Discussion Paper

Central Bureau of Statistics, P.B. 8131 Dep, 0033 Oslo 1, Norway

No. 48

April 1990

Stabilization of emissions of CO_2: A computable general equilibrium assessment

Solveig Glomsrød, Haakon Vennemo and Torgeir Johnsen *

Abstract

Using a multisector applied general equilibrium model, the paper studies economic development perspectives in Norway under limits to emissions of carbon dioxide (CO_2). A wide range of effects are discussed, including impacts on main macroeconomic indicators and economic growth, sectoral allocation of production, labour and capital, and effects on the market for energy. We also assess the impact on emissions of other pollutants than CO_2, and finally the related impact on health, nature and materials.

The results indicate that CO_2 emissions might be stabilized in Norway without dramatically reducing economic growth. Sectoral allocation effects are much larger. A substantial reduction is found in other emissions to air than CO_2, yielding considerable benefits.

---

*Central Bureau of Statistics. P.B. 8131 Dep, 0033 Oslo 1, Norway. Thanks to Knut Alfsen, Vidar Christiansen, Rolf Golombek and Lorents Lorentsen for comments on an earlier draft.

1 Introduction.

Limits to carbon dioxide (CO_2) emissions seem to be an important element in future strategies to combat the greenhouse effect, as CO_2 contributes about 50 percent to global warming at present. Like many other important air pollutants, CO_2 emissions mainly stem from combustion of fossil fuels. But unlike most others, CO_2 can not be treated or removed by economically viable means. Thus, only limiting the consumption of fossil fuels remains as a control strategy. There seems to be an interest in the macroeconomic impact of such a strategy, for instance to what extent it hampers economic growth. Hesitation by industrial countries in implementing policies reducing CO_2 emissions indicate that it is suspected to do so. On the other hand, the World Commission on Environment and Development (1987) advocated more rapid growth as a precondition for control of the environment. The basis for its conclusion is vague, however, as the Commission had no consistent framework for studying growth and development under considerably stricter environmental control.

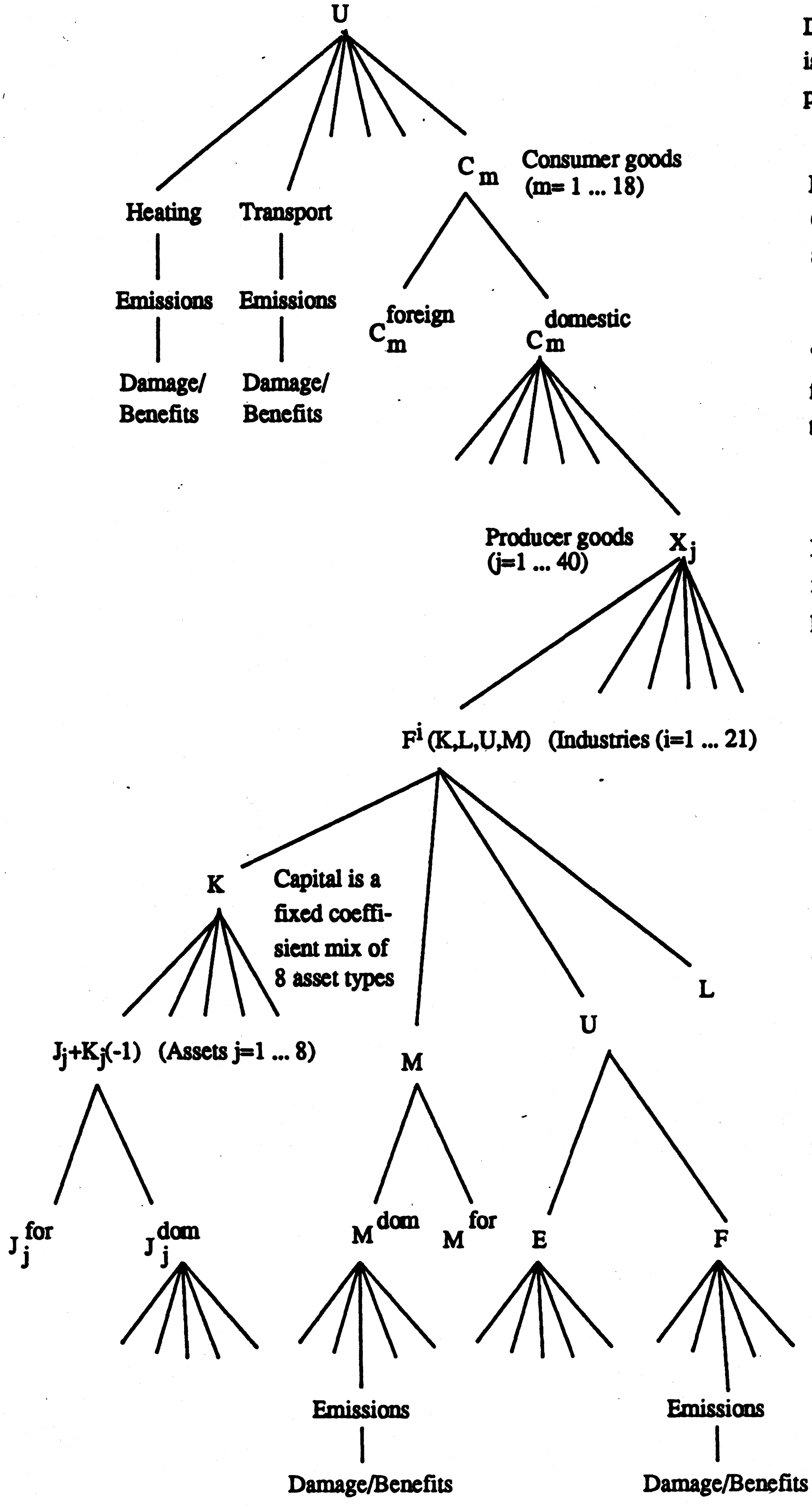
In this paper we study effects of a limit to CO_2 emissions in Norway. These include effects on main macroeconomic indicators and economic growth, sectoral allocation of production, labour and capital, and the effects on the market for energy. We also assess the impact on emissions of other pollutants than CO_2, and finally the related impact on health, nature and materials. The limit to CO_2 emissions is assumed effective from year 2000, according to one proposal for a national policy target in following up the recommendations of the Brundtland Commission.

To measure the impact of CO_2 limitations we utilize an estimated applied general equilibrium model called MSGTAX. The model is an extended and modified version of the Norwegian planning model MSG-4E, which for several years has been used by the Ministry of Finance of Norway to project future production and consumption of energy, as well as providing macroeconomic perspectives.

CO_2 limitations are implemented in the model by making the total use of fossil fuels exogenous. The model determines the price of fuel consistent with such carbon dioxide control. The difference between the cost of fuel production and fuel price may be interpreted as a fuel consumption tax.

The impact of fuel use on climate is not internalized in the model of the Norwegian economy. This is simply because Norway has 0.1 per cent of the world population and contributes 0.2 per cent of total CO_2 emissions. The effects on the global climate of a unilateral control policy in Norway must necessarily be small. The introduction of a CO_2 limit is politically motivated, intended to encourage collective global action. Hence, the focus of the paper is on the economic impact of introducing a certain control policy.

Figure 1. A diagrammatic summary of the model



Demand for consumption goods is a log-linear function of prices and income

Each consumption good is a CES-aggregate of a foreign and domestic variety.

The domestic variety is a fixed coeffisient mix of the 40 producer goods

Each producer good is a fixed coefficient mix of production in 31 industries

Gross production is a c.r.s. function of capital (K), labour (L), energy (U) and material inputs (M). The cost functions are Generalized Leontief. (Ten industries, incl. public production, have fixed coefficients.)

Energy is a c.r.s. function of fuel (F) and electricity (E). The cost functions are Generalized Leontief

E, F and the domestic varieties of J and M are fixed coeffisient mixes of the 40 producer goods.

Emissions to air of SO2, NOx, CO, CO2, VOC, Pb and particulates are calculated on the basis of fuel use and industrial process activity.

Section 2 of this paper presents the framework of the empirical study of CO_2 control, including a description of the model reference scenario. The results of the simulations are presented in sections 3, 4 and 5. Section 6 concludes and gives some directions for future research.

Studies of environmental taxes and control policy based on applied general equilibrium models have been carried out in Norway since 1986. In Alfsen, Hanson and Glomsrød (1986) the impact of introducing a tax on SO_2 emissions from manufacturing industries was studied. The conclusion was that allocation effects amounted to twice the direct costs of higher fuel bills and cleaning expences. Thus it was clearly indicated that a general equilibrium approach to studies of environmental control policy is important. A broad study of economic growth, industrial development and the environment initiated by 4 ministries, was carried out in 1989 (Bye et al. 1989) It showed that CO_2 emissions may be stabilized around year 2000 at the 1987 level by means of a switch in the tax system. A fuel tax of 75 per cent was introduced, and income taxes were lowered to balance the budget. The restructuring of the tax system had a relative moderate impact on economic growth. The level of GDP turned out to be 1-2 per cent lower than the reference scenario in 2000.

More recently, applied general equilibrium models have been used in similar studies by Bergman (1989), Jorgensen and Wilcoxen (1989) and Uri and Boyd (1989).

2 Model structure and reference scenario.

2.1 Structure of the model MSGTAX.

The model MSGTAX is a modification of the fourth version of the Norwegian planning model MSG. A first version of the model was constructed by Leif Johansen, see Johansen (1960) and (1974). Documentations of the fourth version are given in Longva, Lorentsen and Olsen (1985) and Offerdal, Thonstad and Vennemo (1987). The MSG model is an estimated applied general equilibrium model of the Norwegian economy. It has traditionally been used as a tool in long term economic planning, with special focus on sectoral development.

Figure 1 gives a diagrammatic summary of MSGTAX. Starting at the top, there are N identical consumers in the model. Private consumption is distributed on 18 consumption goods according to a log-linear system, with extensions to allow for non-zero "want-elasticities" (*cf.* Frisch (1959) or Bjerkholt and Rinde (1983)) in heating and transport. The system, which is non-homothetic, is estimated on National Accounts data 1962-78 (Bjerkholt and Rinde 1983).

As the model adopts the Armington approach to foreign trade, each consumption good is a composite of domestic and foreign varieties. The foreign share in the composite is a function of the relative price of the foreign variety versus the domestic variety. The foreign share rises if the relative price of the foreign variety falls. A CES-price index describes the substitution possibilities. The elasticity of substitution between domestic and foreign shares is estimated on National Accounts data 1970-87 (Svendsen (1990)). Exports, which are not included in figure 1, are for important goods functions of relative prices of domestic versus world market prices and of world market indicators. The price and market elasticities are estimated on a 1968-1987 data set (Lindquist (1990)). The current account (in current prices) is exogenous in the model.

Each domestically produced variety is a fixed coefficient mix of the 40 model goods, with the coefficients taken from the National Accounts of the base year 1986. The domestic varieties are produced in 31 sectors of production, 21 of which have endogenous behaviour. Each sector produces several of the goods, again according to a 1986-based fixed coefficient mix. One output is singled out as a "main" output.

Production behaviour is modelled in dual terms by Generalized Leontief (GL) cost functions which derivatives have the following form:

$$Z_{ji} = e^{-\varepsilon_i t}\left(c^i_{jj} + \sum_{r\neq j} c^i_{jr}\left(p_{ri}/p_{ji}\right)^{1/2}\right) \qquad (1)$$

j, r = labour, capital, material inputs, energy.

Z_{ji}: unit input of j in sector i

ε_i: rate of Hicks-neutral technical change in sector i

p_{ji}: price of input j in sector i

c^i_{jr}: coefficients

The model of producer behavior contains an element of two stage budgeting. At the "top" level there are four input factors, labour, real capital, material inputs and energy. At the "bottom" level demand for energy is further divided into electricity and fuels according to a GL-subfunction.

All factors (including capital) can be allocated across sectors without costs. Production is constant returns to scale and is subject to exogenous Hicks-neutral technological change. The model of producer behaviour allows for substitution between fuels, electricity, material inputs, capital and labour. The parameters of substitution are estimated using national accounts data 1962-81 (Bye and Frenger (1985)).

Four of the five input factors are produced. This provides a "downwards" link with the rest of the model. Both investment (in each asset) and material inputs are composites of foreign and domestic varieties. The domestic varieties of investment and material inputs are fixed coefficient mixes of the 40 commodities. The same, in principle, are electricity and fuels. In reality, electricity is made up of the single electricity good, and fuels consists of the three goods gasoline, fuel oils and possibly wholesale and retail trade (to take account of handling and service in some industries). These being produced goods, electricity and fuel inputs are linked to the total model as well. Fuel oils and gasoline are for instance produced in the petroleum refining sector (with crude oil as a predominant material input).

In the version of MSGTAX implemented here, both labour and capital are exogenous on a macro level. Investment takes place to compensate for depreciation and to meet exogenous changes in the capital stock over time.

In the base year of the model, all prices (except capital service prices and wages) are set equal to unity. This means that goods are measured in fixed base-year value terms. The two goods gasoline and fuel oil contain physical quantities of fuel. Separate equations in the model calculate these physical quantities and add them together. Total physical fuel quantities are endogenous in the reference scenario, but exogenous in the alternative scenario. As oil is the predominant type of fuel in use in all Norwegian industries, the level of carbon in fuel is equal for all end uses. Exogenous physical quantities of fuel therefore amounts to making emissions of CO_2 exogenous.[1].

Gasoline and fuel oil are used for fuel input, and directly in consumption. In the alternative scenario, fuel input and private consumption of gasoline and fuel oil are taxed. This tax, which may alternatively be interpreted as a price of tradable emission permits to be bought from the government, is an endogenous variable in the model in the alternative scenario (exogenous and equal to zero in the reference scenario). The tax revenue from the CO_2 is rebated in a lump sum fashion.

The model can be interpreted as a general equilibrium model with exogenous state variables. This makes the model fairly similar to a static model. However, the fact that capital is cumulated and depreciated slowly, the assumption of technical progress and the tradition of formulating realistic growth paths in important exogenous variables give the model a dynamic flavor.

Integrated in the model framework are submodels of emission to air (Alfsen,

---

[1] CO_2 process emissions from metal industry and cement productions are not supposed to be limited, neither are emissions from fuel wood combustion. The latter however represent no net CO_2 emissions when based on a sustainable forest yield.

Glomsrød and Vigerust 1986) and their impact on the environment (Brendemoen and Glomsrød 1989).

Emission to air of 7 different air pollutants (SO_2, NO_x, CO, Pb, VOC, CO_2 and particulates) are calculated based on projections of fuel use and industrial process activity from the main model. Emissions from stationary combustion, mobil combustion and industrial processes are treated separately. The model is adjusting for changes in emission technology expected from regulations already decided on.

The submodel for environmental costs is based on data from several studies of environmental damage and related cost, made by the State Pollution Control Authorities, Institute of Transport Economics and committees reporting to the Ministry of the Environment (SFT 1987, 1988). These cost estimates are linked to the specific emission components SO_2, NO_x, CO and particulates, and to indicators of traffic volume.

The environmental cost model calculates the difference between environmental costs between alternative development scenarios. This reflects the fact that complete cost functions are unknown, but that present knowledge contains considerable information on marginal environmental costs around the actual level of pollution. Consequently, the submodel may provide information of cost impacts within a limited range of emission variations only. Marginal costs are supposed to be constant within this range.

Benefits of CO_2 reductions are not included, but benefits from controling emissions of other pollutants causing local or regional damage are. Pollution costs included are acidification of lakes and forests, health effects and corrosion.

Pollution costs are external costs that are not paid by the polluters themselves. To a large extent polluting activities also impose other external costs on the society. This is so with traffic noise (also an environmental effect) and traffic accidents, road damage and efficiency loss during traffic congestion. In principle, these effects should be corrected for by means of separate pigouvian taxes. Consequently, they are included in the model to capture the effect that measures against CO_2 emissions may reduce other inefficiencies of polluting activities as well.

A reduction in traffic as well as pollution, will show up in increased efficiency and GDP growth, but this is not captured by the macroeconomic model available at present.

2.2 Description of the reference scenario.

The Norwegian economy depends heavily upon oil and gas production, which generate roughly 20 per cent of GDP and 30 per cent of total exports. Thus the world market oil price is of crucial importance to the Norwegian economy, besides being a determining factor behind the domestic consumption of fossil fuels in Norway. This makes the world market oil price one of the most important exogenous variables in the model. The nominal oil price is assumed to grow with an average yearly rate of about 5 percent in the period 1990 to 2010, reflecting a real price increase of around 1 per cent per year.

Electricity is only generated by hydro power. Electricity and fuel oils share 90 per cent of the total energy consumption between them. The price of electricity is not assumed to be influenced by the fuel constraint.

Assumptions of development in other important variables are close to the projections made by the Perspective Group (1988), engaged in work on long term economic planning of the Ministry of Finance. Experience with the MSGTAX model indicate that the levels of change in important endogenous variables seem to be fairly robust with respect to choice of reference scenario. Average growth rates in some important endogenous macroeconomic variables over the period 1986–2010 are given in table 1. GDP is assumed to keep an averaged yearly growth rate of 2.8 per cent. Investments increase by 3.7 per cent per year until the turn of the century. Then a considerable fall in oil investments occur, so that growth in average annual investments is as low as 0.1 per cent the following decade. Private consumption fell considerably during the end of the 1980's, keeping the averaged yearly growth rate 1986–2000 as low as 0.6 per cent. During the last decade of the scenario period, private consumption is assumed to grow faster than GDP.

Table 1. Macroeconomic development. Reference scenario.

	Level 1986. Bn NOK	Growth rate 1986-2000	Growth rate 2000-2010
GDP	514	2.9	2.7
Imports	213	1.8	2.6
Exports	195	4.2	3.1
Private consumption	278	0.6	4.3
Public consumption	102	2.0	2.0
Investments	152	3.7	0.1

3 Economic impacts.

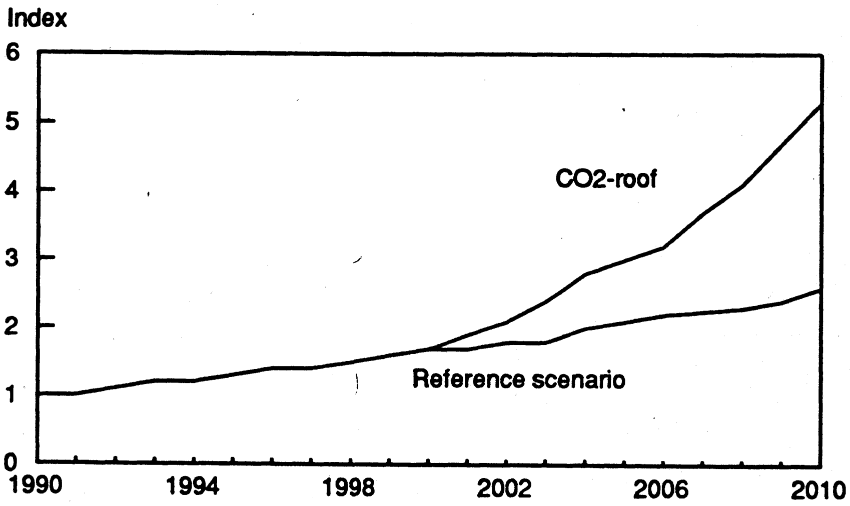
3.1 Tax on fuel input.

CO_2 emissions are assumed to be unrestricted until year 2000. The emission level in year 2000 is set as upper boundary of CO_2 emissions beyond the turn of the century.

Figure 2 illustrates the fuel price rise which is necessary to keep emissions below this future CO_2 limit. In the reference scenario, the fuel price equals the world market price. Under a CO_2 constraint, the fuel tax must make up the difference between world market price and purchaser price as shown in the figure. The tax reflects the potential increase in GDP if an additional unit of fuel were available. As it is positive, the question of whether a CO_2 tax hampers economic growth (*cf.* the introduction) should be resolved. The value of the tax also serves as an indicator of the marginal cost of a more ambitious environmental policy. If it is large, society stands to lose much production at the margin if the CO_2 constraint tightens. But if it is fairly small, so is the marginal cost of a more ambitious policy.

In fact, the tax on fuel is increasing over time. This is due to technological improvement in production sectors, and due to growth in labour and capital stock, making each fuel unit capable of generating more output.

Figure 2. Price of fuel oil. 1990=1



Technological improvement year by year leads to lower fuel input per unit produced. Thus, technological improvement represents a force which holds back the fuel demand and the willingness to pay for additional fuel input. But contrary to this direct effect of technological improvement, work other effects. First, for a given private consumption vector, technological improvements makes fuel and other produced inputs cheaper than the non-produced input, labor. This generates substitution of input demand towards fuel and other produced factors. Second, economic growth allowed for by the exogenous growth in labour and capital stocks increases the scale of production and consumption, and hence the demand for fuel also. In addition, the consumption vector changes with increasing consumption level. Consumption of fuel *intensive* goods like transport and heating increase their budget shares when income increases. All in all, these effects dominate the direct effect of higher fuel efficiency, and increases the general willingness to pay for fuel in the economy.

The fact that the fuel tax rises over time, indicates that taxation of fuels for environmental reasons may prove a stable source of income for the government. This runs contrary to the popular suggestion that tax revenues diminish because people change their consumption patterns, eroding the tax base.

In year 2010 the the fuel price must be roughly 100 per cent above the level in the reference scenario to succeed in keeping the CO_2 limit.

3.2 Effects on main macroeconomic variables.

In the reference scenario, the growth rate is constrained by technological improvement, the labour supply, capital supply and current account. These elements together roughly determine the growth rate of the economy, as all resources are assumed to be fully utilized.

Introducing CO_2 stabilization as an additional constraint on the economy necessarily leads to a lower total output. The question is how deep the allocation effects of CO_2 stabilization dig into the growth generating capacity of given resources and technological improvement. The steep rise in fuel prices implies a considerable loss at the margin. On the other hand, the increase over time in willingness to pay for fuel indicates that the output must still grow strongly under the CO_2 constraint.

Measured in 1986 fixed prices, the level of GDP in year 2010 turns out to be 2.7 per cent lower in the CO_2 scenario. The annual growth rate 2000-2010 is reduced from 2.7 per cent to 2.3 per cent. The accumulated effect of this is certainly important, but on the other hand the generation of goods and services is not showing sign of unbearable stress either. The level of GDP in the alternative scenario in 2010 is after all 88 per cent above the 1986 level, and 25 per cent above the 2000 level. We find the explanation for the limited impact on growth potential in relative low cost shares of fuel, and in the fact that substitution of fuel for other input factors in production dampens the cost increase. Intuitively, the greater the possibilities for substitution, the less harm is done by restricting the input.

Export is the element of total demand which is reduced the most compared to the reference scenario. This is despite increasing export of oil, as the world market for oil is assumed to receive the crude oil that Norway produces, but no longer demands. This assumption may be reasonable as long as no other country introduces similar measures against CO_2. The more traditional export sectors are facing a considerable shrinkage in foreign sale. This is because their costs and product prices are increasing.

The combination of a fall in export volume plus a rise in export prices makes import volumes fall somewhat less than exports. Thus the supply of goods and services for domestic consumption is somewhat sheltered, protecting private consumption from falling as much as other macro-economic variables.

The fall in investment outlays is due to a switch in the asset mix of capital from short lived machinery to long lived buildings. The housing sector in particular increases its capital stock, inducing more builings in the aggregate capital mix. Thus it takes less (gross) investment to meet the exogenous year by year increases in capital. The decrease in investment also contributes to private consumption falling less than production.

Table 2 shows the percentage changes in main components of GDP, measured in constant 1986 prices.

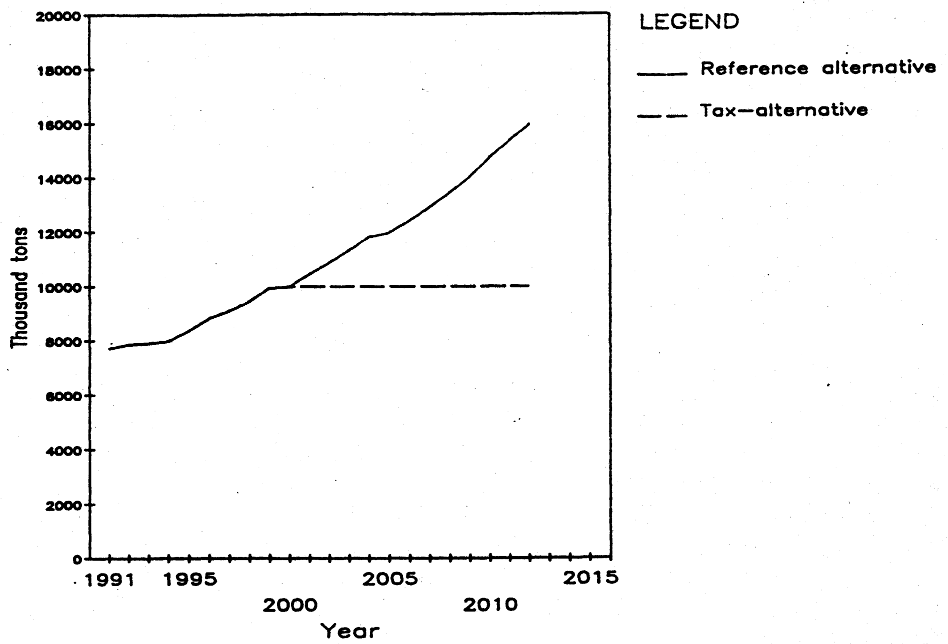
Table 2. Changes in main macroeconomic variables from a stabilization of CO_2. Per cent.

	2010
GDP	-2.7
Import	-4.1
Export	-6.8
Private consumption	-0.9
Investments	-1.3

3.3 Effects on use of energy.

From figure 3 it is seen that the level of fuel consumption is stabilized by year 2000 at a level which is roughly 20 per cent higher than today's level. The fuel price must more than double to keep the CO_2 constraint in 2010. More precisely, the fuel price will have to increase 107 per cent in production sectors and 130 per cent in the household sector.

Figure 3. Use of oil in the two alternatives



While GDP in 2010 is 2.7 per cent lower under CO_2 constraint, consumption of electricity in industries is 8 per cent lower. Producers all in all respond to the increase in fuel price by reducing both fuel use and electricity consumption (see table 3). Thus fuel and electricity act as complementary input factors at an aggregate level. There are several reasons for this. We will indicate some:

Some industries have limited substitution possibilities. This is so for industrial chemicals for instance, where oil input acts as a raw material. In some sectors, like the service sectors, a considerable share of fuel consumption consists of transport oil, a reason why service sectors do not increase their electricity consumption sharply. The fall in electricity demand also has to do with rising export prices and shrinking foreign markets. Important export industries, for example metals and

industrial chemicals are electricity intensive industries. As they adjust production to a considerably lower demand, the general production activity is switching towards less electricity intensive processes.

Input of fuel oil and gasoline measured in tons decrease by 30 and 35 per cent respectively (table 3). Households reduce consumption of heating fuel by 53 per cent in 2010, but compensate somewhat by a 17 per cent increase in demand of (hydro) electricity. Gasoline consumption by households is lowered by 36 per cent.

Net domestic consumption of electricity is reduced by 3.5 percent compared to the reference alternative.

Table 3. Effect on energy consumption[1]. Deviation from reference scenario. 2010. Per cent.

	Fuel price	Gasoline	Heating fuel	Electricity
Production sectors	107	-35	-30	-8
Households	130	-36	-53	17
Total		-35	-32	-3.5

1) Measured in physical units (tons, GWh).

3.4 Effects on industries.

Table 4 shows the impact on output and input factor use by sector. Manufacture of industrial chemicals and pulp and paper experience the sharpest fall in sector output, 33 and 21 per cent respectively. Both are exporting sectors, facing a reduction in exports of about 25 per cent, due to the increase in domestic price level.

The Pulp and paper industry substitutes towards a more capital and labour intensive production, while production of industrial chemicals has few such opportunities, reducing fuel use, capital input and output roughly by same proportions (a third).

Production of non-industrial chemicals and mineral articles is by far the biggest fuel consumer among manufacturing industries. It is also an important export sector, thus seeming particularly sensitive to fuel taxes. However, output is reduced by 15 per cent in 2010, less than in the two not so fuel intensive sectors mentioned above. Within this sector we also see other input factors substituted for fuel. Fuel use is reduced by 50 per cent, capital by 18 per cent, while labour input increases by 6 per cent. Substitution is mitigating the impact of rising costs upon output.

The housing sector is expanding by 8 per cent, leading to an increase of 6 per cent within construction, and a 2 per cent rise in production of timber and wood products.

When restricting the use of fossil fuels, a considerable reallocation of capital among sectors takes place. The restriction introduced implies that capital obtains a lower return when redistributed. The increased consumer housing demand is a reaction to lower capital costs. For the construction sector a fall in the wage level also contributes, as construction is a labour intensive industry.

The fact that the return to capital and the wage.rate fall, indicate that fuel and capital, and fuel and labor are complementary input factors in a macro perspective.

Electricity represents a negligible share of total cost in the construction industry. Behind the enormous relative increase in electricity consumption there is a minor increase in absolute terms.

In the wholesale and retail trade sector, there is a reduction of 60 per cent in fuel use, but only 7 per cent output reduction. This reflects that fuel make up a small share of productions costs (5 per cent), while labour represents roughly 40 per cent. Thus the this sector benefits considerably from the wage reduction taking place.

Table 4. Impact on output and factor input by sector. Deviation from reference scenario. 2010. Per cent.

	Output	Capital	Man-hours	Fuel	El.
Manufact. of food	0.3	1.4	1.9	-29.7	13.8
Manufact.of textiles	7.0	8.7	10.6	-24.1	27.5
Manufact. of timber and wood products	1.5	5.4	7.1	-59.6	-16.7
Manufact. of pulp and paper	-20.8	-10.4	-12.1	-53.0	-22.9
Manufact. of industrial chemicals	-33.3	-31.2	-0.5	-36.4	-36.4
Petroleum refining	-14.8	-14.8	-14.8	-	-14.8
Manufact of non-industrial chemical and mineral articles	-14.7	-18.4	5.7	-49.9	-36.1
Manufact. of metals	-6.1	-4.7	-2.1	-13.0	-13.0
Manufact. of metal products, machinery, ships, and oil platforms	-4.9	-0.1	-4.3	-39.8	12.7
Printing and publishing	-2.5	-1.1	-2.4	-43.1	54.7
Production of electricity	1.7	1.7	1.6	1.7	-
Construction	6.4	7.0	11.7	-18.8	4521.9
Wholesale and retail trade	-6.7	-9.2	-0.7	-60.7	-
Domestic transport	-5.3	-2.0	0.5	-31.4	-1.2
Finance and insurance	-4.4	0.3	-5.6	-4.4	-4.3
Housing	8.4	8.8	9.4	8.4	8.6
Other private services	-2.9	-0.3	-1.3	-29.9	-5.9

3.5 Effects on consumption activities.

The impact on the consumer demand pattern (see table 5) is explained by four main factors. First, a negative income effect tends to decrease consumption of all goods (as all income elasticities are positive in the model). This effect is small however, since aggregate consumption expenditure is reduced 0.9 per cent only. Second, a direct price effect on consumption of petrol and heating reduce these consumption activities by 36 and 56 per cent respectivly. Third, cross-price effects tends to increase consumption of the remaining goods. This effect dominates the income effect, and consumption of the majority of goods increases by 0-5 per cent. Exceptions include purchase of cars, which is complementary to petrol and car maintenance. Purchase of cars decreases by 24 per cent. Hydro electricity, which is alternative to heating fuel, increases by 17 per cent. Fourth, the reduced rate of return favour capital intensive consumer goods. Thus housing consumption increases despite the fact that housing is complementary to heating.

When measured in energy units (GWh), the total household use of energy for heating (heating fuels and electricity) is increasing by 7 per cent (table 6). This may be reasonable when seen in relation to the increase of 8 per cent in housing consumption. More housing capital means more space to be heated, expressed in the model by the assumption of complementarity between housing consumption and fuel.

Table 5. Change in household consumption by consumption activity. 2010. Per cent.

	2010
Foods	1.5
Beverages and tobacco	2.5
Electricity	17.3
Heating fuels	-55.6
Petrol and car maintenance	-35.6
Other goods	3.8
Clothing and footwear	1.8
Other houshold goods	2.5
Other recreation goods	4.4
Purchase of cars etc.	-23.7
Furniture and electrical equipment	4.7
Durable recreation goods	5.9
Housing	8.4
Public transport services	4.6
Medical care and health expenses	-
Public entertainment and education	4.3
Insurance and domestic services	2.1
Other services	2.4
Norwegians consumption abroad	6.1

Table 6. Energy consumption by household. 2010. TWh

	Reference case	CO_2-limit
Electricity	44.5	52.1
Heating fuels	7.1	3.3
Total	51.6	55.4

4 Effects on pollutants.

Figure 4 shows future CO_2 emission development. The emissions do increase slightly between 2000 and 2010 because industrial process emissions and household fuel wood combustion are unaffected by the control policy (see footnote page 5).

Figure 4. CO_2 emissions. 1990–2010

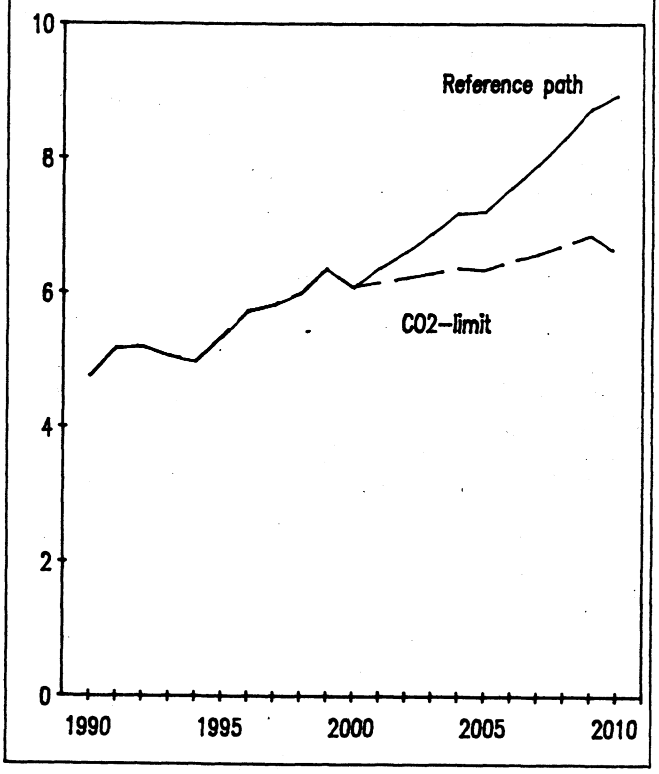


Figure 5. NOx emissions. 1990–2010

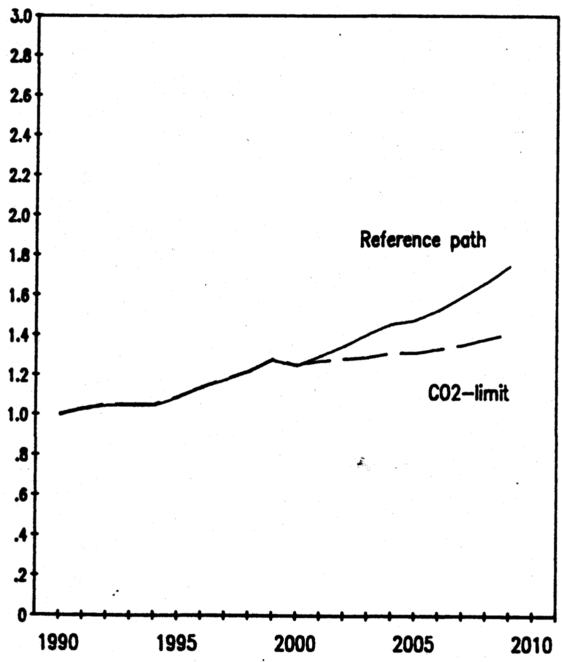


Figure 6. SO2 emissions. 1990–2010

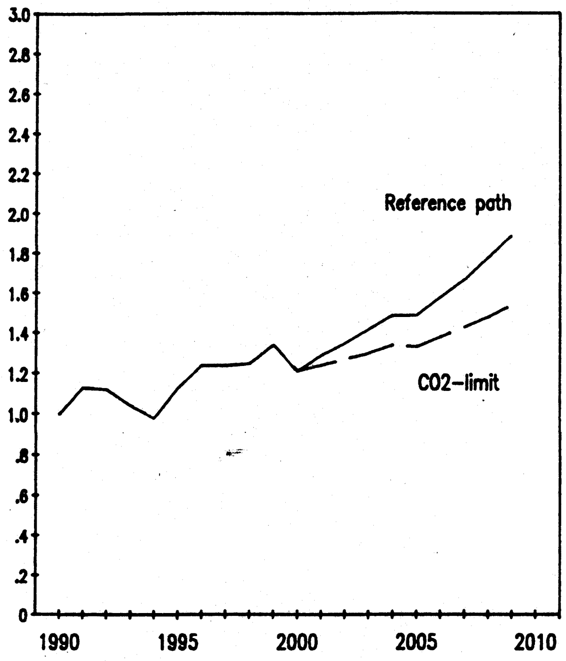


Figure 7. CO emissions. 1990–2010

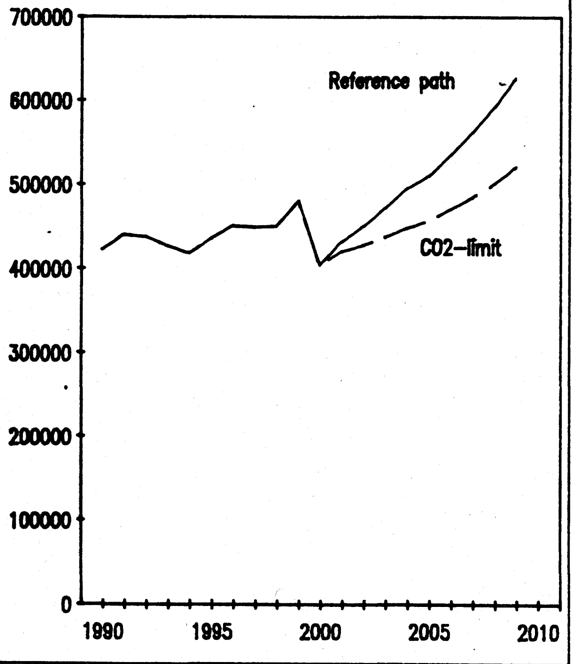
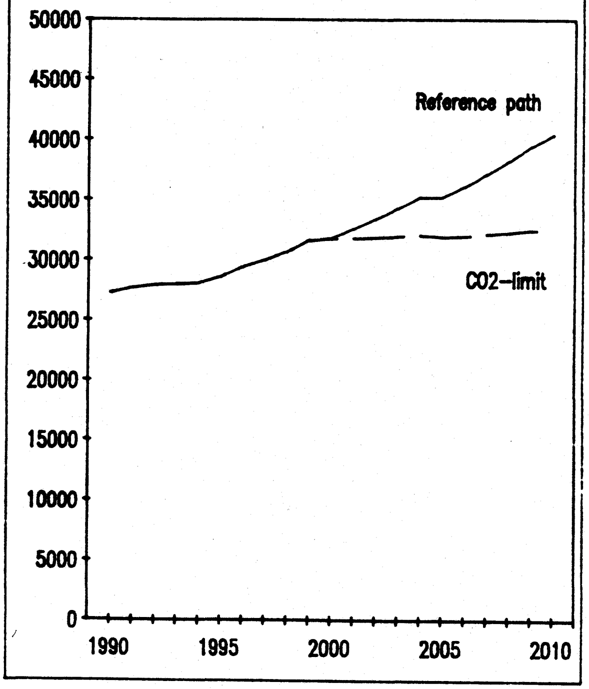


Figure 8. Emissions of particulates. 1990–2010



The CO_2 limit restricts use of fuel which is an important source of other air pollutants as well as CO_2. Hence an interesting aspect of CO_2 control is its contribution to solve those environmental problems also. Here we focus on emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO) and particulates, which also are forecasted by the model.

Deviations between emissions paths in the reference alternative and under CO_2 control are shown in figures 5-8. The reference case shows future emissions when control measures already decided on by the government are implemented. On average, emissions of other pollutants than CO_2 are reduced by about 20-25 per cent in 2010. This is an important byproduct of a policy aimed at curbing CO_2 emissions.

In Norway, control policies towards SO_2, NO_x, CO and particulates consist almost exclusivly of regulations enforcing end of pipe cleaning or investment in prosess improving technology. Benefits and costs of implementing such measures indeed depend upon to what extent fuel constraints already are effective. The emission forecast under the appropriate CO_2 constraint may establish a new benchmark for further control policies concerning SO_2, NO_x, CO and particulates.

5 Benefits from CO_2 control.

The macroeconomic study presented above indicates an income loss of 2.7 per cent of GDP or NOK 27 billion (1986-prices) in 2010. The benefits consist of lower contribution to global warming and of gains from lower emissions causing local damage upon health, nature and materials.

CO_2 is a harmfull greenhouse gas, but does not occur in concentrations that are directly harmful to the local surroundings. SO_2, NO_x, CO and particulates on the other hand cause local damage to people, nature and materials. However, NO_x and CO also play a role in the the greenhouse chemistry. NO_x reacts with methane, other hydrocarbons, or CO, producing tropospheric ozone which is a greenhouse gas, and also have impact on the concentration levels of other greenhouse gases. Per kilogram emitted, NO_x and CO are respectively roughly 16 and 4 times more effective greenhouse gases than CO_2 (Isaksen 1989). However, the scale of CO_2 emissions is 500-1000 times larger than CO and NO_x.

As explained in section 2, CO_2 control policy in Norway is primarily expected to have political significance. However, the CO_2 control policy creates considerable additional benefits on local and regional level. Table 7 lists the local benefits in 2010 that may be obtained from a CO_2 stabilization by year 2000.

Table 7. Benefits from emissions reductions. 2010. Billion 1986 NOK.

Forests and lakes		0.1
Health:		
	NO_x	6.7
	SO_2	0.5
	CO	0
	Particulates	0.4
Corrosion		0.2
Traffic accidents		2.7
Traffic congestion		2.9
Road damage		3.6
Noise		2.1
Total		19.1

Considerable health benefits are associated with reductions in NO_x emissions. These benefits include gains both from reduced sick leaves and increased efficiency during working hours, dimishining demand for health services and increased well-being from less respiratory illnesses of the urban population. Health impacts from reducing other emissions are relatively small. The reason is that pollution levels of other components are low, and marginal gains small compared with that for NO_x.

Benefits from reduced transport activity turn out to be considerable. These benefits are less noise, fewer accidents and less road damage, in addition to a considerable road traffic efficiency gain (less congestion).

Acidification causes high costs in Norway, but almost exclusivly stems from long range transboundary pollution. Thus the impact upon nature by domestic emissons reductions is small. The impact of domestic emissions reductions included here, is the value of increased forest growth and recreational gains from less acidification of soil and lakes.

The model is far from covering all environmental costs from air pollution. However, it has the ambition to capture the dominating elements of air pollution problems on a national scale, to provide rough estimates of environmental costs associated with different scenarios of economic development and pollution control.

6 Conclusions and directions for future research.

In this paper we have attempted to assess the effects of stabilizing CO_2 emissions in Norway by means of a tax on fuel oils. In our view the study has two main conclusions.

The first main conclusion is that macro effects are small when measured as percentage deviations from the reference scenario. A main reason for this is that the growth path in the economy by and large is determined by the growth in the labor force, the capital stock and the rate of technical progress, all of which are exogenous variables in the model. Because the economy is able to substitute away from fuel, restricting fuel consumption does not obstruct economic growth seriously.

In other words, the costs in terms of reduced production and material consumption of a strategy towards curbing growth in CO_2 emissions, are small, provided we organize the economy properly and fully utilize resources.

The marginal cost seems to have become fairly high by the year 2010, indicating that increasing environmental ambitions will be more costly. However, it is possible that the willingness to pay for environmental quality and insurance will increase as well with rising income level.

Stabilizing CO_2 emissions also gives additional benefits in terms of considerable reduction in other pollutants to air. This means the total cost of a CO_2 control policy is even smaller than the calculated loss in GDP would indicate. Our simulation indicates the benefits in terms of improvements of health conditions etc. to be roughly 2/3 of the calculated GDP loss.

The other main conclusion of the study is that the sectoral allocation effects from ten years of CO_2 control are much larger than the macro effects. At a sectoral level, society takes a quite different path of development with CO_2 control than without. This need not imply that the activity level falls drastically in any industry. The main implication is that certain growth trends are reduced.

Nevertheless, it may be that the great allocational differences between alternatives will cause concern in the most affected industries. This may motivate political pressure in the direction of relaxing CO_2 limits.

This study has overlooked several important aspects of CO_2 control policy. Perhaps most important, it is likely that the basic state variables in the economy, the capital stock and the net foreign debt will change as the economy restructures to a different (optimal) dynamic path. Such dynamic restructuring is not captured by the present model. Allowing for dynamic effects will presumably make the cost of CO_2 control lower than estimated in this study, as there is always the option of not changing the state variables, replicating the effects found here.

Another important neglected effect is fuel-specific technical change. The model does endogenously determine higher fuel efficiency, but only as a substitution effect in the cost functions. In addition to this effect, it is a reasonable guess that a (large) tax on CO_2 will initiate R&D investments directed at fuel-specific technical change. When such investments are profitable, they will work in the direction of reducing the harm of CO_2 control.

The benefits from reduced emissions of various pollutants have important links back into the main model. Improved health will improve labor productivity and reduce hospital expences, fewer traffic accidents will also reduce hospital expences, reduced road damage will reduce expences on road maintenance and less traffic congestion will reduce transport costs, to name the most important links. It is a reasonable speculation that including these links in the main model will increase productivity and the provision of private consumption goods, thus further reducing the welfare cost of CO_2 control.

In this study, introducing a tax on CO_2 means to introduce a new distorting tax, as benefits from CO_2 control are not included in the model. The CO_2 tax revenue is rebated to consumers in a lump sum fashion. In reality, if CO_2 becomes a large source of revenue for the government, there is reason to believe that CO_2 taxation will compensate for some other distorting taxes (for instance VAT). While in a second best world it is not generally true that the latter is a better reform than the former, it does seem likely!

The precise effects of the themes mentioned are left for further research. As a final point it is a natural extention of the present research to assess the consequences for the Norwegian economy of an international agreement to control CO_2 emissions. Such an agreement would presumably help traditional exports, which is badly hit in the present paper. Norwegian exports of gas is likely to be boosted also, as gas contains less carbon per energy unit than coal does.

REFERENCES

- **Alfsen, K.H., S. Glomsrød and B. Vigerust (1986):***Method for forecasting emissions to air.* Report of the research program "Natural resources and the society" (NTNF) (In Norwegian)

- **Alfsen, K.H., D.A. Hansen, and S. Glomsrød (1986):***Direct and indirect effects of reducing* SO_2 *emissions: Experimental calculations on the MSG-4E model.* Discussion Paper No. 20, Central Bureau of Statistics. Oslo.

- **Bergan, R. and Ø. Olsen (1985):***Export demand in MODAG A.* Rapporter 85/29. Central Bureau of Statistics. Oslo. (In Norwegian)

- **Bergman, L.(1989):***Energy, Environment and Economic Growth in Sweden: A CGE-Modeling Approach.* Stockholm School of Economics.

- **Bjerkholt, O and J. Rinde (1983):***Consumption demand in the MSG model.* In Bjerkholt, O., S. Longva, Ø. Olsen and S. Strøm (eds.): Analysis of supply and demand of electricity in the Norwegian economy. Samfunnsøkonomiske studier 53. Central Bureau of Statistics. Oslo.

- **Brendemoen, A.C., and S. Glomsrød (1989):***Benefits from environmental control policy.* (In Norwegian). Forthcoming report. Central Bureau of Statistics. Oslo. (In Norwegian)

- **Bye, B., T. Bye and L. Lorentsen (1989):***SIMEN: Studies of Industry, Environment and Energy towards 2000.* Discussion Paper no. 44. Central Bureau of Statistics. Oslo

- **Bye, T. and P. Frenger (1985):***Factor substitution, non-homotheticity and technical change in the Norwegian production sector.* Unpublished paper. Central Bureau of Statistics. Oslo.

- **Frisch, R. (1959):***A complete scheme for computing all direct and cross demand elasticities in a model with many sectors.* Econometrica, 27.

- **Isaksen, I.S.A. (1989):***Impact of air pollutants on the greenhouse effects.* Calculated climate coefficients of air pollutants. Unpublished paper. University of Oslo.

- **Johansen, L. (1960):***A multisectoral study of economic growth.* North-Holland.

- **Johansen, L. (1974):** *A multisectoral study of economic growth.* Second enlarged edition. North-Holland.
- **Jorgensen, D.W. and P.J. Wilcoxen (1989):** *Environmental regulation and U.S. economic growth.* Discussion paper series, Harvard University.
- **Lindquist, K.G. (1990):** Unpublished material. Central Bureau of Statistics. Oslo.
- **Longva, S., L. Lorentsen and Ø. Olsen (1985):** *The multi sectoral growth model MSG-4E.* Formal structure and empirical characteristics. In Førsund, Hoel and Longva (eds.): Production, multisectoral growth and planning. Contributions to economic analysis no 154. North Holland.
- **Offerdal, E., K. Thonstad and H. Vennemo (1987):** *MSG-4. A complete description of the system of equations.* Rapporter 87/14. Central Bureau of Statistics. Oslo
- **The Perspective Group (1988):** *The Norwegian economy in transition.* NOU (88/21), Ministry of Finance. (In Norwegian.)
- **State Pollution Control Authority (1987):** *Further reductions of air pollution in Oslo.* (In Norwegian.)
- **State Pollution Control Authority (1988):** *Reduction of air pollution and noise from road traffic in Sarpsborg/Fredrikstad.* (In Norwegian.)
- **Svendsen, I. (1990):** *The import submodel of MODAG and KVARTS.* Forthcoming report, Central Bureau of Statistics. Oslo. (In Norwegian.)
- **Uri, N.D. and R. Boyd (1989):** *The potential benefits and costs of an increase in US gasoline tax.* Energy Policy, august 1989.
- **World Commission on Environment and Developement (1987):** *Our common future.* Oxford University Press, Oxford, New York.

ISSUED IN THE SERIES DISCUSSION PAPER

No. 1 I. Aslaksen and O. Bjerkholt: Certainty Equivalence Procedures in the Macroeconomic Planning of an Oil Economy.

No. 3 E. Biørn: On the Prediction of Population Totals from Sample surveys Based on Rotating Panels.

No. 4 P. Frenger: A Short Run Dynamic Equilibrium Model of the Norwegian Prduction Sectors.

No. 5 I. Aslaksen and O. Bjerkholt: Certainty Equivalence Procedures in Decision-Making under Uncertainty: an Empirical Application.

No. 6 E. Biørn: Depreciation Profiles and the User Cost of Capital.

No. 7 P. Frenger: A Directional Shadow Elasticity of Substitution.

No. 8 S. Longva, L. Lorentsen, and Ø. Olsen: The Multi-Sectoral Model MSG-4, Formal Structure and Empirical Characteristics.

No. 9 J. Fagerberg and G. Sollie: The Method of Constant Market Shares Revisited.

No.10 E. Biørn: Specification of Consumer Demand Models with Stocahstic Elements in the Utility Function and the first Order Conditions.

No.11 E. Biørn, E. Holmøy, and Ø. Olsen: Gross and Net Capital, Productivity and the form of the Survival Function . Some Norwegian Evidence.

No.12 J. K. Dagsvik: Markov Chains Generated by Maximizing Components of Multidimensional Extremal Processes.

No.13 E. Biørn, M. Jensen, and M. Reymert: KVARTS - A Quarterly Model of the Norwegian Economy.

No.14 R. Aaberge: On the Problem of Measuring Inequality.

No.15 A-M. Jensen and T. Schweder: The Engine of Fertility - Influenced by Interbirth Employment.

No.16 E. Biørn: Energy Price Changes, and Induced Scrapping and Revaluation of Capital - A Putty-Clay Approach.

No.17 E. Biørn and P. Frenger: Expectations, Substitution, and Scrapping in a Putty-Clay Model.

No.18 R. Bergan, Å. Cappelen, S. Longva, and N. M. Stølen: MODAG A - A Medium Term Annual Macroeconomic Model of the Norwegian Economy.

No.19 E. Biørn and H. Olsen: A Generalized Single Equation Error Correction Model and its Application to Quarterly Data.

No.20 K. H. Alfsen, D. A. Hanson, and S. Glomsrød: Direct and Indirect Effects of reducing SO_2 Emissions: Experimental Calculations of the MSG-4E Model.

No.21 J. K. Dagsvik: Econometric Analysis of Labor Supply in a Life Cycle Context with Uncertainty.

No.22 K. A. Brekke, E. Gjelsvik, B. H. Vatne: A Dynamic Supply Side Game Applied to the European Gas Market.

No.23 S. Bartlett, J. K. Dagsvik, Ø. Olsen and S. Strøm: Fuel Choice and the Demand for Natural Gas in Western European Households.

No.24 J. K. Dagsvik and R. Aaberge: Stochastic Properties and Functional Forms in Life Cycle Models for Transitions into and out of Employment.

No.25 T. J. Klette: Taxing or Subsidising an Exporting Industry.

No.26 K. J. Berger, O. Bjerkholt and Ø. Olsen: What are the Options for non-OPEC Producing Countries.

No.27 A. Aaheim: Depletion of Large Gas Fields with Thin Oil Layers and Uncertain Stocks.

No.28 J. K. Dagsvik: A Modification of Heckman's Two Stage Estimation Procedure that is Applicable when the Budget Set is Convex.

No.29 K. Berger, Å. Cappelen and I. Svendsen: Investment Booms in an Oil Economy - The Norwegian Case.

No.30 A. Rygh Swensen: Estimating Change in a Proportion by Combining Measurements from a True and a Fallible Classifier.

No.31 J.K. Dagsvik: The Continuous Generalized Extreme Value Model with Special Reference to Static Models of Labor Supply.

No.32 K. Berger, M. Hoel, S. Holden and Ø. Olsen: The Oil Market as an Oligopoly.

No.33 I.A.K. Anderson, J.K. Dagsvik, S. Strøm and T. Wennemo: Non-Convex Budget Set, Hours Restrictions and Labor Supply in Sweden.

No.34 E. Holmøy and Ø. Olsen: A Note on Myopic Decision Rules in the Neoclassical Theory of Producer Behaviour, 1988.

No.35 E. Biørn and H. Olsen: Production - Demand Adjustment in Norwegian Manufacturing: A Quarterly Error Correction Model, 1988.

No.36 J. K. Dagsvik and S. Strøm: A Labor Supply Model for Married Couples with Non-Convex Budget Sets and Latent Rationing, 1988.

No.37 T. Skoglund and A. Stokka: Problems of Linking Single-Region and Multiregional Economic Models, 1988.

No.38 T. J. Klette: The Norwegian Aluminium industry, Electricity prices and Welfare,1988

No.39 I. Aslaksen, O. Bjerkholt and K. A. Brekke: Optimal Sequencing of Hydroelectric and Thermal Power Generation under Energy Price Uncertainty and Demand Fluctuations, 1988.

No.40 O. Bjerkholt and K.A. Brekke: Optimal Starting and Stopping Rules for Resource Depletion when Price is Exogenous and Stochastic, 1988.

No.41 J. Aasness, E. Biørn and T. Skjerpen: Engel Functions, Panel Data and Latent Variables, 1988.

No.42 R. Aaberge, Ø. Kravdal and T. Wennemo: Unobserved Heterogeneity in Models of Marriage Dissolution, 1989.

No.43 K. A. Mork, H. T. Mysen and Ø. Olsen: Business Cycles and Oil Price Fluctuations: Some evidence for six OECD countries. 1989.

No.44 B. Bye, T. Bye and L. Lorentsen: SIMEN. Studies of Industry, Environment and Energy towards 2000, 1989.

No.45 O. Bjerkholt, E. Gjelsvik and Ø. Olsen: Gas Trade and Demand in Northwest Europe: Regulation, Bargaining and Competition.

No.46 L. S. Stambøl and K. Ø. Sørensen: Migration Analysis and Regional Population Projections, 1989.

No.47 V. Christiansen: A Note On The Short Run Versus Long Run Welfare Gain From A Tax Reform, 1990.

No.48 S. Glomsrød, H. Vennemo and T. Johnsen: Stabilization of emissions of CO_2: A computable general equilibrium assessment, 1990.