54.56	0.00
37	Industrial chemicals	30.22	19.89	49.89	0.00
40	Refineries	0.00	0.00	100.00	0.00
27	Chemicals and minerals	29.60	49.55	20.84	.01
43	Metals	8.63	11.21	80.16	0.00
45	Metal products, machinery	99.54	.27	0.00	.18
50	Construction of ships etc	99.10	.60	0.00	.30
28	Printing and publishing	98.24	0.00	0.00	1.75
72	Electricity production	N/A	N/A	N/A	N/A
73	Electricity distribution	N/A	N/A	N/A	N/A
55	Construction	99.59	0.00	0.00	.41
81	Wholesale & retail trade	93.58	0.00	0.00	6.42
64	Drilling for oil and gas	N/A	N/A	N/A	N/A
68	Production of oil and gas	N/A	N/A	N/A	N/A
60	Ocean transport	N/A	N/A	N/A	N/A
74	Domestic transport	99.70	0.00	0.00	.30
82	Financing, insurance	0.00	0.00	0.00	100.00
83	Housing services	N/A	N/A	N/A	N/A
79	Repair	94.92	0.00	0.00	5.08
84	Other private services	96.63	0.00	0.00	3.37
91	Public administration	97.47	0.00	0.00	2.53
92	Defence	99.64	0.00	0.00	.36
93	Education and research	100.00	0.00	0.00	0.00
94	Health and social service	100.00	0.00	0.00	0.00
95	Other public services	100.00	0.00	0.00	0.00
	Private households	70.60	16.92	0.00	12.48
	Total	45.57	10.92	42.81	.70
	Manufacturing (-refining)	33.49	15.05	51.44	.01

TABLE B.8. SO_2 EMISSIONS FROM OIL: POLICY 1. 1983.

#	Sector	NON-SFT PLANTS (Tons)	POLICY SCALING NON-SFT	SFT PLANTS (Tons)	POLICY SCALING SFT	TOTAL EM. FROM OIL (Tons)	OIL EM. COEF-FICIENT (10^{-3})	REDUCTION EMISSIONS FROM OIL (Percent)	TOTAL EMISSIONS (Tons)	REDUCTION TOTAL EMISSIONS (Percent)
11	Agriculture	504.00	1.00	0.00	1.00	1425.00	9.69	0.00	1511.00	0.00
12	Forestry	0.00	1.00	0.00	1.00	66.00	6.00	0.00	68.00	0.00
13	Fishing and hunting	0.00	1.00	0.00	1.00	2668.00	6.97	0.00	2668.00	0.00
31	Mining and quarrying	632.32	.48	0.00	.48	905.32	14.37	43.45	906.32	43.42
16	Manufacture of food	3118.60	.48	0.00	.48	3745.60	20.47	47.80	3813.60	47.36
17	Beverages and tobacco	214.80	.48	0.00	.48	270.80	18.05	46.59	271.80	46.50
18	Textiles, wearing apparel	173.40	.48	0.00	.48	227.40	13.38	45.60	230.40	45.27
26	Wood products	362.80	.48	0.00	.48	508.80	14.13	43.96	509.80	43.92
34	Paper and pulp	424.28	.48	1081.99	.48	1540.27	13.63	51.82	5379.07	23.55
37	Industrial chemicals	235.72	.48	593.16	.48	974.88	4.62	48.32	5331.28	14.60
40	Refineries	0.00	1.00	0.00	1.00	0.00	N/A	N/A	8386.00	0.00
27	Chemicals and minerals	941.48	.48	380.02	.48	1793.49	13.00	44.76	9515.49	13.25
43	Metals	321.94	.48	937.24	.48	1469.17	12.45	48.52	31681.17	4.19
45	Metal products, machinery	379.60	.48	0.00	.48	675.60	10.24	38.19	680.60	38.01
50	Construction of ships etc	95.80	.48	0.00	.48	223.80	6.78	31.98	226.80	31.69
28	Printing and publishing	9.20	.48	0.00	.48	46.20	6.60	17.50	47.20	17.19
72	Electricity production	0.00	1.00	0.00	1.00	0.00	0.00	N/A	0.00	N/A
73	Electricity distribution	0.00	1.00	0.00	1.00	0.00	0.00	N/A	0.00	N/A
55	Construction	42.00	1.00	0.00	1.00	978.00	6.48	0.00	982.00	0.00
81	Wholesale & retail trade	224.00	1.00	0.00	1.00	1297.00	6.86	0.00	1386.00	0.00
64	Drilling for oil and gas	0.00	1.00	0.00	1.00	0.00	0.00	N/A	0.00	N/A
68	Production of oil and gas	0.00	1.00	0.00	1.00	0.00	0.00	N/A	0.00	N/A
60	Ocean transport	0.00	1.00	0.00	1.00	0.00	0.00	N/A	0.00	N/A
74	Domestic transport	6090.00	1.00	0.00	1.00	11537.00	11.93	0.00	11572.00	0.00
82	Financing, insurance	0.00	1.00	0.00	1.00	0.00	N/A	N/A	5.00	0.00
83	Housing services	0.00	1.00	0.00	1.00	0.00	N/A	N/A	0.00	N/A
79	Repair	0.00	1.00	0.00	1.00	112.00	7.00	0.00	118.00	0.00
84	Other private services	0.00	1.00	0.00	1.00	774.00	6.85	0.00	801.00	0.00
91	Public administration	0.00	1.00	0.00	1.00	77.00	6.42	0.00	79.00	0.00
92	Defence	160.00	1.00	0.00	1.00	826.00	8.26	0.00	829.00	0.00
93	Education and research	0.00	1.00	0.00	1.00	364.00	6.50	0.00	364.00	0.00
94	Health and social services	64.00	1.00	0.00	1.00	465.00	6.55	0.00	465.00	0.00
95	Other public services	0.00	1.00	0.00	1.00	104.00	5.47	0.00	104.00	0.00
	Private households	544.00	1.00	0.00	1.00	3004.00	5.81	0.00	4255.00	0.00
	Total	14537.94		2992.41		36078.35		23.19	92186.55	10.57
	Manufacturing (-ref.)	6909.94		2992.41		12381.35		46.80	58593.55	15.67

TABLE B.9. SO_2 EMISSIONS FROM OIL: POLICY 2. 1983.

#	Sector	NON-SFT PLANTS (Tons)	POLICY SCALING NON-SFT	SFT PLANTS (Tons)	POLICY SCALING SFT	TOTAL EM. FROM OIL (Tons)	OIL EM. COEF-FICIENT (10^{-3})	REDUCTION EMISSIONS FROM OIL (Percent)	TOTAL EMISSIONS (Tons)	REDUCTION TOTAL EMISSIONS (Percent)
11	Agriculture	504.00	1.00	0.00	1.00	1425.00	9.69	0.00	1511.00	0.00
12	Forestry	0.00	1.00	0.00	1.00	66.00	6.00	0.00	68.00	0.00
13	Fishing and hunting	0.00	1.00	0.00	1.00	2668.00	6.97	0.00	2668.00	0.00
31	Mining and quarrying	442.62	.33	0.00	.48	715.62	11.36	55.30	716.62	55.27
16	Manufacture of food	2183.02	.33	0.00	.48	2810.02	15.36	60.84	2878.02	60.27
17	Beverages and tobacco	150.36	.33	0.00	.48	206.36	13.76	59.30	207.36	59.18
18	Textiles, wearing apparel	121.38	.33	0.00	.48	175.38	10.32	58.04	178.38	57.63
26	Wood products	253.96	.33	0.00	.48	399.96	11.11	55.95	400.96	55.89
34	Paper and pulp	297.00	.33	1081.99	.48	1412.99	12.50	55.80	5251.79	25.36
37	Industrial chemicals	165.00	.33	593.16	.48	904.17	4.28	52.07	5260.57	15.74
40	Refineries	0.00	1.00	0.00	1.00	0.00	N/A	N/A	8386.00	0.00
27	Chemicals and minerals	659.03	.33	380.02	.48	1511.05	10.95	53.46	9233.05	15.82
43	Metals	225.36	.33	937.24	.48	1372.59	11.63	51.91	31584.59	4.48
45	Metal products, machinery	265.72	.33	0.00	.48	561.72	8.51	48.61	566.72	48.39
50	Construction of ships etc	67.06	.33	0.00	.48	195.06	5.91	40.71	198.06	40.34
28	Printing and publishing	6.44	.34	0.00	.48	43.44	6.20	22.43	44.44	22.04
72	Electricity production	0.00	1.00	0.00	1.00	0.00	0.00	N/A	0.00	N/A
73	Electricity distribution	0.00	1.00	0.00	1.00	0.00	0.00	N/A	0.00	N/A
55	Construction	42.00	1.00	0.00	1.00	978.00	6.48	0.00	982.00	0.00
81	Wholesale & retail trade	224.00	1.00	0.00	1.00	1297.00	6.86	0.00	1386.00	0.00
64	Drilling for oil and gas	0.00	1.00	0.00	1.00	0.00	0.00	N/A	0.00	N/A
68	Production of oil and gas	0.00	1.00	0.00	1.00	0.00	0.00	N/A	0.00	N/A
60	Ocean transport	0.00	1.00	0.00	1.00	0.00	0.00	N/A	0.00	N/A
74	Domestic transport	6090.00	1.00	0.00	1.00	11537.00	11.93	0.00	11572.00	0.00
82	Financing, insurance	0.00	1.00	0.00	1.00	0.00	N/A	N/A	5.00	0.00
83	Housing services	0.00	1.00	0.00	1.00	0.00	N/A	N/A	0.00	N/A
79	Repair	0.00	1.00	0.00	1.00	112.00	7.00	0.00	118.00	0.00
84	Other private services	0.00	1.00	0.00	1.00	774.00	6.85	0.00	801.00	0.00
91	Public administration	0.00	1.00	0.00	1.00	77.00	6.42	0.00	79.00	0.00
92	Defence	160.00	1.00	0.00	1.00	826.00	8.26	0.00	829.00	0.00
93	Education and research	0.00	1.00	0.00	1.00	364.00	6.50	0.00	364.00	0.00
94	Health and social services	64.00	1.00	0.00	1.00	465.00	6.55	0.00	465.00	0.00
95	Other public services	0.00	1.00	0.00	1.00	104.00	5.47	0.00	104.00	0.00
	Private households	544.00	1.00	0.00	1.00	3004.00	5.81	0.00	4255.00	0.00
	Total	12464.96		2992.41		34005.36		27.60	90113.56	12.58
	Manufacturing (-ref.)	4836.96		2992.41		10308.36		55.71	56520.56	18.66

TABLE B.10. COST OF POLICY 1R.

(AC = MC = 2300.00 NOK PR. TON SO_2)

#	Sector	REDUCTION IN SO_2 EM. (Tons)	CONTROL COST (1000 NOK)	g (Percent) (increase)	TV42*100	PF (Percent) (Increase)	TV42*HV42
11	Agriculture	0.00	0.00	0.00	100.00	0.00	.32
12	Forestry	0.00	0.00	0.00	100.00	0.00	1.80
13	Fishing and hunting	0.00	0.00	0.00	100.00	0.00	.10
31	Mining and quarrying	695.68	1600.06	1.17	233.32	.87	2.07
16	Manufacture of food	3430.40	7889.92	2.02	212.72	1.42	3.88
17	Beverages and tobacco	236.20	543.26	1.72	190.62	1.04	3.68
18	Textiles, wearing apparel	190.60	438.38	1.47	154.81	.88	4.27
26	Wood products	399.20	918.16	1.23	151.01	.72	3.73
34	Paper and pulp	1656.93	3810.93	1.31	252.41	1.02	2.18
37	Industrial chemicals	911.72	2096.95	.70	177.66	.47	1.61
40	Refineries	0.00	0.00	N/A	N/A	N/A	N/A
27	Chemicals and minerals	1453.50	3343.06	.83	160.78	.61	2.22
43	Metals	1384.82	3185.10	1.56	227.41	1.26	3.24
45	Metal products, machinery	417.40	960.02	.55	134.29	.31	2.20
50	Construction of ships etc	105.20	241.96	.33	120.16	.18	2.01
28	Printing and publishing	9.80	22.54	.13	107.52	.03	1.93
72	Electricity production	0.00	0.00	0.00	100.00	0.00	3.00
73	Electricity distribution	0.00	0.00	0.00	100.00	0.00	2.25
55	Construction	0.00	0.00	0.00	100.00	0.00	1.28
81	Wholesale & retail trade	0.00	0.00	0.00	100.00	0.00	-1.67
64	Drilling for oil and gas	0.00	0.00	0.00	100.00	0.00	4.45
68	Production of oil and gas	0.00	0.00	0.00	N/A	0.00	N/A
60	Ocean transport	0.00	0.00	0.00	100.00	0.00	.68
74	Domestic transport	0.00	0.00	0.00	100.00	0.00	.59
82	Financing, insurance	0.00	0.00	N/A	N/A	N/A	N/A
83	Housing services	0.00	0.00	N/A	N/A	N/A	N/A
79	Repair	0.00	0.00	0.00	N/A	0.00	N/A
84	Other private services	0.00	0.00	0.00	100.00	0.00	.32
91	Public administration	0.00	0.00	0.00	100.00	0.00	.91
92	Defence	0.00	0.00	0.00	100.00	0.00	.41
93	Education and research	0.00	0.00	0.00	100.00	0.00	2.22
94	Health and social service	0.00	0.00	0.00	100.00	0.00	2.46
95	Other public services	0.00	0.00	0.00	100.00	0.00	1.26
	Private households	0.00	0.00	N/A	N/A	N/A	N/A
	Total	10891.45	25050.34				
	Manufacturing (-refining)	10891.45	25050.34	1.19			2.61

TABLE B.11. COST OF POLICY 1T.

(AC = MC = 2300.00. SO_2 TAX = 2300.00 NOK PR. TON SO_2)

#	Sector	CONTROL COST (1000 NOK)	TAX (1000 NOK)	TOTAL (1000 NOK)	g (Percent) (Increase)	TV42*100	PF (Percent) (Increase)	TV42*H
11	Agriculture	0.00	3277.50	3277.50	.82	352.03	.57	1.15
12	Forestry	0.00	151.80	151.80	.45	125.30	.28	2.25
13	Fishing and hunting	0.00	6136.40	6136.40	1.18	1327.62	.88	1.28
31	Mining and quarrying	1600.06	2082.24	3682.30	2.69	406.82	2.00	3.60
16	Manufacture of food	7889.92	8614.88	16504.80	4.23	335.80	2.98	6.13
17	Beverages and tobacco	543.26	622.84	1166.10	3.68	294.52	2.24	5.68
18	Textiles, wearing apparel	438.38	523.02	961.40	3.23	220.21	1.94	6.07
26	Wood products	918.16	1170.24	2088.40	2.80	216.02	1.63	5.33
34	Paper and pulp	3810.93	3542.63	7353.56	2.52	394.08	1.98	3.41
37	Industrial chemicals	2096.95	2242.23	4339.18	1.45	260.70	.97	2.37
40	Refineries	0.00	0.00	0.00	N/A	N/A	N/A	N/A
27	Chemicals and minerals	3343.06	4125.04	7468.10	1.85	235.77	1.36	3.25
43	Metals	3185.10	3379.10	6564.20	3.69	362.57	2.60	5.16
45	Metal products, machinery	960.02	1553.88	2513.90	1.44	189.78	.82	3.10
50	Construction of ships etc	241.96	514.74	756.70	1.04	163.06	.57	2.73
28	Printing and publishing	22.54	106.26	128.80	.76	142.95	.15	2.57
72	Electricity production	0.00	0.00	0.00	0.00	100.00	0.00	3.00
73	Electricity distribution	0.00	0.00	0.00	0.00	100.00	0.00	2.25
55	Construction	0.00	2249.40	2249.40	1.89	249.94	.84	3.20
81	Wholesale & retail trade	0.00	2983.10	2983.10	.52	69.25	.31	-1.16
64	Drilling for oil and gas	0.00	0.00	0.00	0.00	100.00	0.00	4.45
68	Production of oil and gas	0.00	0.00	0.00	0.00	N/A	0.00	N/A
60	Ocean transport	0.00	0.00	0.00	0.00	100.00	0.00	.68
74	Domestic transport	0.00	26535.10	26535.10	2.30	490.22	1.02	2.91
82	Financing, insurance	0.00	0.00	0.00	N/A	N/A	N/A	N/A
83	Housing services	0.00	0.00	0.00	N/A	N/A	N/A	N/A
79	Repair	0.00	257.60	257.60	18.42	N/A	.69	N/A
84	Other private services	0.00	1780.20	1780.20	.47	248.34	.18	.78
91	Public administration	0.00	177.10	177.10	.10	111.07	.03	1.02
92	Defence	0.00	1899.80	1899.80	1.54	480.01	.38	1.95
93	Education and research	0.00	837.20	837.20	.52	123.92	.22	2.75
94	Health and social service	0.00	1069.50	1069.50	1.07	144.57	.41	3.56
95	Other public services	0.00	239.20	239.20	.50	139.86	.26	1.77
	Private households	0.00	6909.20	6909.20	N/A	N/A	N/A	N/A
	Total	25050.34	82980.20	108030.54	N/A			
	Manufacturing (-refining)	25050.34	28477.10	53527.44	2.55			3.98

TABLE B.12. COST OF POLICY 2R.

(MC1 = 2300.00 NOK PR TON SO_2, MC2 = 5000.00 NOK PR. TON SO_2)

#	Sector	REDUCTION IN SO_2 EM. (Tons)	CONTROL COST 1 (1000 NOK)	CONTROL COST 2 (1000 NOK)	CONTROL COST (1000 NOK)	AVERAGE COST (1000 NOK)	g (Percent Increase)	TV42* 100	PF (Percent Increase)	TV42*H
11	Agriculture	0.00	0.00	0.00	0.00	N/A	0.00	100.00	0.00	.32
12	Forestry	0.00	0.00	0.00	0.00	N/A	0.00	100.00	0.00	1.80
13	Fishing and hunting	0.00	0.00	0.00	0.00	N/A	0.00	100.00	0.00	.10
31	Mining and quarrying	885.38	1600.06	948.48	2548.54	2878.49	1.86	312.36	1.38	2.77
16	Manufacture of food	4365.98	7889.92	4677.90	12567.82	2878.58	3.22	279.55	2.27	5.10
17	Beverages and tobacco	300.64	543.26	322.20	865.46	2878.72	2.73	244.37	1.66	4.71
18	Textiles, wearing apparel	242.62	438.38	260.10	698.48	2878.90	2.34	187.34	1.41	5.17
26	Wood products	508.04	918.16	544.20	1462.36	2878.43	1.96	181.24	1.14	4.48
34	Paper and pulp	1784.21	3810.93	636.42	4447.36	2492.62	1.52	277.86	1.20	2.40
37	Industrial chemicals	982.43	2096.95	353.58	2450.53	2494.35	.82	190.75	.55	1.73
40	Refineries	0.00	0.00	0.00	0.00	N/A	N/A	N/A	N/A	N/A
27	Chemicals and minerals	1735.95	3343.06	1412.21	4755.28	2739.30	1.18	186.45	.87	2.57
43	Metals	1481.41	3185.10	482.90	3668.00	2476.03	2.06	246.72	1.45	3.51
45	Metal products, machinery	531.28	960.02	569.40	1529.42	2878.74	.88	154.62	.50	2.53
50	Construction of ships etc	133.94	241.96	143.70	385.66	2879.35	.53	132.14	.29	2.21
28	Printing and publishing	12.56	22.54	13.80	36.34	2893.31	.21	112.12	.04	2.01
72	Electricity production	0.00	0.00	0.00	0.00	N/A	0.00	100.00	0.00	3.00
73	Electricity distribution	0.00	0.00	0.00	0.00	N/A	0.00	100.00	0.00	2.25
55	Construction	0.00	0.00	0.00	0.00	N/A	0.00	100.00	0.00	1.28
81	Wholesale & retail trade	0.00	0.00	0.00	0.00	N/A	0.00	100.00	0.00	-1.67
64	Drilling for oil and gas	0.00	0.00	0.00	0.00	N/A	0.00	100.00	0.00	4.45
68	Production of oil and gas	0.00	0.00	0.00	0.00	N/A	0.00	N/A	0.00	N/A
60	Ocean transport	0.00	0.00	0.00	0.00	N/A	0.00	100.00	0.00	.68
74	Domestic transport	0.00	0.00	0.00	0.00	N/A	0.00	100.00	0.00	.59
82	Financing, insurance	0.00	0.00	0.00	0.00	N/A	N/A	N/A	N/A	N/A
83	Housing services	0.00	0.00	0.00	0.00	N/A	N/A	N/A	N/A	N/A
79	Repair	0.00	0.00	0.00	0.00	N/A	0.00	N/A	0.00	N/A
84	Other private services	0.00	0.00	0.00	0.00	N/A	0.00	100.00	0.00	.32
91	Public administration	0.00	0.00	0.00	0.00	N/A	0.00	100.00	0.00	.91
92	Defence	0.00	0.00	0.00	0.00	N/A	0.00	100.00	0.00	.41
93	Education and research	0.00	0.00	0.00	0.00	N/A	0.00	100.00	0.00	2.22
94	Health and social service	0.00	0.00	0.00	0.00	N/A	0.00	100.00	0.00	2.46
95	Other public services	0.00	0.00	0.00	0.00	N/A	0.00	100.00	0.00	1.26
	Private households	0.00	0.00	0.00	0.00	N/A	N/A	N/A	N/A	N/A
	Total	12964.43	25050.34	10364.90	35415.25	2731.72	N/A			
	Manufacturing (-ref.)	12964.43	25050.34	10364.90	35415.25	2731.72	1.68			3.11

TABLE B.13. COST OF POLICY 2T.

(SO_2 TAX = 5000.00 MC1 = 2300.00 MC2 = 5000.00 NOK PR. TON SO_2)

#	Sector	CONTROL COST (1000 NOK)	TAX (1000 NOK)	TOTAL (1000 NOK)	g (Percent) (Increase)	TV42*100	PF (Percent) (Increase)	TV42*H
11	Agriculture	0.00	7125.00	7125.00	1.78	647.89	1.24	2.11
12	Forestry	0.00	330.00	330.00	.97	155.01	.60	2.78
13	Fishing and hunting	0.00	13340.00	13340.00	2.57	2768.74	1.92	2.67
31	Mining and quarrying	2548.54	3578.12	6126.66	4.48	610.50	3.33	5.41
16	Manufacture of food	12567.82	14050.10	26617.92	6.82	480.28	4.81	8.77
17	Beverages and tobacco	865.46	1031.80	1897.26	5.99	416.49	3.64	8.04
18	Textiles, wearing apparel	698.48	876.90	1575.38	5.29	296.98	3.18	8.19
26	Wood products	1462.36	1999.80	3462.16	4.63	292.34	2.70	7.22
34	Paper and pulp	4447.36	7064.94	11512.30	3.95	560.40	3.10	4.85
37	Industrial chemicals	2450.53	4520.84	6971.37	2.32	358.18	1.56	3.26
40	Refineries	0.00	0.00	0.00	N/A	N/A	N/A	N/A
27	Chemicals and minerals	4755.28	7555.26	12310.53	3.04	323.81	2.25	4.46
43	Metals	3668.00	6862.97	10530.97	5.92	521.25	4.18	7.42
45	Metal products, machinery	1529.42	2808.60	4338.02	2.49	254.93	1.41	4.17
50	Construction of ships etc	385.66	975.30	1360.96	1.87	213.41	1.03	3.58
28	Printing and publishing	36.34	217.20	253.54	1.49	184.54	.29	3.32
72	Electricity production	0.00	0.00	0.00	0.00	100.00	0.00	3.00
73	Electricity distribution	0.00	0.00	0.00	0.00	100.00	0.00	2.25
55	Construction	0.00	4890.00	4890.00	4.12	425.97	1.82	5.45
81	Wholesale & retail trade	0.00	6485.00	6485.00	1.14	33.15	.68	-.55
64	Drilling for oil and gas	0.00	0.00	0.00	0.00	100.00	0.00	4.45
68	Production of oil and gas	0.00	0.00	0.00	0.00	N/A	0.00	N/A
60	Ocean transport	0.00	0.00	0.00	0.00	100.00	0.00	.68
74	Domestic transport	0.00	57685.00	57685.00	5.01	948.30	2.22	5.64
82	Financing, insurance	0.00	0.00	0.00	N/A	N/A	N/A	N/A
83	Housing services	0.00	0.00	0.00	N/A	N/A	N/A	N/A
79	Repair	0.00	560.00	560.00	40.04	N/A	1.50	N/A
84	Other private services	0.00	3870.00	3870.00	1.02	422.47	.39	1.34
91	Public administration	0.00	385.00	385.00	.22	124.06	.07	1.13
92	Defence	0.00	4130.00	4130.00	3.35	926.11	.82	3.77
93	Education and research	0.00	1820.00	1820.00	1.13	152.00	.47	3.37
94	Health and social service	0.00	2325.00	2325.00	2.33	196.89	.89	4.85
95	Other public services	0.00	520.00	520.00	1.08	186.65	.56	2.36
	Private households	0.00	15020.00	15020.00	N/A	N/A	N/A	N/A
	Total	35415.25	170026.82	205442.07	N/A			
	Manufacturing (-refining)	35415.25	51541.82	86957.07	4.14			5.60

TABLE B.14. DATA FOR POLICY COSTS.

#	Sector	EXPENDITURE ON FUEL OIL EXCL GASOLINE (Mill.NOK)	HV42 (Percent)	LAMBDA42	FUEL OIL SHARE	AVERAGE FUEL PRICE (NOK)	F 1983 (Mill.NOK)
11	Agriculture	400.53	.32	.70	.70	2724.69	574.10
12	Forestry	33.99	1.80	.61	.62	3090.39	54.70
13	Fishing and hunting	519.57	.10	.75	.75	1356.57	694.20
31	Mining and quarrying	136.72	.88	.74	.74	2170.10	183.90
16	Manufacture of food	390.47	1.82	.69	.70	2133.72	553.70
17	Beverages and tobacco	31.67	1.93	.60	.61	2111.39	52.10
18	Textiles, wearing apparel	29.79	2.76	.58	.60	1752.44	49.60
26	Wood products	74.70	2.47	.57	.58	2075.05	128.40
34	Paper and pulp	291.64	.86	.78	.78	2580.90	371.80
37	Industrial chemicals	299.82	.91	.66	.67	1420.95	447.70
40	Refineries	N/A	N/A	N/A	N/A	N/A	0.00
27	Chemicals and minerals	404.34	1.38	.73	.74	2930.00	548.00
43	Metals	178.01	1.42	.70	.71	1508.55	252.10
45	Metal products, machinery	174.10	1.63	.56	.56	2637.84	308.30
50	Construction of ships etc	72.80	1.68	.54	.55	2206.11	132.50
28	Printing and publishing	16.99	1.80	.19	.20	2427.64	86.50
72	Electricity production	16.60	3.00	.81	.84	2678.37	19.80
73	Electricity distribution	9.80	2.25	.08	.08	2578.94	127.50
55	Construction	118.81	1.28	.44	.44	786.82	268.80
81	Wholesale & retail trade	570.23	-1.67	.61	.60	3017.10	949.40
64	Drilling for oil and gas	72.70	4.45	.40	.42	1135.96	174.40
68	Production of oil and gas	9.00	0.00	.87	.87	48.91	10.30
60	Ocean transport	176.32	.68	.64	.64	722.64	275.30
74	Domestic transport	1151.02	.59	.44	.44	1190.30	2601.50
82	Financing, insurance	0.00	0.00	0.00	0.00	N/A	234.50
83	Housing services	0.00	0.00	0.00	0.00	N/A	15.70
79	Repair	1.40	0.00	.04	.04	87.42	37.30
84	Other private services	380.50	.32	.38	.39	3367.25	984.40
91	Public administration	176.60	.91	.33	.33	14716.25	528.00
92	Defence	123.39	.41	.24	.24	1233.94	506.30
93	Education and research	161.20	2.22	.41	.42	2878.52	384.00
94	Health and social service	99.88	2.46	.37	.38	1406.78	261.50
95	Other public services	48.01	1.26	.52	.52	2526.91	91.90
	Private households	N/A	N/A	N/A	N/A	N/A	
	Total	N/A					11908.20
	Manufacturing (-refining)	2101.06	1.40		.67		3114.60

References.

Alfsen, K. H. and S. Glomsrød (1986a): Future emissions to air in Norway: Forecasts based on the macroeconomic model MSG-4E. To be published in Statistical Journal of United Nations.

Alfsen, K. H. and S. Glomsrød (1986b): Virkninger av lavere oljepriser på framtidige utslipp til luft. Internt Notat 86/36, Central Bureau of Statistics of Norway.

Alfsen, K. H, S. Glomsrød, and B. Vigerust (1986a): Gjennomgang av metode og data for fremskrivninger av utslipp til luft. Report in the series "Naturressurser og Samfunn", NTNF, Oslo.

Alfsen, K. H., S. Glomsrød and D. A. Hanson (1986b): A tax approach to SO_2 emissions reduction: Direct and indirect effects. Paper presented at IAEE 8th International Conference, Tokyo, 5-7 June, 1986.

Baumol, W. J. and W. E. Oates (1975): The theory of environmental policy; externalities, public outlays, and the quality of life. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Bergan, R. and Ø. Olsen (1985): Eksporttilpasning i MODAG A. Rapporter 85/29, Central Bureau of Statistics of Norway.

Berndt, E. R. and D. W. Wood (1979): Engineering and econometric interpretation of energy - capital complementarity, merican Economic Review, Vol. 69.

Bjerkholt, O., S. Longva, Ø. Olsen and S. Strøm (eds.)(1983): Analysis of supply and demand of electricity in the Norwegian economy. Samfunnsøkonomiske Studier no. 53, Central Bureau of Statistics of Norway.

Economic Commision for Europe (ECE) (1985): Protocol to the 1979 convention on long-range transboundary air pollution on the reduction of sulphur emissions or their transboundary fluxes by at least 30 per cent. ECE/EB.AIR/12.

Glomsrød, S. and B. Vigerust (1985): Luftforurensninger og økonomisk vekst, Økonomiske Analyser, no. 8, Central Bureau of Statistics of Norway.

Glomsrød, S. and B. Vigerust (1986): Luftforurensninger og økonomisk vekst. Proceedings of The Clean Air Conference, 1986 in Stavanger.

Governmental report no. 83, 1984 - 1985: Long-term programme 1986 - 1989. Ministry of Finance.

Hanson, D. A., and K. H. Alfsen (1986): Why SO_2 emissions taxes are an unpopular policy instrument: Simulation results from a general equilibrium model of the Norwegian economy. Paper submitted to the Eighth Annual IAEE North American Conference, Boston, Massachucetts, November 19-21. 1986.

Henriksen, J. F., S. E. Haagenrud, and F. Gram (1981): Innvirkning av påbud om lavsvovlig olje på atmosfærisk korrosjonskostnader. NILU oppdragsrapport no. 17/81, Lillestrøm.

Longva, S., L. Lorentsen and Ø. Olsen (1985): The multi-sectoral growth model MSG-4. Formal structure and empirical characteristics. In Planning, Multi-sectoral Growth and Production. Essays in honour of Professor Leif Johansen, North-Holland Publishing Company, Nederland.

Statens forurensningstilsyn (1982): Luftforurensning. Virkninger på helse og miljø. SFT-rapport no. 38.

Vigerust, B. (1986): Energibruk og luftforurensninger. Metode for beregning av utslipp til luft med utgangspunkt i ressursregnskap for energi. 1976 - 1983. Interne Notater 86/33, Central Bureau of Statistics of Norway.

Vogt, T. (1986): Vannkvalitet og helse - analyse av en mulig sammenheng mellom aluminium i drikkevann og aldersdemens. Social and economic studies no. 61, Central Bureau of Statistics of Norway.

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