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Knut H. Alfsen, Torstein Bye and Erling Holmøy (eds.)

MSG-EE: An Applied General Equilibrium Model for Energy and Environmental Analyses

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Statistisk sentralbyrå • Statistics Norway
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Abstract

Knut H. Alfsen, Torstein Bye and Erling Holmøy (eds.)

MSG-EE: An Applied General Equilibrium Model for Energy and Environmental Analyses

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The economic research activity of Statistics Norway has been directed to a considerable extent towards the development of operational tools for policy analysis and planning. Given the importance of various environmental problems in the current policy debate, perhaps with the so called greenhouse effect as the "front runner", it is not surprising that the development of economic models encompassing energy and environmental issues has been a prime concern for Statistics Norway.

This book presents some results from work carried out in this direction. The first part (chapter 1 to 3) describes the background and structure of an integrated economy–energy–environment general equilibrium model for the Norwegian economy called MSG-EE (Multi-Sectoral Growth – Energy and Environment). The second part (chapter 4-7) illustrates the use of the model for various policy analysis (understanding economic growth, carbon taxes, electricity markets and transport). Chapter 8 summarizes and concludes.

Keywords: General equilibrium, integrated economy-environment models, CO_2 taxation, transport modelling

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Sammendrag

Knut H. Alfsen, Torstein Bye and Erling Holmøy (red.)

MSG-EE: En anvendt generell likevektsmodell for energi- og miljøanalyser

Sosiale og økonomiske studier 96 • Statistisk sentralbyrå 1996

Et hovedsiktemål med forskningsvirksomheten i Statistisk sentralbyrå (SSB) er å utvikle operasjonelle verktøy for politikkanalyser og -planlegging til bruk for forvaltningen og andre. Med den rolle miljøspørsmål har fått i den politiske debatten, og kanskje særlig spørsmål knyttet til den såkalte drivhuseffekten, er det naturlig at utviklingen av integrerte økonomi-energi-miljø modeller har hatt høy prioritet i SSB. Denne studien rapporterer fra arbeidet med å utvikle en slik modell, kalt MSG-EE. Navnet står for "Multi Sectoral Growth – Energy and Environment".

Modellen skiller seg fra tidligere versjoner av MSG-modellen først og fremst ved en mer detaljert behandling av produksjon og etterspørsel av elektrisitet og transport. Elektrisitet kan i modellen produseres enten på basis av vannkraft, eller i termiske kraftverk basert på bruk av naturgass. Transporttjenester produseres i den sektoren som etterspør tjenesten (egentransport) og/eller kjøpes fra kommersielle transportselskaper (leietransport). Leietransporten er delt opp i vei-, sjø-, luft- og banetransport i tillegg til post og teletjenester.

Kapittel 1 gir en kort bakgrunn for arbeidet med modellutviklingen, mens kapittel 2 og 3 heholdsvis beskriver modellstruktur og empirisk forankring og utforming av modellen. Kapittel 4 viser langsiktige konsekvenser av den økonomiske veksten i Norge for energibruk og utslipp til luft. Kapittel 5 tar opp spørsmålet om kostnader ved reduksjoner i CO_2-utslipp, mens kapittel 6 analyserer markedet for elektrisitet i Norge under ulike regulerings- og avgiftsregimer. Kapittel 7 tar så opp enkelte sider ved transportutviklingen i et langsiktig makroøkonomisk perspektiv. Kapittel 8 avslutter med en kort oppsummering og noen konklusjoner for videre arbeid.

Emneord: Generell likevekt, integrerte økonomi-miljø modeller, CO_2 avgifter, kraftmarked, transportmodellering

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1. Introduction*

1.1 The problem

One of the main environmental problems of today is related to the man-made enhancement of the greenhouse effect, mainly caused by emission of so-called greenhouse gases. Chief among these are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and chloro-fluoro-carbons – CFCs for short. Being a wealthy, industrialized country, Norway has to take the responsibility for a reasonable part of the sacrifices necessary to reduce global problems. Although only accountable for some 0.2 per cent of the global CO_2 emissions, Norway has nevertheless been a fierce emissary in trying to promote a binding agreement on the reduction of greenhouse gases, at least from the industrialized countries. Since reductions in emission levels are suspected to be more expensive in Norway with electricity production based on hydro power than in most other countries, great weight has been put on formulating cost effective national and international policies. The elaboration of such policies may be made easier by the availability of suitable empirically based nummerical models incorporating essential elements of the working of the Norwegian economy and its interlinkages to energy markets and air pollution problems.

Local, regional and global air pollution problems are of course intimately connected. For instance, measures to control the emission of CO_2 will automatically reduce the emissions of local and regional air pollutants like sulphur dioxide (SO_2), nitrogen oxides (NO_x), cabon monoxide (CO) and particulate matter. This is so because the only economically viable means of reducing CO_2 emissions in the foreseeable future, is to reduce the combustion of fossil fuels - an important source for all air pollutants. Furthermore, changes in

*All the people working in the Research Department of Statistics Norway deserve thanks, both for directly providing support for the work and for keeping up a stimulating working environment. In particular we want to thank Birger Strøm for excellent computer work when the model was implemented and calibrated.

the use of fossil fuels will affect the demand for electricity, currently almost 100 per cent hydro power based in Norway.

Even the use of a clean energy resource like hydro power affects the environment, both through the impact construction of hydro power plants have on the local environment and indirectly by affecting the demand for the main substitute fuel for heating purposes – oil. Also, the remaining hydro power reserves in Norway are limited and further development is subject to decreasing returns to scale. Therefore, continuing economic growth and growth in the use of energy, combined with limited reserves of hydro power, may increase the price of hydro power relative to fossil fuels and thus boost the use of "dirty" fuels. The main alternative to hydro power seems to be electricity produced by use of natural gas ("gas power") which, although cleaner than oil and coal, is still a fossil fuel.

For these reasons, the energy markets are of prime concern in the formulation of sustainable policies in Norway, and this should be properly reflected in the development of analytical tools employed in the analyses of such policies. In this book we will describe one such tool; an empirically based computable general equilibrium model called MSG-EE (for Multi Sectoral Growth - Energy and Environment). Selected examples of uses of the model will also be given. A thorough description the energy markets of course constitutes a central building block of the model. The model can be regarded as a continuation of earlier modelling work in Statistics Norway (Bjerkholt *et al.*, 1983) which built a relatively detailed submodel of the production and consumption of hydro power electricity into the Norwegian macroeconomic planning model MSG-4. This model in turn, can be viewed as the grandchild of the original MSG model, developed by Leif Johansen in the early 1960s (Johansen, 1960, 1974). Thus, the work presented in this book, and outlined in section 1.4 below, forms a part of a rather long tradition in Norway.

1.2 Integrated economy-environment modelling

A large number of national and international integrated environment-economy assessments of the greenhouse problem have been carried out in the last decade or so, usually based on the use of computable general equilibrium models. Typically, the starting point has been the question of what impacts an increase in the prices of fossil fuels will have on future greenhouse gas emissions and economic growth, either on a global scale or on a national scale. Global studies of this question include Edmonds and Reilly (1983a,b), Manne and Richels (1991), Manne (1992), Barns *et al.* (1992), Rutherford (1992), Burniaux et al. (1992), while studies based on regions of smaller size include among many others Hogan and Jorgenson (1991), Jorgenson and Wilcoxen (1989), Bergman (1990), Bye *et al.* (1989), Glomsrød *et al.* (1992), Centraal Planbureau (1989), Conrad and Schröeder (1990), Moum (1992), and Manne and Richels (1990). Recent surveys of works in this field are Hoeller *et al.* (1990, 1991) and Cline (1992). While most of the studies are exclusively concerned with CO_2 emissions from combustion of fossil fuels, some works have included other air pollutants, e.g., regional or local pollutants such as sulphur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO) and particulate matter and other sources of emissions (e.g. Alfsen and Glomsrød, 1987). This has been done in order to capture some of the so called secondary effects of climate policies. As shown in Alfsen *et al.* (1992) and Pearce (1992), these secondary effects can give rise to substantial cost savings offsetting some of the economic costs of controlling CO_2 emissions.

The modelling basis for the analyses varies from extremely aggregated global economic models (e.g., Edmonds and Reilly, 1983a,b, Manne and Richels, 1990) to more disaggregated national economic models (e.g., Jorgenson and Wilcoxen, 1989, Hogan and Jorgenson, 1991, Glomsrød *et al.*, 1992, Alfsen, 1991, 1992). In order to analyze possible future emission of for instance NO_x, which in contrast to CO_2 emission is sensitive to the physical and chemical circumstances under which the combustion takes place, a rather detailed sectorial decomposition of economic growth is needed. Furthermore, in order to capture some of the benefits of reduced local pollution, one must of course know approximately where the emission takes place. These are arguments in favour of integrated economy-energy-environment analysis based on rather disaggregated macroeconomic models of national economies.

1.3 Integrated modelling work in Norway

Norway has a long history in building and using disaggregated multisectoral general equilibrium models for policy purposes. The tradition goes back to the work of Leif Johansen in the early 1960s (Johansen, 1960, 1974) and the work has since then largely been carried out by the Research Department of Statistics Norway. Documentation of some past and current economic models are given in for instance Longva *et al.* (1985), Offerdal *et al.* (1987), Cappelen (1992), Holmøy (1992) and Holmøy *et al.* (1994). Over time, energy and emission modules have been integrated in the economic core model, allowing for consistent analyses of economic, energy and environmental issues based on one and the same modelling framework. The extended modelling tool has been extensively used by the government in Norway for making forecasts of economic development, energy demand and emissions to air.

Early emission forecasts, also covering discharges to water, were made already in 1972 in connection with the government's Long Term Programme released that year. These forecasts were, however, not based on an integrated economy-energy-environmental model. That only became possible in the mid

1980s, but then only for some selected air pullutants like SO_2, NO_x, CO and lead (Alfsen and Glomsrød, 1987). The forecasts, based on the government's current Long Term Programme, showed that without further control policies, Norway would have problems in reaching sulphur emission targets laid down in the Helsinki treaty. This situation, together with an awakening awareness of the climate change issue, was the main motivation behind the initiation of a comprehensive study of policy options within the field of economic policy, industrial development and environmental concerns i 1989. The study, called SIMEN, was the result of a joint effort where, in addition to Statistics Norway, several Ministries, governmental directorates and NGOs participated. The results of the study was reported in Bye *et al.* (1989). At this point, the use of integrated models for deliberation of alternative economic and environmental policies was accepted by the government. The set-up of the study was repeated a few years later, but now with greater emphasis on climate change issues. This study, called KLØKT, was reported in Moum (1992).

From the late 1980s or early 1990s, the use of integrated models has thus become more or less a standard tool in policy formulation process, not only within the field of environmental policy, but also in the deliberation of economic policy issues in general, tax policy and even employment issues.

Over the years, however, various weaknesses of the existing model apparatus has been brought to light by the analyses carried out. Also, the focus of the political agenda and other conditions in Norway has changed somewhat.

- *Transport:* Transport has emerged as an environmentally important activity. In previous Norwgian models this activity has been treated in a rather rudimentary fashion, first by aggregating all commercial domestic transport into one economic sector comprising transport by road, air, rail and sea, together with post and telecommunication services. Secondly, previous models have not separated fuel use for transport purposes within the production sectors from fuel use for heating purposes. Clearly, the different sub-sectors of domestic transport rely on very different production technologies. Furthermore, over the last few years they have shown rather different growth rates. A better understanding of the future behaviour of domestic transport must therefore be based on a more disaggregated modelling of the transport activities. In addition, by linking oil used for heating and transport purposes in the way done previously, severe restrictions has been placed on substitution possibilities between oil use and other input factors. Also the linkage has hampered the analysis of potential policies directed against transport activities like road transport.

- *Production of electricity:* Approximately 100 per cent of the electricity produced in Norway is based on hydro power, and so far the macro models have only recognized two alternatives for electricity supply; domestic hydro power production and import of electricity. Further expansion of the hydro power system is, however, restricted and substitutes will have to be considered in the not too distant future. Chief among the alternatives is gas fired power plants. The environmental consequences of further expansion of the hydro power supply and introduction of gas power are very different. An extension of the model framework to include specification of domestic gas power plant technology and producer behaviour for selecting the least cost alternative, is important for further long term analysis of environmental policy in Norway.

- *Distributional impacts of environmental policies:* Proposals for introduction of environmentally motivated taxes has been accompanied by concern for the effects on the income distribution. The consequences of environmental policies on the income distribution has only been crudely modelled so far. A better grasp on this issue is important for the assessment of future environmental policies.

1.4 A brief outline of the book

The issues briefly touched upon above are among the motives for now revising and expanding the existing models still further. It is our belief that the revised elements implemented in the model (MSG-EE) will improve our ability to analyse questions related to the interactions between economic activity, energy and the environment, both through a better treatment of important economic activities, and by including some of the feedbacks from the environment on the national economy. The plan for the rest of the book is as follows.

Chapter 2 gives an overview of the model by first providing a verbal description before continuing with a more stylized presentation of some of the main features of the model.

Chapter 3 goes on to fill in the details by discussing the actual formulations of the more important relations in MSG-EE and their empirical basis. Together these chapters provides an overview of MSG-EE.

In the rest of the book we employ MSG-EE to give answers to, or at least illuminate some questions and issues related to economic development, energy use and emissions to air.

Chapter 4 presents a long term projection for the Norwegian economy towards 2030. This projection is based on the same forecasts as those presented by the Government in the Long Term Programme 1994-1997 (Ministry of Finance, 1993). We are foremost interested in whether or not the simulated economic development is consistent with international obligations and national targets for air pollution. Related to this issue is the future development of the energy use as well as its composition. This long term projection will serve as a point of reference to which the scenarios in later chapters are compared.

In Chapter 5 the economic impacts of increased taxation of CO_2 emissions are assessed. The simulations are used to shed light on the trade-off between reductions in CO_2 emissions and the level of material welfare measured by traditional indicators such as private consumptions and GDP. We establish a cost function for CO_2 emissions in Norway, and this is compared with corresponding measures reported in some international studies.

Chapter 6 studies the potential efficiency gains from a deregulation of the Norwegian electricity market, and how the market is likely to respond to national and international environmental taxes. A main question is whether or when it will become advantageous to introduce gas power in the Norwegian electricity generating system and the associated impacts it will have on emissions to air.

Chapter 7 studies in more detail transport activities in Norway and the restructuring of the transport sector that is likely to follow from higher taxation of CO_2 emissions.

Chapter 8 concludes the book with a brief summary and an outline for further research and development in the field of applied and integrated modelling.

Lists of production sectors, commodities, consumption activities and household groups in the MSG-EE model are presented in the Appendix.

2. The Structure of MSG-EE

The purpose of this chapter is to present the main structure of the MSG-EE model. We do this in two ways; first by a largely non-technical presentation of the behavioural blocks, then in the next section, by presenting the equations of a simplified and stylized version of the model in order to clarify the general equilibrium structure and closure of the model. The empirical specification of the behavioural relations in the model are described in detail in chapter 3.

2.1 Basic characteristics; a non-technical overview

MSG-EE is intended to serve as a tool for analyses of the linkages between economic activity, the use of energy and air pollution in general, and to shed light upon the particular issues that were addressed in Chapter 1. As pointed out by e.g. Fullerton *et al.* (1984), researchers always face a trade-off between simplicity and accuracy of detail, and in several areas there is no "right" approach. The art of model building is to make the optimal simplifications; we want to maximize the amount of relevant information subject to constraints given by availability of data, computer capacity, solution algorithms and theoretical insight. What has this meant to the design of MSG-EE? And how have the substantive issues addressed in Chapter 1 influenced the model structure?

2.1.1 Theoretical foundation

First, these issues have a long-term perspective. Therefore, it is more important to incorporate mechanisms explaining long-term trends than short-run fluctuations of the economy. Consequently the natural choice for the applied researcher is to base the model on the theory of economic growth which is a special discipline of General Equilibrium theory. Contrary to typical macro-econometric models in the Keynes-Klein tradition, the driving forces of growth in the macroeconomic aggregates are expansion of the endowments of primary input factors in the production process. This supply side oriented approach is particularly relevant when studying the utilization of natural resources such as waterfalls for hydro power production and depletion of oil and natural gas. Applying this theoretical framework does not mean that we consider the achievement of a general equilibrium to be realistic even in the long-run. We do not see any reasons for not observing unexpected shocks and business cycles in the future as we have done in the past. However, we believe that the underlying trends around which the economy fluctuates, are better explained by general equilibrium theory than any other theoretical framework presently available for implementation in a numerical large-scale model. The adoption of general equilibrium theory in a realistic empirical representation the Norwegian economy puts MSG-EE in the category of Applied General Equilibrium (AGE) models.

While the interest in large scale macroeconomic models in the Keynes-Klein-Tinbergen tradition has waned at academic research centres, but not that much in advisory bodies for government or business (Mankiw, 1988), AGE models have became increasingly popular in the 1980s. These models have mostly been applied to policy issues in the fields of development economics, international trade, resources and taxation. An impression of the large number of AGE models that have been developed over the last decades and of their structure can be obtained from surveys like Fullerton *et al.* (1984), Shoven and Whalley (1984, 1992), Bovenberg (1985b), Bergman (1988), Melo (1988), Pereira and Shoven (1988), Bandara (1991) and Henderson (1991). The first successful example of an AGE model was the MSG model developed by Johansen (1960). As a matter of fact, Johansen's model can be regarded as the great-great-grandfather to MSG-EE, which is a special version of the fifth official generation of the MSG-model. However, the differences between these model generations are many and important as will become clear to anyone who compares the subsequent exposition with the work of Johansen.

The major strength of an AGE model is its solid theoretical foundation. Behaviour of agents is modelled explicitly and is based on microeconomic optimization principles. Parameters in utility functions and production functions are structural parameters, representing tastes and technology. Therefore, the model may be less vulnerable to the Lucas critique (Bovenberg, 1985a). These aspects are of course highly desirable for any applied study, but they are particularly important when addressing the long run effects of the changes in relative prices induced by taxation of emissions of air pollutants.

2.1.2 Aggregation

The description in Chapter 1 of the air pollution problems facing Norway clearly calls for a disaggregated approach. More concretely, the model specifies 47 commodities of which 10 are non-competing imports and 4 are public goods. The number of industries is 33, see Appendix A. Indeed, as stated also by

Jorgenson and Wilcoxen (1990), we believe that a large scale, i.e. disaggregated, model is essential for studying for instance carbon tax induced impacts on energy use and environmental damages. Disaggregation applies to the industry classification because industries differ greatly in energy and emission intensities. Furthermore, a detailed commodity classification is desirable because different kinds of emissions are related to the use of specific goods, such as gasoline and autodiesel, fuels for heating purposes, etc. However, a realistic description of the substitution possibilities between these activities is necessary if a disaggregated model of factor demand is to be superior to models which rely on the simplifying assumption that pollutants are emitted in fixed proportions to industry output levels. It is easier to obtain reliable and autonomous estimates of industrial production structures the more homogeneous the firms within each industry are. However, homogeneous industries can only be obtained at the cost of a more disaggregated model.

With a high degree of dispersion between the emissions of air pollutants that can be related to the specified activities, the model captures the fact that reductions in the emissions can be obtained through substitutions at many levels of the demand structure. For instance, consider the case of a tax on fossil fuels. Even if the individual industries have small possibilities to substitute fossil fuels for other inputs, price sensitivity in the demand for final products will contribute to shifts in the industry structure so that the aggregate use of fossil fuels declines.

When choosing the classification of industries and commodities in a long-term model, one should, at least in principle, take into consideration that the observed industries represent only a small subset of the potential number of industries. This point is especially relevant for small open economies that may gain large benefits from specializing the industry structure and thereby exploiting their comparative advantages. Norway is, in addition to Iceland, perhaps the most typical example in Western Europe of an economy with a highly specialized industry structure with respect to production of tradeables. The main exporting industries are resource based like the production of oil and gas, fishery, forestry and manufacture of pulp and paper articles, and energy (hydro power) intensive industries like manufacture of metals and industrial chemicals. In addition, the combination of being a very open economy, the geographic localization and high savings propensity has probably given Norway some comparative advantages for shipping through learning by doing. In principle, our model should therefore provide an explanation of the present industrial structure as an endogenous result and not only describe it according to the base year statistics. This would require that we specify potential industries, or technologies, not yet observed presumably because they are not able to give a satisfactory remuneration to the input factors under the present conditions. By "present condition" we do not only mean world market prices and technology. All kinds of protection and direct and indirect industrial support given by the government should also be included.

The specification of the technology for gas power production in MSG-EE is in accordance with these lines of reasoning. Gas power production has so far not been introduced in Norway. But, as argued in Chapter 1, the technology is considered to be the most profitable alternative to hydro power, and in a growth scenario it may well become more profitable than further expansion of the hydro power capacity. However, gas power is the only non-existing industry which technology has been incorporated into the model. Therefore, MSG-EE may be regarded as the outcome of a specialization process corresponding to the solution of an underlying model specifying technologies of a larger number of presently active and non-existent industries.

Based on the interpretation made above about the specified industry and commodity classification, the rationale for relying on a model like MSG-EE for long-term projections is that the exogenous changes supposed to take place do not change the comparative advantages between the industries in favour of any new industries not represented in the model. Thus, in our simulations air pollution will not be reduced through reallocation of resources into new and "cleaner" industries. In MSG-EE such a development has to be simulated in an ad hoc way by putting new products and new technologies into those industries already specified, combined with proper adjustments of exogenous technology parameters. This illustrates a general point in applied modelling: The simulated figures are the result both of the properties of the formal model and of the way the model is used.

In addition to the general arguments in favour of disaggregation, the energy-environmental focus calls for a detailed description of the market for certain especially important goods such as energy and transport. A detailed documentation of the modelling work concerning the energy and transport sectors is given in Chapter 3. Here we confine the exposition to cover the most important qualitative aspects.

The major energy producing industries include the production of crude oil and natural gas, the refining of crude oil and sectors producing electricity. The latter includes electricity production based on hydro power and electricity produced by use of natural gas. Expansion of the hydro power capacity is characterized by irreversible investments and decreasing returns to scale. Electricity consumption implies in reality consumption of three distinct goods; homogeneous electricity net of transfer cost produced by hydro power or gas power, transmission services and distribution services. Unit costs of electricity consumption will therefore differ between consumers due to differences in the composition of these components. In addition, various forms of regulations of the electricity market have resulted in price discrimination between different consumers, and the model has been designed to study the effects of deregulation of these arrangements. With respect to disaggregation, such a focus implies that each of the specified groups of agents on the demand side of the electricity market should be relatively homogeneous with respect to the degree of price discrimination that they face. Historically, price discrimination has favoured the major energy intensive industries: Manufacturing of pulp and paper, Manufacturing of metals and Manufacturing of industrial chemicals. Consequently, these industries are individual production sectors in the model.

Since transport is a major source of air pollution, MSG-EE treats the transport sector in considerable detail. Differences in production technologies have motivated a disaggregation of commercial transport into Domestic road transport, Domestic air transport, Domestic rail transport and Domestic sea transport, together with Post and telecommunication. Railway transport and post and telecommunication are obviously relatively clean transport technologies, and a shift in the composition of aggregate transport in favour of these will contribute to reduced air pollution. Such a substitution may take place at the micro level as well as being the result of disproportionate growth of industries with different composition of their transport services. In MSG-EE, data limitations have prevented incorporation of reliable estimates of the substitution possibilities between different transport services at the industry level. On the other hand, the choice of a relatively disaggregated industry classificatication makes the model relevant for studying substitution caused by changes in the industry structure.

In order to give an adequate representation of the use of transport services, transport services produced by the users on their own (own transport) have to be accounted for in addition to the purchase of transport services from the commercial transport sectors. Especially for road transport, own transport constitutes a significant share of the total use. The volume of own transport services within the individual industries is approximated by the service flow from the transport equipment together with the input of gasoline and diesel. Thus, the ambition of including own transport in the model have necessitated that oil products used for transport are separated from oil used for heating purposes and that transport equipment is distinguished as a specific type of real capital.

2.1.3 The production structure and producer behaviour

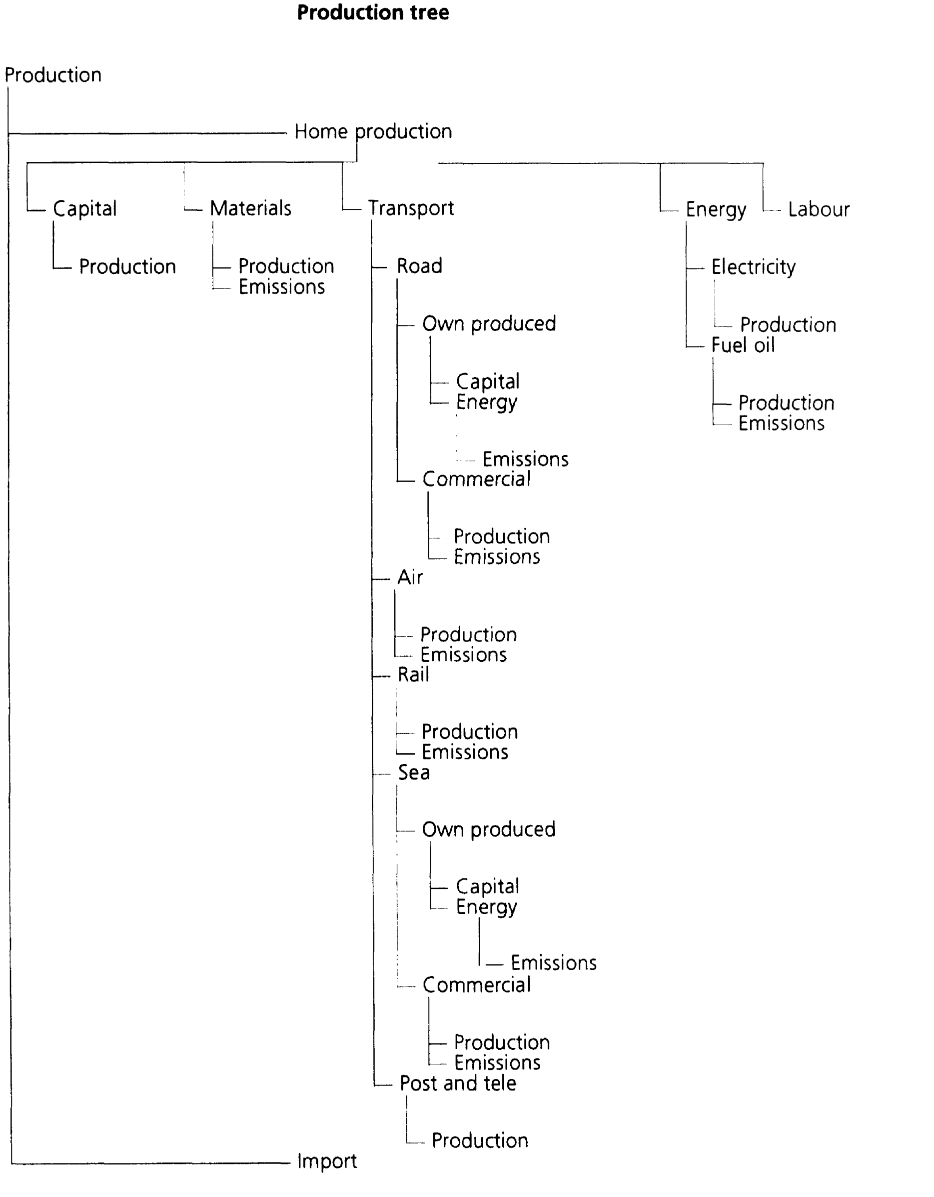
The firms within the industries are assumed to behave competitively on both output and input markets. In general, each sector produces several commodities. Each sector is labelled according to its main commodity. With some exceptions, this commodity composition is fixed corresponding to the description given by the National Accounts (NA) in the base year.

In most sectors, the demand for inputs follows a recursive budgeting procedure involving several stages, see figure 2.1.

At the "top" level, there are five input factors: capital except transport equipment, other material inputs, transport services, energy and labour (man-hours). These factors are optimally combined according to a constant returns to scale flexible technology which may shift exogenously over time through technical change. Energy is used for stationary combustion, mainly heating. It is further divided into electricity and fuel for heating purposes according to a constant returns CES production function. For most of the sectors the technology parameters have been estimated econometrically using time series from the energy accounts. The exact functional forms and the econometric work are documented in Chapter 3.

Transport services is a composite of five types of transport services, i.e. transport by road, air, sea, rail and post and telecommunications. Due to data limitations, the composition is exogenous and equal to the base year description in the national accounts. The factor input of each of the five transport services can in principle be supplied by own production and purchases in the market from the corresponding transport sector. However, the model has no ambition of explaining the organizational set up for the supply of transport services, and it is assumed that the use of own produced transport services are linked to the input of the corresponding commercial services by fixed coefficients. Only own production of road and sea transport services take place in Norway today, and this pattern is assumed not to change in any of the policy simulations. In each industry, the input of services from capital items such as cars, lorries, etc., gasoline and autodiesel are allocated to the production of road transport services. The input of services from ships, boats and marine fuels are allocated to the production of sea transport services.

Figure 2.1. The structure of production in the MSG-EE model



The capital stock in each sector, net of transport equipment, is a sector specific Leontief aggregate of 8 capital goods. Each of these capital goods is a Leontief aggregate of the 47 basic composite commodities in the model. Also the other produced input factors are in principle sector specific Leontief aggregates of the basic commodities. The bottom stage of the cost minimization involves the determination of the home share in each commodity. Most of these shares are price sensitive, since we have adopted the Armington assumption of imperfect substitutability between domestic and similar foreign products.

However, several sectors are not described by endogenous producer behaviour. In the four specified government production sectors, all factor inputs are fixed exogenously. Except for the central government sector Defence, these sectors are further disaggregated into central and local government. Similarly, in the three sectors constituting the petroleum and shipping activity, employment and investment have to be given by the model user, whereas fixed Leontief coefficients determine the input per unit of production of the other factors. Fixed Leontief coefficients determine input of all factors relative to production in Petroleum refining. In Hydro power production, fixed Leontief coefficients determine input of all factors except capital relative to production. The input coefficient of capital in this sector is positively related to the capacity because of decreasing returns to scale when the hydro power capacity is expanded in an optimal way.

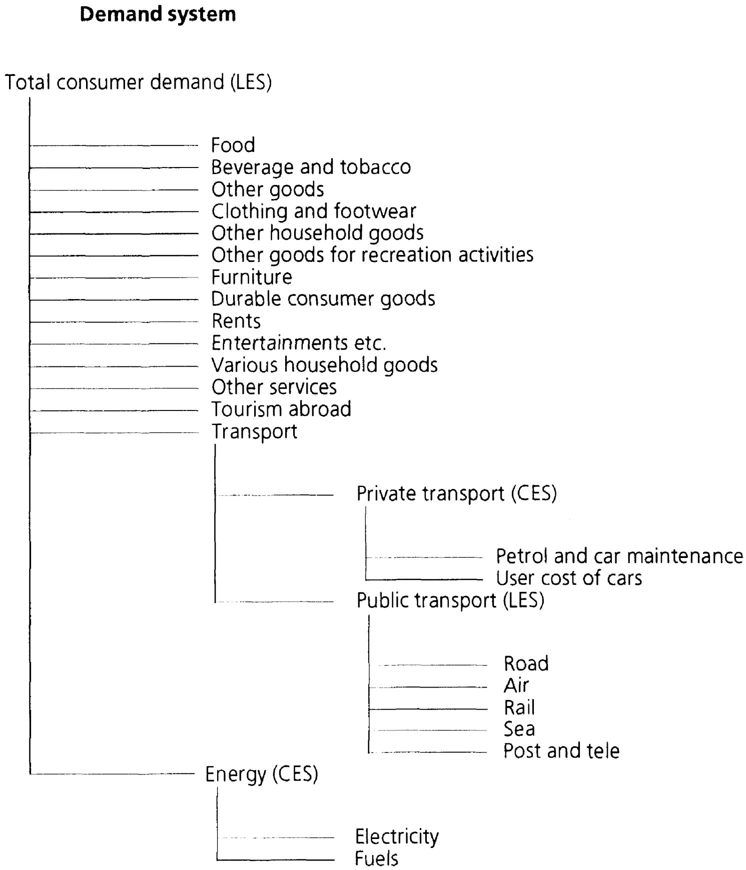
The assumption of constant returns to scale is similarly not realistic in the long run for resource based industries such as Agriculture, Fishing and breeding of fish, etc., Production and pipeline transport of oil and gas. In these sectors, the output level is exogenous, and exogenous factor specific productivity parameters may be used to adjust the factor demand for decreasing returns to scale.

2.1.4 Household consumption

A system of household demand functions plays a central role in the model, determining the allocation of total consumption expenditure among 22 different consumption activities. Substitution possibilities are introduced only between these aggregates. Commodity demand follows from the assumption of fixed commodity by activity coefficients (Leontief aggregation). Finally, a price dependent distribution between the domestic and foreign commodity varieties follows according to an activity specific CES aggregation function.

The demand system of MSG-EE is derived from utility maximizing households. The utility functions are household specific, allowing the model to capture the effect of both household size and household composition. There are 14 household groups in the model, distinguished by socio-economic and demographic characteristics. The mapping from various income categories to household income is generated by data from the Norwegian Income and Property Statistics. A separate sub-model transforms exogenous demographic projections into projections for each of the different household groups.

Figure 2.2. The structure of total consumer demand in the MSG-EE model



As for the structure of the utility functions, weakly separable non-homothetic preferences are introduced, see figure 2.2. At the top level, the households allocate total consumption expenditure to 15 consumption goods according to a non-homothetic linear expenditure system (LES) derived from Stone-Geary utility functions. At the intermediate level, consumption of transport services is allocated to private and public transport services according to a non-homothetic LES. At the bottom level, both private transport services and energy are linearly homogeneous price dependent CES-aggregates, whereas a non-homothetic LES allocates the expenditure devoted to Public transport services is allocated between 1) Bus and taxi transport (road transport), 2) Air transport, 3) Railways, tramways and subways, 4) Boats and ferries, and 5) Post and telecommunications. A given level of private transport services requires services from the stock of cars and petrol and from car maintenance in proportions which are not necessarily fixed. Energy demand can be satisfied by different combinations of electricity and fuels. The demand functions have been estimated econometrically using microeconometric techniques on panel data for Norwegian households, see Aasness and Holtsmark (1993) and Aasness, Biørn and Skjerpen (1995). Chapter 3 provides a more comprehensive description of the microeconometric estimates and how these have been transformed into the consumer demand system in MSG-EE.

While the structure imposed implies strong restrictions on the Slutsky matrix and gives a recursive demand system, important features of the household's ability to substitute between specific activities are retained. In particular, it is intended to be relevant for studies of energy and environmental issues. Since the indirect utility function is a Gorman polar form (Gorman, 1953), it also allows for perfect aggregation of the demand systems across households. Hence, aggregate consumer demand for each consumption good is a function of prices, aggregate consumption expenditure, the number of children, the number of adults less elderly in public institutions, and the estimated levels of minimum consumption for the individual household types. This level of aggregate consumption expenditure is determined purely from supply conditions; there are no intertemporal aspects built into household behaviour. Total consumption expenditure accommodates to ensure full capacity utilization in the economy.

2.1.5 The government sector

Government decisions affect the economy directly through two channels. First, production in government sectors requires resources. Government production is split into four sectors: Defence, Education and research, Health care, etc., and Other government services. Except for Defence, the model also distinguishes between central and local government production of these services. Both investment, employment and the purchase of goods and services allocated to these sectors are exogenous policy instruments in MSG-EE.

Second, the government collects taxes affecting prices and incomes. Due to the fairly detailed input-output structure, indirect taxes and subsidies are modelled in great detail. This makes it relatively easy to study the consequences of indirect taxes on e.g. fossil fuels. The model distinguishes between tax rates ad valorem and on quantities as well as commodity-related and sector-related taxes. Commodity-related taxes and subsidies are specified according to information on the tax base, tax rate and tax payer. Sector-related taxes are transfers to production sectors and contribute to the factor income. The model assumes that these transfers are proportional to gross production and the factor of proportionality may be interpreted as a sectoral tax rate. Also the system of capital income taxation both at the enterprise level and at the personal level is implemented in considerable detail, see Holmøy *et al.* (1993, 1994). Larsen and Vennemo (1993) and Holmøy, Nordén and Strøm (1994). The effects of capital income taxation on production costs and factor substitution are summarized in the user cost of capital expressions. With respect to taxation of labour, MSG-EE specifies employers' contribution to social security and National Insurance as a component in the wage cost in each sector. The model also includes an account of direct taxes and transfers to household. These income flows are, however, modelled with less rigour because they have no direct real effects on the economy due to the absence of any link (such as the Keynesian consumption function) between disposable household income and household expenditure.

2.1.6 The determination of prices

The basic principle for the determination of the domestic prices in MSG-EE is that in a long run equilibrium where all entry/exit incentives are eliminated, domestic producer prices have to equal total unit costs. Due to the assumption of constant returns to scale, combined with exogenous output determination in those sectors where economies to scale is regarded essential, unit costs are independent of the scale of production. Total unit costs include both the user cost of capital and net taxes levied on the sector per unit of production. The relevant prices of commodities used as inputs are purchaser prices, which include indirect taxes and trade margins.

The determination of the price of electricity deviates from this basic principle. As explained in more detail in section 3.5, electricity may be produced by two technologies, Hydro Power and Gas Power. In each period the capacity in both sectors is predetermined by previous irreversible investment, which implies a vertical short-run supply curve. The market clearing price may then include pure profits. Accordingly, the time path for the equilibrium price will depend on the capacity in the two sectors. The investment policy rule, which has been most frequently applied in MSG-EE simulations, is to expand the production capacity up to the level where price equals the long-run marginal cost. However, the model also allows for exogenous deviations from this investment policy. Today, electricity is produced by Hydro Power solely, but Gas Power may become profitable in the future. This possibility is particularly plausible along a growth scenario because the long-run marginal costs are increasing along an optimal expansion path of the Hydro power sector, whereas the long-run technology in Gas power production exhibits constant returns to scale.

The wage rates differ between sectors. Strictly, this is inconsistent with a definition of equilibrium in a model where a homogeneous labour force can be reallocated across sectors without cost. However, the model user has the option to control the relative wage differentials exogenously.

Another empirical fact is that real rates of return to capital also vary significantly across sectors in the Norwegian economy. Part of these differentials is due to distortions caused by the Norwegian system of capital income taxation (see Holmøy and Vennemo, 1995). However, the effects of capital income taxation cannot account for all of the variance of the rates of return across sectors, and it is still an unsolved task to identify how much of the remaining variance is due to different risk premia and/or to different kinds of disequilibrium phenomena.

Through the price-cost relations in the model, all endogenous domestic prices become functions of what we call primary cost components. These are the sectoral wage rates, capital costs per Norwegian krone invested, import prices, productivity parameters, indirect tax rates and domestic prices of public services. Due to decreasing returns to scale in the electricity sector, the domestic prices are in principle also dependent on the activity level in the economy through the electricity demand. However, the practical importance of this quantity effect is small for most domestic prices.

2.1.7 Foreign trade

Since our study concerns a small open economy and focuses on natural resources, it would be natural to develop our numerical model from the so-called Heckscher-Ohlin-Samuelson (HOS) model of comparative advantages based on international differences between the endowments of primary factors of production. Formally, this is not done in MSG-EE. Instead we have adopted the Armington approach according to which Norwegian products differ from the corresponding foreign varieties. The Armington hypothesis is often justified in AGE-models, because the model results become consistent with observed facts like intra industry trade and lack of complete specialization. However, it implies that Norwegian producers face a declining demand curve on the international markets and that they have some degree of market power. Furthermore, the domestic price of a tradeable can deviate from the world market price of the corresponding product. These implications of the Armington approach have often been attacked as being an unrealistic long-run description of a small open economy. However, this is not a criticism of the Armington hypothesis as such, but of the empirical magnitude of the estimated price elasticities of export demand which typically turn out to be much smaller than one would expect from the fact that Norwegian exporters have insignificant market power even if they agree on collusive behaviour.

Slow adjustments to changes in relative prices may, however, have other explanations than small price elasticities. Norman (1990) characterizes the tradition of adopting the Armington hypothesis as a "purely ad hoc means of describing intra-industry trade flows and reducing the sensitivity of trade flows to changes in relative prices - essentially, it is an attempt to capture supply-side imperfections through modifications of the model's demand side". He concludes that "the Armington hypothesis is no substitute for explicit incorporation of oligopolistic interaction and product differentiation at the firm level". However, Branson (1990) and Winters (1990) concludes in their comments to Norman's article, that the Armington approach serves fairly well as an approximation to monopolistic competition if the number of firms is large. It belongs to the future development of the MSG-EE model to pursue the implications of this criticism.

Export demand is endogenous for most of the manufactures and for some services, which jointly cover about fifty per cent of total exports. For these commodities, Norwegian firms face export demand curves which depend negatively on the ratio between the domestic price and the exogenous world market price. In addition, an index for world market demand can shift this demand function. The export demand functions were estimated by Lindquist (1993). For the rest of the commodities, most notably Crude oil, Natural gas, Oil and gas pipeline transport and Oil and gas exploration and drilling, Leasing of oil drilling rigs and Ocean transport, export demand is fixed by the model user. The same is true for exports of second-hand real capital.

Production of resource based commodities like primary industry products, Crude oil and Natural gas, is exogenous and assumed to be determined by supply side conditions. For these commodities, imports are determined residually as the difference between total demand and domestic supply. Except for non-competitive commodities, imports of each of the remaining commodities are determined via import shares. The import shares are both commodity specific and, in general, depend on the demand components. For manufactured goods, which cover more than half of total imports, the import shares increase endogenously if the domestic price is raised relative to the corresponding import price. Formally, the import shares follow from Shephard's lemma as the derivative of the price of the composite good with respect to import price. However, the relative price dependence of the import shares is only commodity specific and does not vary across different kinds of domestic use. The substitution parameters were estimated by Svendsen (1990). For services, except domestic transport services, the import shares are exogenous.

The exchange rate is the numeraire in the model. Due to the assumption that domestic and foreign varieties are imperfect substitutes, domestic prices of tradeables need not be equal to the corresponding world market prices. Exceptions are the products Crude oil, Natural gas, Oil and gas pipeline transport and Oil and gas exploration and drilling, Leasing of oil drilling rigs and Ocean transport, all of which face perfectly elastic demand on the export markets.

2.2 A stylized version of MSG-EE

The conceptual and empirical basis for MSG-EE is the national accounts (NA), and a model simulation provides a description of the development of the economy according to a detailed national account framework, including a high degree of detail with respect to policy instruments. This makes the model operational for analyses of concrete policy changes, and the results can be evaluated by concepts which have a precise empirical content. On the other hand, these features contribute to increase the number of variables and equations, and makes it more difficult to identify the empirically most important aspects of the model structure. This difficulty is reinforced by the selective and relatively detailed treatment of various sectors. In this section we want to focus on the general equilibrium nature of the model. For this purpose we find it pedagogical to consider the formal structure of a stylized version of the model. Compared to the implemented model the exposition of the stylised model abstracts from the following aspects:

- All factor specific productivity parameters are neglected.
- Indirect taxes are represented by a commodity specific tax rate on the basic value.
- Demand for inventories, re-exports and exports of second-hand capital goods are neglected.
- The number of households in the different household groups is assumed to be constant. The demographic variables are therefore suppressed.
- Each sector produces a single commodity.
- The technology in all sectors except Hydro power production exhibits constant returns to scale.
- Import shares are independent of the use of the commodity.

2.2.1 Producer behaviour and the structure of the price model

Elimination of all entry/exit incentives requires equality between domestic producer prices and sectoral unit costs. In all industries, except Hydro power production, the production functions exhibit constant returns to scale, which implies that unit costs equal marginal costs. It is convenient to treat the determination of the activities and output prices of Hydro power and Gas power production separately. At this stage we therefore let the producer prices of electricity take on a preliminary exogenous value.

Elimination of entry/exit incentives may, however, not be the case in the base year or in other years along a path intended to be a neutral projection. Therefore, a parameter γ_j^P is specified for each production sector j capturing possible deviations from the equilibrium price with free entry/exit

$$(1) \qquad \gamma_j^P B_j^H = \frac{1}{\varepsilon_j} c_j \left(PL_j, PK_j^X, PU_j, PT_j, PV_j\right) + t_j^s, \quad j \in PS \backslash \{H, G\}$$

where $PS\backslash\{H,G\}$ is the set of n production sectors excluding Production of hydro (H) and gas (G) power, and γ_j^P is an exogenous parameter correcting for (short-term) deviations between the sectoral basic price and estimated total unit costs in sector j. Furthermore, B_j^H is the domestic price of commodity j (basic value), PL_j is the wage cost per man-hour, PK_j^X is the user cost of capital net of transport equipment, PU_j is a price index on energy for heating purposes, PT_j is a price index on transport services, PV_j is a price index on other material inputs, ε_j represents an exogenous Hicks-neutral productivity parameter, and t_j^s is the exogenous net sectorial tax rate proportional to gross production in sector j.

The sectorial tax rates, t_j^s, and the commodity tax rates, are weighted averages of different indirect taxes. The unit cost function, $c_j(\cdot)$, is independent of output, reflecting the underlying assumption of constant returns to scale. Electricity supply is given a rather more detailed treatment, which we will describe later on. According to Shephard's lemma, the optimal input coefficient of factor i in sector j is given by

$$(2) \qquad c_{ji} \equiv \frac{\partial c_j(\cdot)}{\partial Pi_j},$$

where $i = L, K^X, U, T, V$ (labour, capital, energy for heating purposes, transport services and other material inputs, respectively).

The input activity *Transport services* includes both commercial transport services purchased in the market for transport services as well as own produced transport services, i.e. transport services produced by the sector itself. Although the production sectors are classified as functional sectors, data (though poor in many respects) indicate significant input of own transport of road and sea transport in some sectors. We will return to a closer description of the composition of the transport aggregate below, and more details are presented in Chapter 3. However, it is convenient at this stage of the exposition to point out that the inclusion of own transport in the transport aggregate affects the definitions of the other input factors. In principle we should identify the allocation of the sector's total use of L, K^X, U, T and V on the production of final goods and the production of own transport. Our data did not provide us with sufficient information for undertaking this task. Instead, we have used the input of marine fuels as an indicator or proxy for the volume of own sea transport. The volume of own road transport is measured by the service flow from transport equipment intended for road transport which is combined with the transport fuels gasoline and autodiesel. Hence, the capital stock in sector j, K_j^X, does not include transport equipment, and transport fuels are netted out of from the energy aggregate U_j.

Labour is treated as a homogeneous input that can be reallocated between sectors without costs. Under this assumption, the equilibrium sectoral wage rates, net of taxes, should therefore be equalized. However, this assumption is an oversimplification of reality; it is beyond the scope of the model to say anything about these differentials which are introduced as exogenous variables:

$$(3) \qquad PL_j = \gamma_j^L w, \quad j \in PS$$

where w is a general index of the level of the wage rate paid by the producers, and γ_j^L is an exogenous parameter reflecting imperfections in the labour market, the fact that labour is a heterogenous input with sector specific composition, and differences in employer's tax on labour. Note that differences in wage rates paid by the producers between sectors, imply that the marginal product of labour differs across sectors, giving rise to possible gains or losses from reallocations of labour.

The stock of capital in sector j which is used in road transport (buses, cars, etc.), is denoted K_j^R. The remaining stock of capital in sector j is denoted K_j^X. The service flow from K_j^X is employed directly in the production of the sectoral output. K_j^R is at a first stage employed in the sector's own production of road transport services. These services are in turn combined with other kinds of transport services. The resulting aggregate of transport services is then employed in the production of output. The cost of capital is derived from the intertemporal neoclassical theory of investment, where the producer undertakes investments in order to maximize the present value of the net of tax cash flow received by the owners of the capital. The price of capital services per year is then given by a standard user cost of capital formula taking into account the Norwegian system for capital income taxation. We refer to Holmøy, Larsen and Vennemo (1993) and Holmøy, Nordén and Strøm (1994) for a description of these formulas. Here, we write the expressions in a very general form

$$(4) \qquad PK_j^s = \gamma f_j\left(r, \delta_j^s, t_{Kj}^s, PJ_j^{s*}\right) PJ_j^s + \psi_j^s, \quad j \in PS, \quad s = X, R$$

where γ is a general indicator of the rate of return to real capital, r is the nominal interest rate, δ_j^s is the depreciation rate of capital of type s in sector j, t_{Kj}^s is a vector of tax rates, rates of tax depreciation and other variables characterizing how the system of capital income taxation affects the costs of using capital of type s. PJ_j^s is a price index on investment goods of the type s, PJ_j^{s*} is the expected level of PJ_j^s one period ahead, and ψ_j^s is an exogenous variable which may be used to capture deviations from equilibrium. $\psi_j^s = 0$ for $s = R$.

The observed rates of return are typically quite different from the pre-tax rate of return implied by the user cost formula. Hence, we may have unexplained differences between the sectoral rates of return to capital. According to standard neoclassical investment theory, expectations about relevant future variables are comprised into expectations about the price of the capital good in the next period. The model treats these expectations as exogenous variables. The path simulated by the model will then in general deviate from a perfect foresight equilibrium path. Most theoretical intertemporal equilibrium models assume perfect foresight, and Jorgenson and Wilcoxen (1989, 1991) and Goulder and Summers (1989) have implemented and solved large scale models based on perfect foresight. However, the perfect foresight assumption seriously complicates the solution of the model, and this has been the decisive argument against this type of intertemporal closure rule. Under our assumptions all arguments in the function $f_j(\cdot)$ are exogenous.

The purchaser price indices on investment goods are given by

$$(5) \qquad PJ_j^s = \sum_{i \in v} \lambda_{ij}^{Js} (1 + t_i) B_i, \qquad j \in PS, \quad s = X, R$$

where t_i is the indirect tax rate on good i, and B_i is the basic price of commodity i. v denotes the set of m commodities which includes n goods that may be produced domestically and $m - n$ goods that can only be supplied through imports, while λ^{Js} is a matrix of Leontief coefficients describing the commodity composition of investment in capital type s by sector.

The purchaser price indices on other material inputs are given by a formula analogous to eq. (5)

$$(6) \qquad PV_j = \sum_{i \in v} \lambda_{ij}^{V} (1 + t_i) B_i, \qquad j \in PS.$$

The adjustment of the input of energy for other purposes than own transport is modelled as a two-stage budgeting problem. The energy aggregate U is assumed to be linearly homogeneous in electricity, E, and fuel oils used for non-transport purposes F^X. The input coefficients of these two energy goods are optimally adjusted according to the relative prices. The resulting unit cost/price function representing both technology and cost minimizing competitive behaviour becomes

$$PU_j = PU_j\left(PE_j, PF_j^X\right). \tag{7}$$

The price index PF_j^X is determined in the same way as the other purchaser prices

$$PF_j^X = \sum_{i \in v} \lambda_{ij}^{FX}\,(1 + t_i)\,B_i, \quad j \in PS. \tag{8}$$

The purchaser price of electricity is calculated from

$$PE_j = (1 + t_E)(1 + d_j)(\lambda_{jE}^E B_E + \lambda_{jD}^E B_D), \quad j \in PS \tag{9}$$

where t_E is the indirect tax rate on electricity. In this simplified exposition we disregard sectorial differences in this tax rate. The coefficient d_j reflects pure price discrimination between sectors. B_E is the basic price of electric power and B_D is the basic price of distribution services.

Finally, consider the price index on the transport services which is also an aggregate intermediate good "produced" by the five different groups of transport services: Road transport, designated T^R; air transport, T^L; sea transport, T^S; rail transport, T^B; and transport by post and tele communication, T^P.

As mentioned, transport services are both purchased in the market and produced by the sector itself. Our model relates the input of commercial transport to sectoral production by exogenous input coefficients. We have introduced proxies indicating the volume of sectoral own transport. For example, the inputs needed for own road transport are services from capital equipment (cars, buses, etc.), K^R, combined with gasoline and autodiesel in fixed proportions, F^R. Moreover, there is a fixed coefficient relating this proxy of the volume of own road transport to the sector's input of aggregate commercial transport services. If road transport were the only type of own transport, the dual picture of the transport technology can be written

$$PT_j = PT_j^C + \left(ZKF_j^R PF_j^R + PK_j^R\right) ZK_j^R ZTF_j^R, \quad j \in PS \tag{10}$$

where the n-dimensional vectors have the following interpretations: PT_j^C is the purchaser price of aggregate commercial transport, PF_j^R is the purchaser price of autodiesel and gasoline used in own road transport, and PK_j^R is the user cost of capital related to own road transport equipment. Furthermore, ZTF_j^R is equal to the input of own road transport per unit of aggregate commercial transport, ZK_j^R is input of capital goods in own road transport per unit of own road transport, and ZKF_j^R is input of autodiesel and gasoline per unit of capital goods used in own road transport. The prices of different types of transport fuels are determined in the same way as PF^X in eq. (8). It is easily verified that the expression for PT_j, the price index of aggregate transport, can be rewritten as:

$$(11) \qquad PT_j = PT_j^C + PF_j^R \frac{F_j^R}{T_j^C} + PK_j^R \frac{K_j^R}{T_j^C} + PF_j^S \frac{F_j^S}{T_j^C}, \qquad j \in PS.$$

Except for the four public goods and the nine non-competing imports, all commodities are composite goods consisting of a domestic and a foreign product (variety). The composition is independent of scale. For manufacturing goods, covering more than half of total imports, the composition is endogenous, depending on the relative prices between the domestic and the corresponding foreign product. The dual price function of the composite good is in general commodity specific and also dependent on the demand component. However, in this stylized version, the price functions are independent of the use of the commodity

$$(12) \qquad B_i = B_i \left(B_i^H, B_i^I \right), \qquad i \in v.$$

$B_{iH} \equiv \frac{\partial B_i}{\partial B_i^H}$ and $B_{iI} \equiv \frac{\partial B_i}{\partial B_i^I}$ are the optimal input coefficients of the domestic and the foreign product, respectively. The exchange rate is the nûmeraire in the model and the import prices are measured in Norwegian currency. For Shipping services, Crude oil and Natural gas, Norwegian producers are assumed to face a perfectly elastic demand curve on the international market, which implies that the domestic price is equal to the world price for these products.

The price model contains $13n + m$ equations in the same number of endogenous variables included in the 13 n-dimensional vectors B^H, PL, PK^X, PK^R, PU, PE, PF^X, PF^R, PJ^X, PJ^R, PM, PT, $PT^C$and the m-dimensional vector B. Thus, all prices can be interpreted as being built up from the prices of primary cost components. Among these are the index of the common wage rate, the world market prices, the nominal interest rate, sectoral rates of productivity indices, indirect tax rates and exogenous prices of public goods. The solution is completely independent of the quantities due to the assumption of constant returns to scale. In fact, it is an input-output model of prices with endogenous input-output coefficients. This is easily seen when we carry out a logarithmic differentiation of the price model. Assuming r, δ^s, t, t_K^s, γ^L, $\gamma^P$and t^sconstant, we get

$$(13) \qquad \dot{B}_j^H = \Theta_{jL}\dot{P}L_j + \Theta_{jK}\dot{P}K_j^X + \Theta_{jU}\dot{P}U_j + \Theta_{jT}\dot{P}T_j + \Theta_{jV}\dot{P}V_j - \dot{\varepsilon}_j$$

where $\dot{\varepsilon}_j$ is Hicks neutral technical change in sector j, the Θ's are the cost shares of the factors and a dot above a variable represents the corresponding logarithmic differential $\left(\dot{X} \equiv \frac{dX/dt}{X}\right)$. Logarithmic differentiation of (3) - (12), and some trivial algebra leaves us with the system

$$
\begin{aligned}
\dot{B}_j^H &= \sum_{i \in v} a_{ij} \Theta_i^H \dot{B}_i^H + \Theta_{jL} \dot{w} + \Theta_{jK} \dot{\gamma} + \Theta_{jV} \Theta_{jE}^V \Theta_{jE}^E \dot{B}_E \\
&- \dot{\varepsilon}_j + \sum_{i \in v} a_{ij} \Theta_i^I \dot{B}_i^I
\end{aligned} \tag{14}
$$

where

$$
\begin{aligned}
a_{ij} &\equiv \Theta_{jK} \Theta_{ij}^{JX} + \Theta_{jU} \left(\Theta_{iE}^U \Theta_{ij}^E + \Theta_{jFX}^U \right) + \Theta_{jV} \Theta_{ij}^V \\
&+ \Theta_{jT} \left(\Theta_{jC}^T \Theta_{ij}^{CT} + \Theta_{jFR}^T \Theta_{ij}^{FR} + \Theta_{jKR}^T \Theta_{ij}^{JR} + \Theta_{jFS}^T \Theta_{ij}^{FS} \right)
\end{aligned} \tag{15}
$$

and Θ_i^H is the budget share of the domestic product in the composite good i. The corresponding budget share of imports is $\Theta_i^I = 1 - \Theta_i^H$. Θ_{ij}^l is the cost share of good i in factor j in sector l.

The term $a_{ij}\Theta_i^H$ measures how much a given small change in B_i^H is carried over to a change in unit costs and thereby B_j^H, when we recognize that good i may be used both as a capital good, energy good, transport service or as other material inputs. We define the following matrices:

$$
A^H \equiv \begin{bmatrix} a_{11}\Theta_1^H & \dots & a_{1n}\Theta_1^H \\ \vdots & & \vdots \\ a_{n1}\Theta_n^H & \dots & a_{nn}\Theta_n^H \end{bmatrix} \quad A^I \equiv \begin{bmatrix} a_{11}\Theta_1^I & \dots & a_{1m}\Theta_m^I \\ \vdots & & \vdots \\ a_{n1}\Theta_1^I & \dots & a_{nm}\Theta_m^I \end{bmatrix} \tag{16}
$$

The relative change in the domestic prices can then be written compactly:

$$
\dot{B}^H = \left(1 - A^H\right)^{-1} \left[\Theta_L \dot{w} + \Theta_K \dot{\gamma} + \Theta_V \Theta_E^V \Theta_E^E B_E - \dot{\varepsilon} + A^I \dot{B}^I\right] \tag{17}
$$

where $\dot{\varepsilon}, \Theta_L, \Theta_K, \Theta_V, \Theta_E^V$ and Θ_E^E are n-dimensional column vectors of the sectoral rates of technical change, cost shares of labour, cost shares of capital and cost shares of material inputs, respectively. Θ_E^V is a n-dimensional column vector of the sectoral cost shares of electricity in the material input expenditure, and Θ_E^E is a n-dimensional column vector of the sectoral cost shares of homogeneous electric power in the total electricity outlay. $\dot{B}$ is a m-dimensional vector of the changes in world market basic prices, and $\dot{w}$ and $\dot{\gamma}$ are scalars. The interpretation of (17) is that a change in one of the primary cost components is carried over to a relative change in the domestic prices according to the direct and indirect cost shares of the primary cost components.

From equation (17) it is straightforward to calculate the relative changes in the other price indices and the unit coefficients in the price model.

2.2.2 The determination of demand and resource allocation

When entering this part of the model we can take all prices and price dependent coefficients as given by the solution of the price model. The aim of the quantity model is therefore not to find the equilibrium price vector, since all supply curves in the product markets, the capital market, and the market for foreign currency, are horizontal. Instead the quantity model finds the composition of demand which leads to full employment of an exogenous supply of labour.

We start by the determination of factor demand from the production sectors. From Shephard's lemma we have

$$
\begin{array}{lrcl}
(18) & V_j & = & c_{jV} \cdot X_j \\
& L_j & = & c_{jL} \cdot X_j \\
& T_j & = & c_{jT} \cdot X_j \\
& E_j & = & c_{jU} \cdot PU_{jE} \cdot X_j \\
& F_j^X & = & c_{jU} \cdot PU_{jF} \cdot X_j \\
& K_j^X & = & c_{jK} \cdot X_j \\
& K_j^R & = & ZK_j^R \cdot ZTF_j^R \cdot T_j \\
& F_j^R & = & ZKF_j^R \cdot K_j^R \\
& F_j^S & = & ZTF_j^S \cdot T_j
\end{array}
$$

where X_j is the gross production in sector j, L_j is input of labour, T_j is input of transport services, E_j is input of electricity, F_j^X is input of fuel oils used for non-transport purposes, K_j^X is input of capital services from non-transport equipment, K_j^R is input of capital services from capital goods designed for road transport, F_j^R is input of gasoline and autodiesel used for own road transport, and F_j^S is input of marine fuels used for own sea transport in sector j.

Investment by sector is given by

$$(19) \qquad J_j^s = K_j^s\left(1+\delta_j^s\right) - K_{j(t-1)}^s, \quad j \in PS, \quad s = X, R$$

where $K_{j(t-1)}^s$ is the capital stock of type s at the end of the previous period (year). Note that investment has full capacity effect in the same period as investment takes place. Depreciation is calculated also on new capital.

Next, we consider household demand. Since the Linear Expenditure System (LES) allows perfect aggregation of the individual household demand systems, consumer demand for each consumption good is derived as if one household maximized its (intratemporal) utility. The aggregate consumer demand functions can then be written

$$C_l = g_l\left(PC, W; \mu\right), \quad l \in C \tag{20}$$

where C is the set of consumption goods, W is total consumption expenditure and μ is a vector of exogenous variables including the substitution parameters in the three nests and those related to changes in the number of households in the different household groups. PC is the vector of consumer good prices. These are derived by equations analogous to, e.g., equation (5).

Due to the properties of the LES, it is straightforward to calculate household utilities in terms of money metric utility functions. These functions are evaluated in base-year prices and their base-year values are equal to household consumption. Aggregate welfare is calculated as the sum of the individual utility functions.

In this stylized version of the model, Norwegian firms face declining export demand curves depending negatively on the ratio between the domestic price and the exogenous world market price

$$A_j = A_j\left(B_j^H / B_j^I\right), \quad j \in PS \tag{21}$$

where A_j is exports of good j.

Equilibrium in each product market, except for electricity, implies

$$\begin{aligned} X_j &= B_{jH}[\textstyle\sum_{i \in PS}\left(\lambda_{ij}^V V_i + \lambda_{ij}^T T_i + \lambda_{ij}^{FX} F_i^X + \lambda_{ij}^{FR} F_i^R\right. \\ &+ \left.\lambda_{ij}^{FS} F_i^S + \lambda_{ij}^E E_i + \lambda_{ij}^{JX} J_i^X + \lambda_{ij}^{JR} J_i^R\right) \\ &+ \textstyle\sum_{l \in C} \lambda_{lj}^C C_l] + A_j, \qquad j \in PS \setminus \{H, G\} \end{aligned} \tag{22}$$

where B_{jH} is the home share of good j and λ_{lj}^C is the fixed share of good j in consumption good l.

Since hydro power and gas power are perfect substitutes, equilibrium in the market for homogeneous electricity requires

$$X_H + X_G + I_E = \sum_{j \in PS} \lambda_{jE}^E E_j + \sum_{l \in C} \lambda_{lE}^C C_i + A_E \tag{23}$$

where electricity imports, I_E, and exports, A_E, are exogenous.

Assuming product market equilibrium, the total demand for labour, L, and real capital, K, becomes

$$L = \sum_{j \in PS} L_j \tag{24}$$

(25) $$K = \sum_{s\in\{X,R\}} \sum_{j\in PS} K_j^s.$$

Finally, the net total demand for foreign currency is equal to the deficit on the current account given by

(26) $$N(t) - N(t-1) = rN(t-1) + \Delta,$$

where N is the net foreign wealth and Δ is the value of the trade surplus defined by

$$\begin{aligned}\Delta &= \sum_{j\in PS} B_j^H A_j - \sum_{i\in H} P_i^I B_{iI} \Bigg[\sum_{j\in PS} \Big(\lambda_{ij}^V V_j + \lambda_{ij}^{FX} F_j^X + \lambda_{ij}^{FR} F_j^R \\ &+ \lambda_{ij}^{FS} F_j^S + \lambda_{ij}^T T_j + \lambda_{ij}^{JX} J_j^X + \lambda_{ij}^{JR} J_j^R + \lambda_{ij}^E E_j\Big) + \sum_{l\in C} \lambda_{il}^C C_l\Bigg].\end{aligned} \quad (27)$$

Here, B_{iI} is the import share of good i, and P_i^I is equal to B_i^I net of customs duty.

2.3 The general equilibrium closure of MSG-EE

In order to understand the simultaneous general equilibrium structure and the closure of MSG-EE, it is instructive to write the model on a reduced form. From the discussion of the price determination, we know that all domestic basic prices can be expressed as functions of primary cost components. Among these, some are by nature exogenous: import prices, the world market interest rate, tax rates and technology parameters. In addition the exchange rate is normalized to unity. However, the determination of the wage rate index, w, and the shadow price of capital, γ, will depend on how the model is closed. The implications of different closure rules is also most conveniently discussed by considering a reduced form of the model. Thus, in the subsequent derivations it should be remembered that prices and input coefficients, home shares, import shares and exports all are functions of w and γ.

Successively inserting into the product market equilibrium conditions, yields the dynamic Leontief system

(28) $$X = \left(1 - \Omega'\right)^{-1} \left[S - K^H(t-1)\right],$$

where X is the column vector of gross production by industry except gross production of hydro and gas power, S is a column vector of final demands where the i-th element is defined by

$$S_i \equiv B_{iH}\left[\sum_{l\in v}\lambda_{il}^{C}g_l(\cdot,W)+j\in\{H,G\}\sum\Omega_{ij}X_j\right]+A_i$$

(29) $$= S_i(W,X_H,X_G), \qquad i\in PS\backslash\{H,G\}.$$

Ω is a matrix of optimal input-output coefficients determined once the price model is solved. The ij–element is

(30) $$\begin{aligned}\Omega_{ij} &\equiv \lambda_{ij}^{V}c_{iV}+\lambda_{ij}^{JX}\left(1+\delta_i^X\right)c_{iK}+\left(\lambda_{ij}^{E}PU_{iE}+\lambda_{ij}^{F}PU_{iF}\right)c_{iU}\\ &+\left[\lambda_{ij}^{T}+ZK_i^RZTF_i^R\left(1+\delta_i^R\right)\lambda_{ij}^{JR}+ZKF_i^R\lambda_{ij}^{FR}\right]c_{iT},\end{aligned}$$

where $i,j\in PS$. The matrix Ω' in equation 28 is equal to the matrix Ω, except that the rows and columns associated with $(i,j)=(H,G)$ are omitted.

$K^H(t-1)$ is a column vector of stocks of commodities used as capital in the previous period. The exact definition is

(31) $$K_i^H(t-1)\equiv B_{iH}\sum_{j\in PS}\left[\lambda_{ij}^{JX}K_j^X(t-1)+\lambda_{ij}^{JR}K_j^R(t-1)\right].$$

Denoting the ij–element in the matrix $\left(1-\Omega'\right)^{-1}$ by h_{ij}, we have from the labour market equilibrium:

(32) $$L=\sum_{j\in PS}c_{jL}\sum_{i\in PS}h_{ij}\left[S_i(W,X_H,X_G)-K_i^H(t-1)\right],$$

which determines the consumption expenditure level W in period t contingent on X_H and X_G.

We can now express the electricity demand from the production sectors in terms of W, X_H and X_G. Equilibrium in the electricity market can then be written

(33) $$\begin{aligned}&X_H+X_G+I_E-A_E=\textstyle\sum_{j\in PS}\lambda_{jE}^{E}C_{jE}\sum_{i\in PS}h_{ij}\\ &\left[S_i(W,X_H,X_G)-K_i^H(t-1)\right]+\textstyle\sum_{l\in H}\lambda_{lE}^{C}g_l(W)\end{aligned}$$

For given levels of X_H and X_G, this equation determines the equilibrium price of homogeneous electricity, B_E.

As to the determination of X_H and X_G, the default procedure in MSG-EE is to picture a social optimum approach derived from a partial cost-benefit analysis of the dimension of the power system. MSG-EE also recognizes the irreversibility of the investments in hydro and gas power capacity. This implies that $X_j \geq X_j\left(t-1\right),\ j \in \{H, G\}$, when we ignore depreciation of the capacities and the possibility that the equilibrium price might fall short of the short-run marginal cost.

The social optimum approach involves a measure of the social marginal willingness to pay; SMW. SMW is equal to the market price corrected for the negative shift in the demand curve for electricity, induced by the indirect tax on electricity

$$(34) \qquad SMW_j = B_j + t_j, \qquad j \in \{H, G\}$$

where $B_j = B_E - \mu_j B_T$. B_T is the (basic) price of transmission services and μ_j reflects that the costs associated with transmission services are different for hydro power and gas power. B_T is determined in the same way as the other commodity prices.

Given these definitions and premises, the capacity in the electricity sectors are determined in the following way:

$$(35) \qquad X_j = X_j\left(t-1\right), \qquad j \in \{H, G\}$$

if

$$B_j + t_j \leq C^{'}_{jX}\left(PL_j, PK_j^X, PU_j, PT_j, PV_j, X_j(t-1)\right)$$

and

$$(36) \qquad B_j + t_j = C^{'}_{jX}\left(PL_j, PK_j^X, PU_j, PT_j, PV_j, X_j\right), \qquad j \in \{H, G\}$$

if

$$B_j + t_j > C^{'}_{jX}\left(PL_j, PK_j^X, PU_j, PT_j, PV_j, X_j(t-1)\right).$$

Here $C^{'}_{jX} \equiv \frac{\partial C_j}{\partial X_j}$ is the long-run marginal cost associated with expanding the capacity in electricity sector j.

In both electricity sectors, MSG-EE recognizes decreasing return to scale. However, the empirical importance of this aspect is much greater for the hydro power production than for electricity generation based on gas. Note that the above equations ensures that the capacity of electricity production is expanded by using the most cost efficient technology.

Contingent on w and γ, the equilibrium solution of all variables can now be calculated recursively. For example, the total demand for real capital becomes:

$$K = \sum_{j \in PS} \left(c_{jK} + ZK_j^R ZTF_j^R c_{jT} \right) \sum_{i \in PS} h_{ij}$$

$$\left[S_i(W, X_H, X_G) - K_i^H(t-1) \right] \tag{37}$$

The value of the trade surplus becomes

$$\begin{aligned} \Delta = & \sum_{j \in PS} B_j^H A_j \\ & - \sum_{i \in V} P_i^I B_{iI} \left\{ \sum_{j \in PS} h_{ij} \left[S_j(W, X_H, X_G) - K_j^H(t-1) \right] \right. \\ & \left. + \sum_{l \in C} \lambda_{il}^C g_l(W) \right\} \end{aligned} \tag{38}$$

Equations (37) and (38) can be interpreted in two different ways. First, they can be considered as pure accounting equations where the variable on the l.h.s. of the equations calculates total demand for real capital and the trade surplus. The other interpretation is to regard these equations as constraints and thereby equilibrium conditions. In this case K and Δ are exogenous variables, and the wage index, w, and the shadow price of capital, γ, have to adjust endogenously in order to determine the general equilibrium. The choice of a closure rule is formally nothing but choosing which two variables have to be determined endogenously by (37) and (38). The fact that we have to choose a closure rule is a short-coming of MSG-EE because we believe that all four variables are endogenously determined in the real world. Basically, it reflects that an intertemporal theory for the savings-consumption decision has not been incorporated in the model. An intertemporal model with perfect foresight would typically treat γ as exogenous (and equal to 1 in the absence of adjustment cost), but the user cost of capital would still be endogenous since it should include the endogenous growth rate of the price of capital goods (PJ) reflecting the assumption of perfect foresight. The capital stock should be allowed to adjust endogenously, but the adjustments in any period would be dependent on the complete sequence of solutions for future periods. Moreover, a transversality condition should be imposed on the net foreign wealth. Thus, the trade surplus would adjust in each period basically reflecting the preference for consumption smoothing. However, the level of consumption would have to meet the intertemporal budget constraint implied by the transversality condition. The meeting of this constraint would imply endogenous adjustment of the domestic price level through the wage rate. The properties of an aggregated intertemporal perfect foresight model of this type is analyzed in Bye and Holmøy (1992).

Lacking a complete intertemporal model, it is not obvious that K and Δ should be endogenous and w and γ exogenous. Instead the choice of closure rule should reflect the primary aim of the model simulation. Below we list some arguments for the different options. Note that a constraint on the current account is basically equivalent to a constraint on the trade surplus.

- **Closure rule 1:** Exogenous: wage rate (w) and shadow price of capital (γ). Endogenous: trade surplus (Δ) and capital stock (K).

This closure rule implies a nearly recursive structure of the model. Except for the weak effect through increasing marginal cost in hydro power production, prices are independent of the demand side. This particular closure rule was applied in an earlier version of the model labelled MSG-4E, see Longva *et al.* (1985) for discussion. For long-run projections the most serious problem is probably that the absolute value of the stock of net foreign wealth eventually explodes, which reflects that a transversality condition on this state variable is missing. The intertemporal budget constraint is violated. Thus, there is no feed-back mechanism adjusting any of the variables that influence the current account.

- **Closure rule 2:** Exogenous: trade surplus (Δ) and shadow price of capital (γ). Endogenous: wage rate (w) and capital stock (K).

This choice of closure rule can be considered as a natural response to the weaknesses related to closure rule 1. The model now becomes highly simultaneous in prices and quantities. However, a fixed current account balance in each period (year) is obviously a poor substitute for a transversality condition on net foreign wealth. The possibility for an open economy to smooth consumption and welfare through "trade in time" is excluded. The closure rule has often been chosen when the model user wants to "fine-tune" the time path for the economy consistent with a specific target for the development of the external economy. The closure rule has also been frequently used in normative policy studies of welfare and resource allocation. The rationale is that one wants to exclude welfare gains that are financed by increasing foreign debt. Such gains may be suspected to be illusionary because future generations have to pay for them.

- **Closure rule 3:** Exogenous: wage rate (w) and capital stock (K). Endogenous: trade surplus (Δ) and shadow price of capital (γ).

This closure rule is the original one presented by Johansen (1960). The model now answers questions about how the economy, especially the industry structure and the composition of demand, adjusts along a growth path which is mainly exogenously given through the growth in the labour force, the capital stock and productivity. A choice of this closure rule may be justified by the same arguments as those mentioned for closure rule 2.

- **Closure rule 4:** Exogenous: trade surplus (Δ) and capital stock (K). Endogenous: wage rate (w) and shadow price of capital (γ).

This closure rule gives feedback from both state variables to the prices. The service price of capital is endogenized in order to clear the market for physical capital. Hence the service price may deviate from the price of new capital goods. The closure rule has been used mostly in normative analyses, e.g. of the effects of tax reforms, see for example Holmøy and Vennemo (1995). In absence of an intertemporal model, one restricts the analysis to focus on effects of intratemporal reallocations. In order to identify these, welfare effects caused by a reduction of future consumption possibilities through increased foreign debt and/or a lower capital stock should be excluded. In other words: one does not want the normative results to be mixed by contributions from changes in savings behaviour.

2.4 Correcting for disequilibrium

Like most other applied general equilibrium models, MSG-EE is calibrated to a base year. The base year situation may be influenced by disequilibrium phenomena and abnormal events. The philosophy for MSG-users has been to calibrate the model so that it reproduces a situation which is considered to be "normal" with respect to exogenous conditions, rather than direct calibration to a given base year. Identification and quantification of deviations between the observed situation and a hypothetical "normal" equilibrium, is obviously a nearly impossible task, as general equilibrium in a strict sense never has been, nor will be, observed. However, some information about the "order" of disequilibrium is often available, making it worthwhile to incorporate exogenous correction parameters for optional use by the model user.

One obvious example is information about unemployment. The time path generated by the model will, of course, depend heavily on how fast and to what extent the model user believes that unemployment will be eliminated. Moreover, the productive capital stock in each sector may be adjusted for observed slack in capacity utilization. A third kind of disequilibrium arises if operative surplus is not equal to the pre-tax return to capital implied by an independent interest rate, risk premium, expected capital gains, etc. Such a difference may be white noise, but it may also be due to market power and pure profits, imperfect assessment of the risk premium, economic depreciation, expected capital gains, etc. Though the model incorporates appropriate parameters capturing these phenomena, they are clearly very hard to assess quantitatively.

Another class of parameters is incorporated into the model in order to identify special characteristics of the base year. Energy demand for heating depends on the temperature, and the firm and household demand for energy are corrected for deviations from average temperature. Differences between simulated and actual base-year values in econometric equations also belong to this class of parameters.

2.5 Dynamics

MSG-EE is a dynamic model through the process of capital accumulation. In fact it can be regarded as a dynamic input-output model with variable input-output coefficients. A growth path simulated by the model will in general not be a balanced one, because the various sectors will not converge towards the same rate of expansion. On the contrary, price and income effects will typically cause non-proportional changes in the demand of the different goods in the economy implying that the sectoral equilibrium outputs will grow at different rates. In fact, the ability to simulate numerically how total pollution and the demand for energy depends on a disaggregated picture of the growth process has been one of the main intentions when constructing the MSG-EE model, and the empirical importance of this approach is quantified in chapter 4.

The combined effect of the dynamics caused by capital formation and the lack of intertemporal consumer behaviour often makes it difficult to interpret the multipliers simulated by MSG-EE. Consider for example the effects of an increase in an indirect tax rate, possibly related to the emissions of CO_2, simulated under closure rule 1 where w and γ are exogenous. First, it is not possible to single out one measure of the effect of this policy change; the dynamics of the model makes the multipliers time dependent. Therefore, we have to compare a new equilibrium time path with what we call a reference path. In most cases the multipliers converge to a stationary value. This stationary value is labelled "long term total elasticity" in Longva *et al.* (1985). However, it is somewhat misleading to use the term "long-run" in this setting. In all periods the simulated results are generated by model long-run mechanisms. Hence, we should not interpret the multiplier values generated in the periods prior to the one when the convergence towards stationarity is finished, as a description of short- and medium term effects. It is beyond the ambitions of the model to provide a realistic description of such transition periods.

In our example the stationary effects on the macroeconomic aggregates will be the following. An increase in the tax rate will increase the price of produced input factors relative to wages. Hence, the capital stock and the input of other produced input factors will be reduced compared to a "reference path". Hence, the production capacity is reduced which is reflected in a decrease in GDP.

Investment declines too, due to lower replacement investments. Export volumes and home shares in domestic demand are negatively affected by the increase in the domestic prices. On the other hand, a positive terms-of-trade effect and reduced demand for imports due to lower activity, makes the effect on the trade surplus ambiguous. In some years in the transition periods, consumption will be higher than in the reference path. The reason is that the reduction in the capital stock has a strong negative impact on investments. In order to keep the labour force employed, a larger fraction of the production capacity must be allocated to sectors producing consumption goods. However, the stationary effect on consumption is lower than in the first periods, because the aggregate production capacity has been reduced.

Thus, an evaluation of welfare effects of this policy change is of course negatively biased if only the stationary multipliers are considered. A natural alternative would be to add the present values of the changes in consumption (or the money metric of the utility function) as a welfare indicator. However, the model results can not be used directly for such a purpose, because the lack of realism in the modelling of the dynamic adjustment process implies that the relevant discount rates for the various periods are unknown. In most cases "adjustments happen too fast" compared to intuition or results provided by models with more focus on the short-run performance of the economy.

2.6 Environmental links

The formal presentation of MSG-EE given above only includes the core of the model. Several subroutines are linked to this core model. One subroutine calculates national account figures in fixed and current prices according the level of aggregation in the model. Energy flows are also transformed to physical units. MSG-EE also includes an income account for the main institutional sectors. This makes it possible to compute for instance the effects on the government budget of different policies. Of particular relevance for environmental policy studies is a separate submodel which relates the use of fossil fuels and material inputs in the production sectors and the households to emissions of several air pollutants.

2.6.1 Calculating emissions to air

In the present version of the emission model, documented in more detail in Brendemoen *et al.* (1994), 8 polluting compounds are considered. For some of the compounds (sulphur dioxide - SO_2, nitrogen oxides - NO_x and non-methane volatile organic compounds - NMVOC) Norway has international obligations through various conventions and protocols. These are compounds that, in addition to having local effects, also have regional consequences through acid rain and the formation of ground level ozone (O_3). Other compounds like carbon monoxide (CO) and particulate matter (technically particles with diameter less than 10 μm - PM_{10}) are local pollutants. Finally, there are compounds with mainly global effects in that they directly affect the radiation transfer of the atmosphere. Among these so called greenhouse gases we include carbon dioxide - CO_2, methane - CH_4 and nitrous oxide N_2O.

The generic procedure for calculating emissions
The model calculates emissions from 5 different types of sources for each economic sector and the private households. Emissions from stationary combustion sources (ST) are termed stationary emissions, while emissions from mobile combustion sources are categorized according to the transport mode. Thus there are mobile emissions from road (MV), sea (MS), rail (MB) and air (ML) transport. All of the previous types of emissions are due to the burning of fossil fuels only. The fifth and final type of emission sources covers the remaining emissions which are then generally unrelated to combustion. These emissions are termed process emissions and this source type is designated PR. Examples of process emissions are evaporation and emissions from electrolytic processes (for instance used in the production of metals).

Abstractly, the calculation of the emissions from the various types of sources can be represented as follows

(39)
$$\begin{aligned} E_t &= \zeta_t \cdot C_0 \cdot A_t + E_t^0 \\ C_0 &= \frac{E_0}{A_0} \end{aligned}$$

Here, E_t is the emission level in year t (with $t = 0$ designating the base year), while E_t^0 is an exogenous term. C_0 is a fixed emission coefficient determined in the base year. The variable A_t is an activity variable that varies according to the type of source considered. Usually the activity variables listed in table 2.1. are employed.

Table 2.1. Emissions sources and activity variables

Emission sources	Activity variables (A)
Stationary combustion (ST)	Fuel oil for heating (F^X)
Mobile emissions from road transport (MV)	Transport oil for road transport (F^R)
Mobile emissions from sea transport (MS)	Marine fuels (F^S)
Mobile emissions from air transport (ML)	Transport oil for air transport (F^L)
Mobile emissions from rail transport (MB)	Transport oil for rail transport (F^B)
Process emissions (PR)	Intermediate deliveries (V)

The time dependent parameter ζ_t, is meant to take care of expected changes in emission intensities that are not taken into account in the economic model. For instance, stringent regulation of emissions from gasoline powered light vehicles in Norway imply that new cars must be fitted with three way catalytic converters. As the stock of cars is renewed, the emission intensity declines and this is reflected in a reduction in ζ_t. Similarly, a long term plan to reduce the sulphur content of oil can be reflected in a declining ζ_t associated with sulphur emissions. Of course, any price effects associated with these changes should also be taken into account in the economic modelling.

It is worth emphasizing that the sectoral emissions are projected by using input factors (heating oil, transport oils, intermediate deliveries) as activity variables. This implies that any technical change (factor specific or factor neutral) included in the modelling of the economic behaviour is also reflected in the calculation of the emissions. Thus, if technological progress reduces the need for input factors by, say, 10 per cent over a specific time period in a sector, the emission intensities, measured as emissions per unit real output, are also reduced correspondingly.

Exceptions to the rule
There are several exceptions to the generic rule described above. Some of the exceptions are of a permanent character, while others are only introduced in particular studies.

Exceptions to the generic rule that have a permanent character
Fishing is treated as a single economic sector in the model. In reality, however, it consists of at least to very different activities with very different emission characteristics; ocean fishing and breeding and rearing of fish. There are usually few reasons to believe that these two activities will grow at the same rate. Historically, the growth in the breeding of fish has far outstripped the growth in the traditional fisheries. While the fishing fleet is a major emission source in Norway, in particular of NO_x emissions, breeding and rearing of fish have few if any air pollutants directly associated with it[1]. The emission generating activities within the fishing sector are both characterized by being very difficult to model in economic terms. Thus, usually the emissions from all types of sources in this sector are treated exogenously.

Burning of wood for heating in the private households is a major source of emissions of particulate matter in Norway. However, the fuel wood is only seldom bought at the open market. More often, it is harvested directly in forests, either owned by the household or freely available to the household. It is thus difficult to stipulate a price of this fuel, and correspondingly difficult to model the demand for fuel wood in economic terms. For this reason, emissions from burning of wood in the households are usually treated exogenously.

[1] A third source of emissions classified as coming from the fishing sector, is the liming of fresh water lakes.

Emissions from the production of coal is usually kept at a constant (base year) level.

One of the economic sectors; Manufacture of intermediate inputs and capital goods (sector 25), is comprised of a large number of polluting activities. Some of these activities have deliveries to only one or a few other sectors. The emissions from these activities are therefore linked to the activity levels in the receiving sectors rather than to the activity level of the aggregate sector 25. Thus;

- Emissions from the production of anodes are linked to the activity level in the Manufacture of metals (sector 43).
- Emissions from the production of cement are linked to a weighted average activity level calculated from the activity levels in the sectors Construction (sector 55) and Building of ships and oil-platform (sector 50).
- Emissions from the production of Leca (a building material) are linked to the activity level in the sector Construction (sector 55).
- Process emissions of NMVOC from production of beer and bread are related to private consumption of food.
- Process emissions of NMVOC from the sectors Domestic road transport (sector 75) and Wholesale and retail trade (sector 81) are related to the development in total gross demand for gasoline in the economy. These emissions are mainly from the storage and handling of the fuel.

Occasional exceptions to the generic rule
Burning and storage of waste generates emission to air. Methane generated by the decomposition of organic materials is sometimes collected and used as fuel. The combustion of this fuel generates emissions to air. Sometimes the amount of waste generated is modelled as a function of private consumption of food and other non-durable goods and the activity levels in some waste intensive production activities. In other cases the amount of waste is given exogenously. In almost all cases the division of the waste among incinerators and waste dumps is given exogenously.

The economic modelling of the activity level in the petroleum sector is exogenous. Emissions from this sector is sometimes calculated on the basis of the generic rule, at other times it is treated exogenously.

2.6.2 Benefits of reductions in use of fossil fuels

Changes in fossil fuel use will affect emissions to air and also the volume of road traffic in general. This will in turn have impacts on the external costs of emissions and road traffic. Quantifying these costs are at present a very difficult task. Nevertheless, we have taken a step towards this goal by developing a post model based on projections of fuel demand for road transport from the core model and emissions from the emission submodel. The parameter estimates entering the model are of course highly uncertain and must be used with caution. The cost components considered covers the following issues:

- Damage to nature due to acidification damage of forests and fresh water lakes
- Damage to some important materials due to sulphur induced corrosion
- Damage to human health
- Road traffic related damage due to accidents, congestion, wear and tear of the roads and noise.

Table 2.2. Parameters. Marginal environmental and traffic costs in thousand 1990-Nkr per tonne emission or fuel (b_i^j). Share of emissions causing health damage in per cent (a_k^j)

Type of costs	Relations	Parameter	Low	Medium	High
Fresh water damage	$b_1(SO_2+NO_x)$	b_1	0.11	0.19	0.31
Forest damage	$b_2(SO_2 + NO_x)$	b_2	0.41	0.49	0.51
Health damage	$b_3^j(a_m^j M_j + a_s^j S_j)$	b_3^{SO2}	59	155	259
from SO_2		$a_m^{SO_2}$	9	18	27
		$a_s^{SO_2}$	3	7	11
Health damage		$b_3^{NO_x}$	194	555	1 070
from NO_x		$a_m^{NO_x}$	8	18	28
		$a_s^{NO_x}$	3	6	10
Health damage		b_3^{CO}	0.06	0.1	0.31
from CO		a_m^{CO}	9	20	31
		a_s^{CO}	5	14	23
Health damage		b_3^{Prt}	194	555	1 070
from parti-		a_m^{Prt}	6	7	8
culates		a_s^{Prt}	8	17	26
Corrosion	b_4SO_2	b_4	0	4.2	8.4
Traffic accidents	b_i(petrol+diesel)	b_5	0.66	1.53	4.37
Congestion		b_6	0	1.64	3.28
Road damage		b_7	0	2.05	4.09
Noise		b_8	0.44	0.76	1.08

Only damage from Norwegian emissions are considered. The marginal damage of national emissions of SO_2 and NO_x on nature has been estimated from the economic value of timber and fish and supplemented by contingent valuation studies of the recreational value of forests and fishing opportunities. Damage to materials has been estimated on the basis of physical damage functions (corrosion rates as a function of sulphur concentration in the atmosphere), the economic life time of various materials and the cost of maintenance. Damage to health of excessive SO_2, NO_x, CO and particulate matter concentrations are estimated on the basis of epistomethodological studies of the effect of sulphur and particulate matter on morbidity and mortality in the United States. Assuming that recommended WHO-standards for other air pollutants reflect the same marginal damage as SO_2 at the recommended standard, and using expert assessment of the value of bringing one person from above the recommended limit to below that level, marginal benefits of reducing emissions of SO_2, NO_x, CO and particular matter are obtained. Finally, damage estimates associated with road traffic are based on various Norwegian studies.

Table 2.2 defines the parameters and reports the result (best estimates) together with a subjective assessment of the range of uncertainty for each parameter. It should be noted that quite substantial efforts are under way in Statistics Norway with the aim of refining and correcting all of the parameter estimates in the table. The table therefore only represents preliminary data which may be changed, perhaps radically, sometimes in the future.

Marginal health damage takes into account that only a fraction of emissions from mobile (M) and stationary (S) combustion takes place in densely populated areas where health damage is most likely to occur. Also the amount of traffic work carried out is assumed to be proportional to the amount of petrol and auto diesel consumed. Further documentation of the data sources and the methodology employed in deriving these estimates is provided in Brendemoen *et al.* (1992).

3. Production and consumption structures

In this chapter we empirically quantify input activities and substitution elasticities in the production sectors (section 3.1 to 3.5) and Engel and price elasticities in the consumption system (section 3.6) in MSG-EE.

3.1 Classification of industries and input activities

In general the primal production function for most of the private service sectors, the manufacturing industries and the primary sectors are specified as constant returns to scale production functions

$$X = F(K^X, L, U, V, T), \tag{40}$$

where X is output in an industry, K^X is capital input except transport capital, L is the labour input, V is intermediates, U is the energy input net of transport oils, and T is an aggregate of transports. These upper level production technologies are further discussed in section 3.2.

The intermediate input (V) in each sector is a Leontief aggregate of 47 commodities of which 37 are domestically produced, see appendix A. Energy (U) is a constant elasticity of substitution (CES)-aggregate of fossil fuels, except transport oils, and electricity. In section 3.3 production and cost functions and empirical tests of several functional forms for these energy aggregates are presented.

The capital stock (K^X) is an aggregate of four different capital assets: buildings, constructions, machineries, rigs and platforms. Three additional capital assets within each industry are part of the transport aggregate (T); cars, boats and planes. In addition, the transport aggregate in principle consists of the industry specific labour force for transport activities, necessary intermediate input for fulfilling the transport activity and transport fuels. However, because of limitations in the available data, only capital and transport fuels are included in the transport aggregate. In addition to the transport generated within the production sectors for their own use (own transport), the transport aggregate also generally includes commercial transport services. A detailed presentation of these aggregates is presented in section 3.4.

Power generation, transmission and distribution of electricity are specified somewhat differently from the production (or cost) functions in the other production sectors. The production structure in the electricity sectors are presented in section 3.5.

3.2 Total cost functions

The most common parametric production functions place rather restrictive constraints on the flexibility of the production technologies when more than two inputs are included. To avoid these restrictions, the MSG-EE model applies flexible cost functions. A number of highly general flexible cost functions have been proposed in the literature, such as the Generalized Leontief (GL) (Diewert, 1971), Trans-Log (TL) (Berndt and Christensen, 1973), Generalized Square Root Quadratic (GSRQ) (Berndt and Khaled, 1979) and the Symmetric Generalized McFadden (SGM) functions (Manera, 1991, Diewert and Wales, 1986). The function most often applied in analyses on Norwegian data is the GL function (Bjerkholt *et al.*, 1983)[2].

3.2.1 The GL-cost function

Let X be the output from a sector, and q_i and P_i $(i = K^X, L, U, V, T)$ the inputs and the input prices, respectively[3]. The total Generalized Leontief cost function $\tilde{C}(X,P)$[4] is then written

$$(41) \qquad \tilde{C}(X,P) = X \sum_i \sum_j b_{ij} (P_i P_j)^{1/2}, \qquad i,j = K^X, L, U, V, T,$$

where $B = [b_{ij}]$ is a symmetric coefficient matrix. The function may be made to represent an arbitrary homothetic technology by replacing X with $h(X)$, where h is a monotone increasing function. Similarly, Hicks neutral technical change

[2] The choice among flexible functional forms could be based on Bayesian criterion, as in Berndt et al. (1977), or alternatively one may specify a highly general functional form that takes GL, TL or GSRQ as special forms or limiting cases, see Berndt and Khaled (1979). Statistical procedures could then be applied to test among these functional forms. An example of such a flexible form is the Generalized Box Cox (GBC) function. Berndt and Khaled tested the GRSQ, GL and TL functional form against the GBC functional form for the U.S. total manufacturing sector. The GRSQ and the TL functions were rejected against the GBC function. The GL function was not rejected. Bye and Mysen (1993) came up with the same conclusion when testing these functions on data for Norwegian manufacturing industry.

[3] The theoretical model in this chapter is based on the model in Bye and Frenger (1992a).

[4] For ease of presentation, sectoral indices are omitted here.

may be introduced by making h a function of time (t) also. This may be an important extension when estimating on historical data. In the estimation period, i.e. a restricted history, non-homotheticity and non-neutral technical change may possibly have been the case in several sectors. To identify the elasticities of substitution, we then have to separate the possible effects of non-homotheticity and non-neutral technical change by employing econometric tests. However, in a long term general equilibrium *simulation* model it may be reasonable to assume constant returns to scale.

Non-homotheticity and non-neutral technical change in econometric work have been introduced by Parks (1971) and Woodland (1975) by adding terms which are functions of prices and output, and prices and a trend t to equation (41). These modifications have the effect of making the diagonal elements of the B matrix, which are the lower asymptotes of the unit isoquant, functions of X and t. However, homotheticity and Hicks neutral technical change do not fit as special cases of this generalization. Hence, we have in our econometric work instead used a generalization of the GL cost function which allows for both a non-homothetic technology and factor augmenting technical change in each of the inputs. For further discussion of this point, see Bye and Frenger (1992a). The generalized cost function we employ may be written

$$(42)\quad C(X,P,t) = X\sum_i\sum_j h_{ij}(X,t)b_{ij}(P_i P_j)^{1/2}, \qquad i,j = K^X, L, U, V, T,$$

where

$$(43)\quad h_{ij}(X,t) = 1 - \frac{1}{2}(\gamma_i+\gamma_j)\ln X_* - \frac{1}{2}(\tau_i+\tau_j)t + \omega \ln X_*^2 + \xi t^2 + \psi(\ln X_*)t,$$

and where γ_i, τ_i, ω, ξ and ψ are parameters for the first and second order technological change and scale terms, and X_* denotes normalized output. The function $C(X,P,t)$ is linear homogeneous in the price vector P[5]. According to Shephard's lemma, the cost minimizing input coefficients are given by the first order derivatives of the total cost function with respect to factor prices

$$(44)\qquad c_i = \frac{q_i}{X} = \sum_j h_{ij}(X,t)b_{ij}\left(\frac{P_j}{P_i}\right)^{1/2}, \qquad i,j = K^X, L, U, V, T.$$

Here, q_i denotes input of factor i. Our choice of functional form in equations (42) and (43) stems in large part from the fact that it leads to some interesting

[5] $C(X,P,t)$ will be concave for all P and given X_* and t if and only if $b_{ij} \geq 0$ for $j \neq i$, i.e. a rather restrictive assumption. Whether input i and input j are substitutes or complements will then depend on the sign of $b_{ij}h_{ij}(X,t)$, which may change with output or technical change over time. Other estimated coefficient combinations should be tested for concavity both in the historical and forecasted price domains.

special cases. If $\gamma_i = \gamma$ and $\tau_i = \tau$ for all input factors i, and $\omega = \xi = \psi = 0$, we get a homothetic technology with Hicks neutral technical change[6]

$$
\begin{aligned}
C(X,P,t) &= X(1-\gamma \ln X_* - \tau t)\sum_i \sum_j b_{ij}\,(P_i P_j)^{1/2}, \\
&\qquad i,j = K^X, L, U, V, T\ .
\end{aligned} \tag{45}
$$

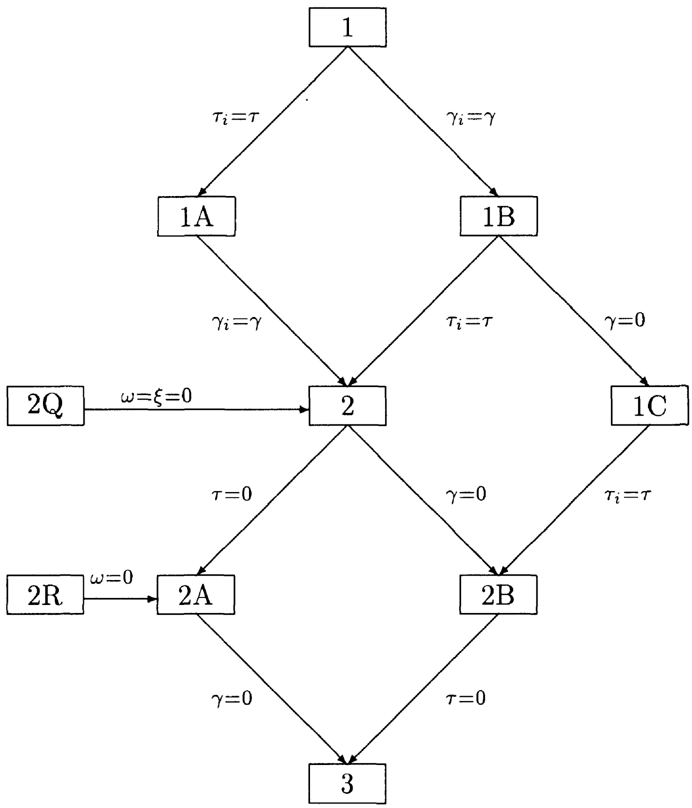
Further restrictions are obtained by setting either γ or τ equal to zero, while the homogenous GL function is obtained when both γ and τ are zero. The minus signs in front of the $\ln X_*$ and t terms in the definition of h_{ij} are convenient sign conventions, while the use of the normalized index X_* represents a renormalization of the γ_i parameters. In the estimation we concentrated on the 10 models summarized in figure 3.1.

One may go from one model to one positioned below in the figure by imposing the specified parameter restrictions. This allows us to test by statistical means various hypothesis. It may be noted that while model 1 (i.e. equation 42) imposes both non-homotheticity and non-neutral technical change, model 1A imposes Hicks neutral technical change and model 1B is homothetic. Homothetic technology combined with neutral technological change (i.e. equation 45) is represented by model 2, while the homogenous GL function is given by model 3 in figure 3.1[7].

[6] For a discussion of other possible spesifications, se Bye and Frenger (1992a).

[7] Non-negativity is a basic requirement of a cost function, i.e. $C(X,P,t) \geq 0$. Our choice of the $h_{ij}(X,t)$ functions imply that these conditions may be violated for sufficiently small or large values of X or t, depending on the sign of the γ_i and τ_i coefficients. Thus, we have to check the estimated functions for this restriction. The conditions upon the second order derivatives of the cost function all stem from the requirement that the function be concave in prices. According to Lau (1978), concavity requires that the own second derivatives be non-positive. In terms of the GL model 3, this is equivalent to $c_i = \frac{q_i}{X} \geq b_{ii}$, i.e. the input coefficient must be greater than the constant term in the cost function. Concavity restrictions also put constraints upon the elasticities of substitution.

Figure 3.1. Hierarchic presentation of the models



As a measure of the substitutability between the inputs, we use the *Shadow Elasticity of Substitution* (SES)[8]. The shadow elasticity of substitution between factor i and factor j in a flexible multifactor function was defined by McFadden (1963) as the negative of the elasticity of the input ratio $q_i(X,P,t)/q_j(X,P,t)$ with respect to changes in the price ratio P_i/P_j, holding output, all other

[8]The SES is a special case of the *Directional Shadow Elasticity of Substitution* (DSES). The DSES measures the curvature of the factor price frontier of a cost function in an arbitrary direction in the tangent plane at given output and total cost:

$$\text{(46)} \qquad \text{DSES}(v) = -\frac{\sum_i \sum_j C_{ij}\, v_i\, v_j}{\sum_i q_i\, v_i\, \frac{v_i}{P_i}}, \quad i,j = K^X, L, U, V, T,$$

where v_i represents an arbitrary direction in the tangent plane, see Frenger (1978).

prices, and total cost constant,

$$(47) \qquad \sigma_{ij} = -\left.\frac{\partial \ln \frac{q_i(X,P,t)}{q_j(X,P,t)}}{\partial \ln \frac{P_i}{P_j}}\right|_{X,C,P_k,\ k\neq i,j.}$$

In terms of first and second order derivatives of the cost functions this is equal to

$$(48) \qquad \sigma_{ij} = \frac{-\frac{C_{ii}}{C_i^2} + 2\frac{C_{ij}}{C_iC_j} - \frac{C_{jj}}{C_j^2}}{\frac{1}{P_iC_i} + \frac{1}{P_jC_j}}, \qquad i,j = K^X, L, U, V, T, \qquad i \neq j.$$

A first test for concavity in the historical price domain is to test whether the shadow elasticities of substitution are non-negative. Concavity then implies that $\sigma_{ij} \geq 0$. When selecting a model for implementation, the basic requirements of non-negativity and concavity were central objectives[9]. For a detailed presentation of estimated technological change and scale effects, see Bye and Frenger (1992a).

3.2.2 Data

When estimating factor input functions (44), assuming a specification of the $h_{ij}(X,t)$ function as in (43), we use time series observations from the national accounts for Norway[10] for the period 1962-1989. Observations for quantities and corresponding price indices are constructed by aggregating commodity flows in the national accounts in current and constant prices. All prices and quantities, except for labour and capital, are normalized by setting prices equal to unity in the base year (1988). Prices of labour includes pay-roll tax and a social insurance premium. Prices of capital services are normalized to the user cost of capital (the sum of the depreciation rate and the demanded rate of return)[11].

The user cost of capital is calculated as a specified function of an ex post estimated rate of return for each manufacturing sector, the sectorial depreciation rate and a sector specific price of investments and registered capital in the national accounts. The rate of return component in the calculated user cost of capital should be interpreted as a hurdle rate which may differ from the ex post return calculated from the operating surplus, i.e. the cost shares do not exhaust the production value. This is especially important in the services sectors and in primary industries, since an average rate of return from manufacturing industry

[9]Frenger (1978) shows that $\sigma_{ij} > 0$ does not necessarily imply concave cost functions even in a global price domain. In that respect DSES> 0 is a better test of concavity. We also used tests of concavity by the DSES in our econometric work.

[10]Except for energy where we used the energy accounts, see section 3.3.

[11]Calculations of the user cost of capital follow Bye and Frenger (1992b).

is applied when calculating the user cost of capital in these industries. The high cost share of capital in the Housing sector, see table 3.1, reflects that we have used a high rate of return compared to the actual surplus in this sector.

In collecting *time series* observations from the national accounts, we were not able to separate inputs to the transport aggregate (labour, capital, materials and energy) from inputs of the same factors in the upper level cost functions, equation (42). Neither were we able to separate out purchase of commercial transport services from the Leontief aggregate of materials for the whole time series. Thus, in the estimations, transport capital is included in the capital aggregate at the upper level and hired transports is included in the materials input aggregate. However, transport oil is excluded from the energy aggregate. This may result in some biases in the estimated elasticities of substitution, but since transport equipment in most sectors represents a small share of the total capital stock, and hired transport represents a negligible share of total material input, the biases are expected to be small.

However, in the base year of the model we were able to separate out inputs of transport capital, hired transport and transport oil, see section 3.4. When calibrating the model in the base year, the deviation between the estimated factor demand at the upper level and observed input were included in the error term in the base year of the model. That is, the error term includes both a traditional white noise error term and errors due to biases in the estimated parameters mentioned above.

The energy aggregate U consists of oil for stationary combustion and electricity for heating and use in technical equipment. A CES energy function is estimated and then calibrated to ensure that the energy price index equals unity in the base year, see section 3.3 for further details.

The base year value shares s_j (input costs relative to gross production value) are reported in table 3.1. These differ from the average input volume shares $\frac{q_i}{X_j}$ (1962-1989) which are reported as left hand side mean in table 3.2, partly because the latter are averages over a long time period, but also because user cost of capital and labour cost are not calibrated to unity in the base year in the econometric specification. From table 3.1 we notice that materials input (s_V) dominates the input cost, while energy (s_U) is a minor cost component for most sectors. The labour cost shares (s_L) vary considerably by sector and are highest in private service sectors.

3.2.3 Empirical results

In the estimation a two stage procedure, made possible by the assumption of homogenous separability of the energy cost function $PU(PE, PF^X)$, was

Table 3.1. Factor cost shares in the base year 1989

Sector	Materials s_V	Labour s_L	Energy s_U	Capital s_K
11 Agriculture	0.562	0.166	0.024	0.509
12 Forestry	0.126	0.304	0.000	0.242
13 Fishing, etc.	0.553	0.147	0,000	0.286
15 Manuf. of consumption goods	0.743	0.131	0.016	0.075
25 Manuf. of intermediates and capital goods	0.600	0.253	0.030	0.119
34 Manuf. of pulp and paper	0.676	0.121	0.062	0.088
37 Manuf. of ind. chemicals	0.614	0.133	0.065	0.111
43 Manuf. of metals	0.609	0.109	0.093	0.134
45 Manuf. of metal products	0.602	0.292	0.017	0.088
50 Building of ships and platforms	0.810	0.134	0.005	0.052
55 Construction	0.642	0.316	0.005	0.042
63 Finance and insurance	0.319	0.288	0.006	0.120
81 Wholesale and retail trade	0.373	0.436	0.020	0.081
83 Housing services	0.250	0.008	0.001	1.510

followed. This procedure is explained in Fuss (1977). We simultaneously estimated the set of four factor input equations

$$(49) \qquad \frac{q_i}{X} = \sum_j h_{ij}(X,t) b_{ij} \left(\frac{P_j}{P_i}\right)^{1/2} + u_i, \qquad i = K^X, L, U, M,$$

for each of the submodels outlined in figure 3.1 for the production sectors of the MSG-EE model[12]. The stochastic term u_i is assumed to have an expected value of zero and the covariance $COV(u_i, u_j)$ is expected to be constant.

The selection of a best fit model for each sector is based upon tests of concavity, significance tests and optimal log likelihood tests. We have applied a likelihood ratio function to test the various hypotheses. Let H_i denote the i'th hypothesis, θ_i denote the maximum likelihood estimate of the parameters, k_i denote the number of parameters estimated under H_i, and let L_i denote the estimated value of the likelihood function. Assume that H_j is an alternative hypothesis which is nested within H_i. Then, on the assumption that H_i is true, the parameter

$$(50) \qquad \Theta = -2 \ln \frac{L_j}{L_i} = N\,[\mathrm{FCN}(\theta_j) - \mathrm{FCN}(\theta_i)] \to \chi^2(k_i - k_j),$$

has an asymptotic χ^2 distribution with $k_i - k_j$ degrees of freedom, where $k_i - k_j$ represents the number of restrictions which H_j imposes upon H_i. FCN is a

[12]The $h_{ij}(X,t)$-function is specified in eq. (43). We denote material input by M to indicate the inclusion of transport in the aggregate.

scaled form of the negative of the (concentrated) log-likelihood function. N is the number of observations.

In the tables 3.2a-c we present the coefficient estimates for the selected "best" model in each sector with the standard errors in parenthesis. We give the normalized value of the log likelihood function (FCN) and some summary statistics, the latter being all single equation statistics. The last item is the "left hand side mean" which gives the average input coefficient over the sample period, and provides an indicator of the relative magnitudes of the various inputs.

Out of a total of 35 production sectors, 15 are estimated in accordance to the scheme presented above. The rest are either treated as exogenous, as for example the government sectors and oil and gas production, or they are treated in a particular manner like for instance the production, transmission and distribution of electricity, see section 3.5.

In most of the estimated sectors the hypothesis of scale effect on factor demand are accepted, see tables 3.2a-c. Only for Fisheries and Wholesale and retail trade does this not seem to be the case, which is somewhat surprising. In 9 out of 15 sectors, the selected factor demand functions include a significant neutral technological change effect. The fact that in as many as 6 sectors no technological change were identified may be the result of identification problems. In 6 of the sectors we found that a second order term for scale or technological change contributed significantly to the explanation of variation in demand. In no sectors were non-neutral technological change identified as the best hypothesis. In just one sector, Manufacturing of industrial chemicals, was non-homotheticity identified as a significant contribution. We find however, that in this sector the shadow elasticities of substitution are rather high compared to other sectors, which may indicate that the data set used for this sector is not entirely reliable.

In three sectors, Forestry, Fishing and breeding of fish, etc. and Finance and insurance, a three factor demand system are estimated. According to the energy accounts, Forestry and Fisheries have no energy use for stationary combustion. In the national accounts the Finance and insurance sector's energy use for stationary combustion is tabled as energy use in the Housing services sector. In the Paper and pulp industry and Construction, a fixed energy input coefficient were estimated, that is no energy substitution against the other inputs were identified.

Table 3.2a. Estimated parameters and statistical indicators for the selected sectoral simultaneous factor equations. Continued in table 3.2b and 3.2c

	Agriculture	Forestry	Fishery	Consumption goods	Capital goods
Selected model	2Q	2Q	2B	2A	2R
b_{mm}	0.4770	0.1086	-0.2521	0.4517	0.1661
	(0.0638)	(0.0326)	(0.0847)	(0.0148)	(0.0310)
b_{mu}	-0.0180			0.0103	0.0258
	(0.0122)			(0.0061)	(0.0222)
b_{ml}	1.1421	0.0278	2.9368	1.0279	1.4974
	(0.5013)	(0.1037)	(0.2862)	(0.0463)	(0.0939)
b_{mk}	-0.0037	0.0926	0.3143	-0.1197	-0.1398
	(0.1376)	(0.0657)	(0.1691)	(0.0214)	(0.0583)
b_{uu}	-0.0047			0.0037	-0.0352
	(0.0065)			(0.0053)	(0.0218)
b_{ul}	0.2075			0.0300	0.2017
	(0.0633)			(0.0156)	(0.0621)
b_{uk}	0.0493			-0.0123	-0.0539
	(0.0499)			(0.0126)	(0.0438)
b_{ll}	-22.2346	6.3378	-6.0090	-3.0037	-4.0238
	(1.5449)	(0.6888)	(2.6204)	(0.1546)	(0.3196)
b_{lk}	9.2626	-0.6361	-2.4375	0.7364	1.1009
	(1.4392)	(0.1779)	(0.3525)	(0.0415)	(0.1236)
b_{kk}	0.2093	2.2272	1.4308	0.2729	0.3416
	(0.8036)	(0.0965)	(0.3701)	(0.0463)	(0.1218)
τ_m					
τ_u					
τ_l	-0.0029	-0.0090	0.0003		
	(0.0032)	(0.0022)	(0.0030)		
τ_k					
γ_m					
γ_u					
γ_l	-0.4263	0.6478		0.3572	-0.0362
	(0.3547)	(0.1059)		(0.0546)	(0.0469)
γ_k					
ξ	0.0006	-0.0001			
	(0.0003)	(0.0001)			
ω	4.9880	-0.7841			-0.4219
	(2.5700)	(0.2118)			(0.0735)
ψ	-0.1620	0.0005			
	(0.0578)	(0.0040)			
FCN	73.0906	48.0535	56.6087	72.2793	74.5887
R-square:					
M	0.7545	-0.6236	0.5142	0.7088	0.8752
U	0.5020	0.0000	0.0000	0.2821	-0.5650
L	0.9643	-0.3797	0.4532	0.9815	0.9872
K	0.8567	0.6002	0.3566	0.9642	0.8957
Durbin Watson:					
M	0.7180	0.0936	0.5412	1.2605	1.2127
U	0.5123	0.0000	0.0000	1.6009	0.5095
L	0.6310	0.0509	0.3908	0.4183	1.2099
K	0.8912	0.0495	0.5202	0.7053	0.8343
Sum of squared residuals:					
M	0.0221	0.0254	0.0835	0.0096	0.0059
U	0.0001	0.0000	0.0000	0.0001	0.0010
L	28.3636	161.7800	79.6138	0.4356	0.5470
K	0.1824	0.8440	1.1569	0.0037	0.0178
Left hand side mean:					
M	0.6125	0.1524	0.3032	0.7259	0.5853
U	0.0200	0.0000	0.0000	0.0201	0.0363
L	14.1626	5.8065	7.1515	2.4572	3.7491
K	3.8619	1.9861	1.3832	0.4517	0.6865

Table 3.2b. Estimated parameters and statistical indicators for the selected sectoral simultaneous factor equations. Continued from table 3.2a

	Paper and pulp	Ind. chemicals	Metals	Metal products	Ships and platforms
Selected model	2	1A	2	2A	2R
b_{mm}	0.3125	0.4774	0.4614	0.0751	-0.3484
	(0.0350)	(0.0987)	(0.0357)	(0.0298)	(0.0620)
b_{mu}		0.1362	0.0764	0.0280	0.0110
		(0.0942)	(0.0214)	(0.0085)	(0.0052)
b_{ml}	0.9072	-0.0084	0.1882	1.6260	2.8418
	(0.0886)	(0.1922)	(0.1207)	(0.0808)	(0.1255)
b_{mk}	0.1475	0.0618	-0.1242	-0.1217	0.3919
	(0.0775)	(0.0330)	(0.0383)	(0.408)	(0.0782)
b_{uu}	0.0586	-0.3810	-0.0920	-0.0046	-0.0015
	(0.0026)	(0.2082)	(0.0293)	(0.0068)	(0.0039)
b_{ul}		1.0431	0.3999	0.0208	0.0082
		(0.4959)	(0.0431)	(0.0131)	(0.0067)
b_{uk}		-0.0767	-0.0754	-0.0364	-0.0128
		(0.0553)	(0.0295)	(0.0163)	(0.0085)
b_{ll}	-2.5064	-2.8884	-1.8781	-3.1178	-6.1712
	(0.2415)	(1.2974)	(0.2836)	(0.2404)	(0.3120)
b_{lk}	1.1355	0.9546	1.3115	0.9391	-0.4022
	(0.0812)	(0.1513)	(0.0986)	(0.0608)	(0.1088)
b_{kk}	-0.7534	-0.0570	0.2540	0.1810	-0.2734
	(0.2386)	(0.0643)	(0.0931)	(0.0952)	(0.1522)
τ_m					
τ_u					
τ_l	0.0050	0.0057	-0.0023		
	(0.0041)	(0.0059)	(0.0011)		
τ_k					
γ_m		-0.1790			
		(0.1412)			
γ_u		-0.7260			
		(0.3371)			
γ_l	0.4896	-0.0621	0.4498	0.2770	-0.0161
	(0.2402)	(0.5164)	(0.0496)	(0.0207)	(0.0241)
γ_k		5.2173			
		(0.9697)			
ξ					
ω					-0.1202
					(0.0256)
ψ					
FCN	68.9773	68.8096	70.4837	69.6406	67.9812
R-square:					
M	0.6931	0.3356	0.5965	0.6560	0.9212
U	-0.2185	0.2161	0.8055	0.6643	0.1275
L	0.9827	0.9131	0.9388	0.9864	0.9695
K	0.8631	0.9568	0.8808	0.8672	0.5878
Durbin Watson:					
M	1.1046	0.5388	0.6785	1.1827	1.6032
U	0.3339	0.4279	1.5519	0.0001	0.0000
L	0.9902	0.2912	0.5238	1.0980	1.1285
K	0.8238	0.5086	1.4957	0.4216	0.6608
Sum of squared residuals:					
M	0.0348	0.0579	0.0463	0.0090	0.0136
U	0.0055	0.0477	0.0008	0.0001	0.0000
L	0.5472	4.6273	0.6495	0.6442	1.6809
K	0.0874	0.5200	0.0389	0.0206	0.0903
Left hand side mean:					
M	0.7506	0.6008	0.6156	0.5931	0.7195
U	0.0707	0.1129	0.1142	0.0204	0.0080
L	2.6276	2.4452	2.0117	4.2428	2.8885
K	0.8732	2.1786	0.8488	0.5577	0.3648

Table 3.2c. Estimated parameters and statistical indicators for the selected sectoral simultaneous factor equations. Continued from table 3.2a and 3.2b

	Constructions	Finance and ins.	Trade	Housing	Private services
Selected model	2	2	2B	2R	2R
b_{mm}	0.1478	0.2408	0.0104	0.0919	0.0588
	(0.0359)	(0.0347)	(0.0336)	(0.0278)	(0.0396)
b_{mu}			0.0163	0.0007	0.0181
			(0.0140)	(0.0004)	(0.0158)
b_{ml}	1.9378	0.3339	1.1611	0.0581	0.9794
	(0.1150)	(0.1371)	(0.0931)	(0.0054)	(0.0488)
b_{mk}	-0.1981	-0.2235	-0.0788	0.5088	-0.0921
	(0.0305)	(0.1222)	(0.0222)	(0.0993)	(0.0560)
b_{uu}	0.0047		-0.0239	0.0005	-0.0222
	(0.0002)		(0.0120)	(0.0003)	(0.0077)
b_{ul}			0.1502	0.0002	0.1122
			(0.0157)	(0.0008)	(0.0153)
b_{uk}			-0.0349	-0.0017	-0.0357
			(0.0139)	(0.0007)	(0.0203)
b_{ll}	-3.9632	0.0535	-1.1145	-0.0627	-0.6442
	(0.3764)	(0.7744)	(0.2645)	(0.0103)	(0.1297)
b_{lk}	0.6873	1.5625	0.5607	-0.0282	1.0549
	(0.0371)	(0.5172)	(0.0259)	(0.0155)	(0.0954)
b_{kk}	0.1266	-0.2857	0.1380	15.1940	0.5377
	(0.0479)	(0.2607)	(0.0285)	(0.2646)	(0.1224)
τ_m					
τ_u					
τ_l	-0.0084	-0.0304	0.0136		
	(0.0040)	(0.0054)	(0.0015)		
τ_k					
γ_m					
γ_u					
γ_l	0.5321	0.6506		0.1260	-0.1218
	(0.0978)	(0.1335)		(0.0404)	(0.0337)
γ_k					
ξ					
ω				0.1494	-0.221
				(0.0319)	(0.0335)
ψ					
FCN	71.4386	57.5116	74.4209	55.0436	72.7869
R-square:					
M	0.0268	0.5290	0.6203	0.5673	0.8805
U	-0.0746	0.0000	0.7364	0.3725	0.8475
L	0.9736	0.0965	0.9806	0.9406	0.9932
K	0.9314	0.6818	0.8233	0.8780	0.6928
Durbin Watson:					
M	0.6460	0.2405	0.6035	0.2419	0.7366
U	0.0000	0.0000	0.0002	0.0000	0.0001
L	0.6909	0.8736	0.6659	1.2230	1.3318
K	0.8485	0.1066	0.9024	0.9220	0.3417
Sum of squared residuals:					
M	0.0179	0.0600	0.0107	0.0091	0.0015
U	0.0000	0.0000	0.0002	0.0000	0.0001
L	1.2105	0.1180	1.0916	0.0005	0.1063
K	0.0021	0.4855	0.0016	0.3861	0.0903
Left hand side mean:					
M	0.6570	0.2385	0.3451	0.2543	0.3191
U	0.0050	0.0000	0.0150	0.0008	0.0135
L	4.0371	2.3463	5.8102	0.0926	4.8357
K	0.1414	0.5278	0.2436	17.0815	1.0121

In table 3.3 we show the shadow elasticities of substitution between input factors in the estimated sectors. They are all above zero, but vary a lot. It seems to be a tendency that the elasticities of substitution between materials and labour are higher than the other elasticities for most sectors. This is rather surprising even if a possible explanation for substitution between the two factors may be that increasing prices of a large cost component as materials demand increased focus on organization of the use of materials. Another possible explanation may be that over time relatively labour intensive firms within an aggregated sector may have increased their sectorial output share, i.e. our estimated effect is likely to be a sectorial composition effect instead of a strictly substitution effect.

The elasticity of substitution between labour and capital comes next in magnitude. The shadow elasticity of substitution between energy and the other inputs are less than the elasticities of substitution between labour, capital and materials, respectively. The smallest elasticity of substitution is between capital and energy. This is intuitively obvious, since complementary between capital and energy may be the case at the firm level. As mentioned above, the magnitude of the elasticities of substitution seems to be comparable to other studies, except for the elasticities in the Manufacturing of industrial chemicals. A shadow elasticity of substitution above 4 between energy and labour is not reliable. The size of this sector has changed very much during the estimation period, especially since the mid 1970s. This is likely to have had a severe impact of the structure of the sector.

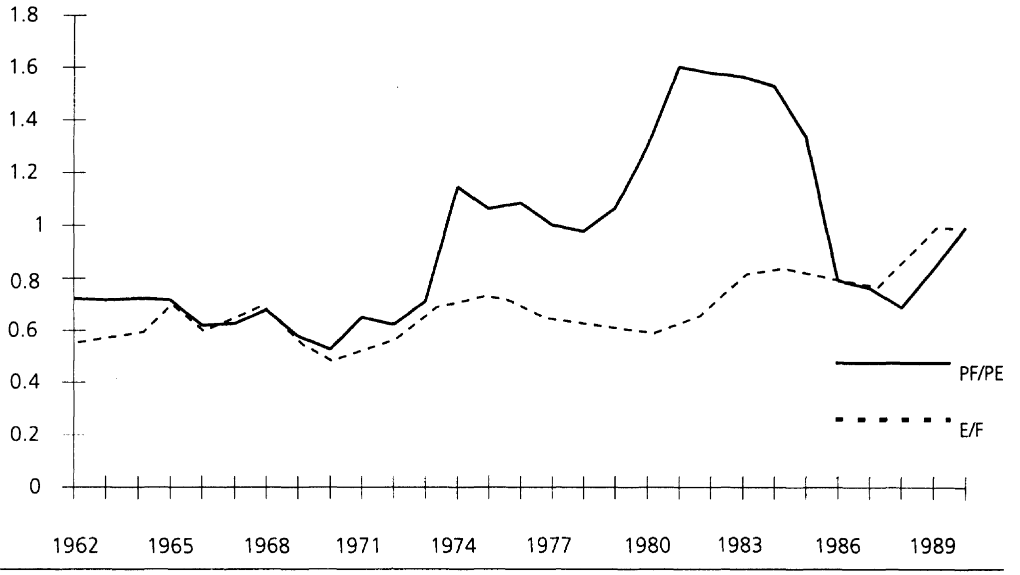
Table 3.3. Shadow elasticities of substitution in the base year of the estimations 1988

	σ_{MU}	σ_{ML}	σ_{MK}	σ_{UL}	σ_{UK}	σ_{LK}
11 Agriculture	0.5530	1.4288	0.3106	0.8237	0.6197	1.9390
12 Forestry	0.0096	0.0877	0.0641	0.0008	0.0054	0.1308
13 Fishing, etc.	0.0883	2.3613	0.3665	0.5186	0.0287	0.4173
15 Manuf. of consumption goods	0.4143	1.9925	0.1954	0.6645	0.3293	1.3305
25 Manuf. of intermediates and capital goods	0.9627	1.6835	0.2300	1.2415	0.6759	1.0195
34 Manuf. of pulp and paper	0.0203	1.7147	0.8857	0.4385	0.3324	1.6932
37 Manuf. of ind. chemicals	2.1469	2.0384	0.5000	4.1177	1.2477	1.9479
43 Manuf. of metals	0.9730	1.0383	0.2238	1.6083	0.6211	1.3680
45 Manuf. of metal products	0.6733	1.4756	0.3047	0.6803	0.4620	0.8041
50 Building of ships and platforms	0.6196	3.3325	1.1055	0.6985	0.5593	1.0736
55 Construction	0.0025	1.6230	0.0790	0.0181	0.0188	0.6067
63 Finance and insurance	0.0017	0.3046	0.3578	0.0060	0.0445	0.8647
81 Wholesale and retail trade	1.0641	1.0492	0.1809	1.1423	0.6987	0.5107
83 Housing	0.1611	1.0492	0.3751	0.2231	0.1578	0.9845
85 Other private services	1.1011	0.9062	0.2390	1.1476	0.9116	0.5606

3.3 The energy aggregate

Energy for stationary combustion is an aggregate of electricity and fuel oil. Historically the electricity–fuel substitution in Norway is characterized by increases in the electricity to fuel ratio even in periods when the price of electricity is increasing relatively to the price of oil, see figure 3.2.

Figure 3.2. The development of the electricity-fuel oil ratio (E/F) and the ratio of the fuel oil price to the price of electricity (PF/PE). Indices. 1962-1990



One possible explanation may be that there are considerable lags in the effect of relative price changes on energy use, especially from price shocks like those for crude oil in 1974, 1979 and 1986 (decrease). However, three years after the crude oil price decrease in 1986, almost no effect on oil use has been traced. Another likely explanation is that increasing use of electricity specific equipment tends to increase the total electricity share (electricity to electricity specific end use and heating). However, the most plausible explanation is perhaps that the choice of energy carrier is related to the capital costs as well as the prices of electricity and fuels. An increase in the price of oil-based heating capital equipment (oil burners) relative to the price of capital equipment using electricity may lead to an increase in the electricity-fuel ratio even if the price of electricity is increasing relatively to oil (see Nesbakken and Strøm, 1993).

During the 1970s and 1980s governmental regulations of the emissions from the manufacturing industries were introduced, especially for emissions of sulphur dioxide (SO_2). These regulations partly influenced the installation of abatement technologies, and partly affected the ratio between demand for electricity and fossil fuel. Parallel regulations of the electricity market took place for instance by the introduction of new and renewal of old long term electricity contracts with the energy intensive manufacturing industries. These industries have contracts with fixed volumes and prices. At historical price levels, these industries were rationed, which again may have influenced the electricity to oil ratio.

One hypothesis often discussed is that during the 1960s and the 1970s technical development in the energy equipment sector was very much driven by the assumption of falling electricity prices relative to petroleum product prices. This led to increased competition in developing electricity based equipment, which on the demand side led to a electricity biased technological change in the aggregate.

3.3.1 Energy demand functions

Due to the data situation, a rather simple technology is estimated[13]

$$U = g(E, F^X; X, \tau) \tag{51}$$

where E is electricity, F^X is fuel oil for heating, τ represents technological change and X (total output) represents a scale effect. However, in this general specification the X and τ factors may also serve as instruments for omitted variables. If these "instruments" are highly correlated to the omitted variables, we may be able to approximately identify elasticities of substitution. Technological change and scale biases for electricity and oil are also taken into account in Bye and Hansen (1989). They found that due to identification problems it was only possible to estimate an aggregate biased technological change.

We specify the energy aggregate U as a CES production function

$$U = \left[A_E^{-\frac{1}{\sigma}} E^{\frac{\sigma+1}{\sigma}} + (1 - A_E)^{-\frac{1}{\sigma}} \left(F^X\right)^{\frac{\sigma+1}{\sigma}}\right]^{\frac{\sigma}{\sigma+1}} . \tag{52}$$

where A_E is a distribution parameter and σ is the elasticity of substitution. Non-homotheticity and non-neutral technical change may be introduced into the model by letting A_E vary with the scale (X) and time t as follows

$$A_E = X_t^{\beta} e^{\alpha+\tau t} + 1 \ , \tag{53}$$

[13]See Mysen (1991) for further details.

where we have substituted X_t for U_t because energy is an endogenous variable. This is trivial if energy is a fixed proportion of output. Since we estimate a flexible function at the upper level, i.e. total energy is not a fixed proportion of output, our definition of "non-homotheticity" is only an approximation.

Differentiation of the cost function dual to (52) with respect to the factor prices, gives the demand functions for the input factors (electricity and oil). Demand for electricity relative to demand for oil, taking into account the possibility of non-homotheticity, non-neutral technological change and dynamics, can now be specified as

$$(54)\quad \ln(\frac{E}{FX})_t = \ln\frac{A_E}{1-A_E} + \sigma\ln(\frac{PE}{PF^X})_t + \tau t + \beta\ln X_{t-1} + \gamma\ln(\frac{E}{FX})_{t-1}$$

where PE and PF^X are prices of electricity and fuel oil for heating, respectively. To circumvent the problem of the simultaneous decision of output and input, lagged output X_{t-1} is introduced as an instrument for the actual output. It may be unsatisfactory to utilize models implying non-neutral technological change and non-homotheticity as instrument variables for other explicit causes. Establishment of a data source allowing a more detailed analysis of the possible explanations of the trend towards more use of electricity, is thus desirable. It is uncertain how long the instruments will show a high correlation with the real factors of explanation. This fact calls for caution by the user of the model, and presentation of the uncertainty in connection with the simulation results should be stressed.

One way of modelling dynamics is to introduce lagged endogenous variables as in equation (54). Another possibility is to specify an error correction model following Harvey (1981). A general error correction model in our case can be specified as

$$(55)\quad \begin{aligned} \Delta\ln(\tfrac{E}{FX})_t = \rho_0 + \rho_1\Delta\ln(\tfrac{PE}{PFX})_t + \mu\ln(\tfrac{E}{FX})_{t-1} - \lambda\ln(\tfrac{PE}{PFX})_{t-1} \\ -\theta T_{t-1} + \rho_2\Delta\ln X_{t-1} - \kappa\ln X_{t-2}\ , \end{aligned}$$

where Δ represents the rate of change in the variables from one period to the next and T represents a time trend. A translation between the parameters in the equations (54) and (55) is straightforward, see Mysen (1991).

Several criteria for model evaluations were taken into consideration when the final parameters were selected. First, the parameter estimates should be significant and have the "right" sign, that is the elasticities of substitution should be positive. Second, the explanatory power of the model should be as high as possible, or equivalent, the standard error of the estimated residual should be as small as possible. Furthermore, we checked the estimations for autocorrelation and heteroscedasticity and stability in the estimated elasticities of substitutions. Finally, the models' ability to simulate post-sample empirical observations were checked. Selection of parameters were based on all these criteria[14].

3.3.2 Data

Data on energy consumption and energy prices are based on the Norwegian energy accounts (Hetland *et al.*, 1990). This data source is in general regarded as superior to alternative sources, including the national accounts which have used in earlier estimations of energy demand in Norway. Since the energy accounts deviates from the national accounts (Bye, 1984), the choice of data source influences the estimations results. More emphasis is put on quality control, implementation of new information from sectoral statistics and general updating in the energy accounts than in the national accounts[15]. The first order parameters in the implemented equations are adjusted to secure that the energy account – national accounts adjustment do not disturb the second order substitution effects in the model. This is essential when running energy tax scenarios on the model.

Contrary to previous versions of Norwegian macro models, transport fuels are omitted from the fuel aggregate. The historical data series also include data from the periods where the fuel oil price decreased drastically relatively to the price of electricity (from 1986), see figure 3.2. This gave us an opportunity to test the price symmetry assumptions in the equations[16].

3.3.3 Estimation results

Equation (54) and (55) and restricted versions of these are estimated and tested against each other according to the above referred criteria. The tables 3.4 and 3.4b present results for the best fit equations for each production sector. Models allowing for non-neutral technological change or non-homotheticity are best fit equations for all production sectors (the first is chosen for all the private sectors and the second for all the public sectors). Except for Manufacturing of pulp and paper and Manufacturing of metal products, machinery and equipment, the error correction models provide best fit for all sectors. In the MSG-EE model the derived long term parameters are implemented. For each sector, a static production function, unit cost function and the relative logarithmic demand function are implemented.

The fit measured by R^2 (RSQ) varies between sectors from 0.47 as the lowest in Private services and 0.90 in Manufacturing of metals as the highest. This

[14]For a formal presentation of the tests, see Mysen (1991).

[15]In 1995 a general revision of the Norwegian national accounts will include the energy accounting system.

[16]See also Bye (1987).

indicates that relevant explanatory variables probably are left out; the introduced "instrumental" variables contribute significantly to the model fit, but do not fully replace omitted variables. Further research on electricity-fuel substitution should possibly focus on collecting data for energy using equipment and their costs.

The estimations suggest considerably lower elasticities of substitution than obtained in earlier studies based on a simple dynamic specification by the lagged dependent variable, see Bye (1984). The elasticities are even lower than in Bye (1987), who also allowed for the possibility of non-homotheticity and non-neutral technological change and claimed reasonable stability of the parameters. The empirical and theoretical differences in the Bye (1987) and the Mysen (1991) studies may be summarized by: i) the extension of the estimation period with a longer history of decreasing fuel oil prices relative to electricity and ii) the introduction of a different lag structure through the implementation of an error correction model in the Mysen (1991) study. Lower elasticities of substitution implies that taxes on fossil fuels will have less effect in the MSG-EE model than in models based on earlier econometric work, see Bye and Mysen (1991).

Table 3.4a. Estimated parameters and statistical indicators for the selected equations by sector. Continued in table 3.4b

	Agri-culture	Consumption goods	Capital goods	Paper and pulp	Ind. chemicals	Metals	Ships and platform
α				1.5228		1.9411	
				(0.1489)		(0.0677)	
σ				-1.3447		-0.2861	
				(0.3383)		(0.1368)	
τ				0.1814		0.1084	
				(0.0235)		(0.0115)	
ρ_0	1.19543	1.5228	0.6435		1.2366		1.8008
	(0.2754)	(0.2372)	(0.1971)		(0.3932)	(0.5683)	(0.5064)
ρ_1		-0.2100			-0.2610		
		(0.0685)			(0.1867)		
μ	-0.9486	-1.5781	-0.5323		-0.5622		-0.8546
	(0.2347)	(0.2583)	(0.1486)		(0.2176)		(0.2974)
λ	0.2658	0.3586	0.5116		-0.0299		-0.0621
	(0.0902)	(0.0726)	(0.1026)		(0.1264)		(0.1517)
θ	-0.1136	-0.1403	-0.0619		-0.0852		-0.0923
	(0.0275)	(0.0230)	(0.0204)		(0.0240)		(0.0298)
Elasticity of substitution	0.2802	0.2355	0.9611	1.3447		0.2861	
Trend	0.1198	0.0921	0.1163	0.1814	0.1515	0.1084	0.1080
RSQ	0.6635	0.8550	0.7721	0.8851	0.7223	0.9032	0.5246
SER	0.0695	0.0414	0.0754	0.3170	0.1034	0.1412	0.1650
DW	1.8259	1.8042	2.2071	1.3686	1.8786	1.2456	1.7725

Table 3.4b. Estimated parameters and statistical indicators for the selected equations by sector. Continued from table 3.4a

	Construc-tions	Trade	Private services	Defence	Educa-tion	Health services	Government services
α				1.5228		1.9411	
				(0.1489)		(0.0677)	
σ				-1.3447		-0.2861	
				(0.3383)		(0.1368)	
τ				0.1814		0.1084	
				(0.0235)		(0.0115)	
ρ_0	2.2715	1.4276	1.0396	1.2722	1.7912	2.4552	2.8215
	(0.6593)	(0.4259)	(0.4011)	(0.4708)	(0.6442)	(0.4585	
ρ_1	-0.3523	-0.2128		0.3548			
	(0.1730)	(0.1489)		(0.2670)			
μ	-1.3278	-0.5405	-0.4707	-0.9319	-0.7057	-1.0275	-0.9568
	(0.3030)	(0.2757)	(0.2195)	(0.2767)	(0.1969)	(0.2933)	(0.1618)
λ	0.1750	0.2010	0.0864	0.2418	0.2244	0.3695	0.3639
	(0.1219)	(0.0822)	(0.0703)	(0.1587)	(0.0699)	(0.1572)	(0.0771)
θ	-0.0764	-0.0719	-0.0581	-0.0743	-0.0983	-0.1470	-0.1532
	(0.0210)	(0.0318)	(0.0237)	(0.0252)	(0.0269)	(0.0374)	(0.0251)
Elasticity of substitution	0.1318	0.3719	0.1838	0.2595	0.3180	0.3596	0.3803
Trend	0.0575	0.1330	0.1234	0.0797	0.1393	0.1431	0.1601
RSQ	0.7383	0.6019	0.4732	0.6571	0.6385	0.7142	0.8172
SER	0.0881	0.0648	0.0656	0.1359	0.0559	0.1194	0.0598
DW	2.1443	1.7747	1.0994	1.7605	1.2933	1.4693	1.5802

3.4 Commercial and own produced transport

3.4.1 The price structure

Approximately 40 per cent of the total Norwegian domestic emissions of CO_2, 80 per cent of the NO_x emissions and 20 per cent of the SO_2 emissions came from mobile sources in 1990. Thus, from an environmental point of view, a good representation of the transport sector is important in a general equilibrium model which is meant to be used for environmental analyses.

The input structure (capital, labour, energy and materials) of the different categories of transport (road, sea, rail, air and post and telecommunications) vary. In addition, capacity utilization seems to differ between commercial and own produced transport, in particular in the utilization of transport capital. The ratio between own transport and commercial transport vary between different sectors. Because of these facts, accumulation of transport capital may differ according to the structural composition of economic growth. Thus, a detailed modelling of the transport activities are required.

Extensions of the transport modelling in MSG-EE, compared to earlier versions of long term equilibrium models in Norway, are along two dimensions. First, as we have seen, the set of aggregate input factors in the production sectors is enlarged from the traditional (K, L, U, M) set of capital, labour, energy and materials, to also include transport services as a separate input factor, see equation (40). Furthermore, transport in each sector is partly supplied by five commercial transport sectors (T^C) and partly produced in the production sectors themselves as own produced transport (T^O)

$$(56) \qquad T = t(T^O, T^C).$$

Second, the supply of transport was previously lumped together in one commodity, domestic transport, but is now disaggregated into five subactivities: road transport (R), air transport (L), sea transport (S), rail transport (B) and post and telecommunications (P). Both own produced transport and commercial transport are then aggregates of the different transport modes

$$(57) \qquad T^C = t^C(T^R, T^L, T^S, T^B, T^P)$$

$$(58) \qquad T^O = t^O(T^O_R, T^O_S).$$

In the own transport aggregate, both rail transport, air transport and post and telecommunications are excluded, since these mainly are commercial activities.

In MSG-EE, total transport within an industry j is a fixed base year calibrated proportion of output

$$(59) \qquad T_j = c_{jT} \cdot X_j.$$

Total unit cost of transports (PT_j) is an input weighted average of unit cost of commercial transport and the aggregated unit cost of own produced transport. The own transport aggregate should ideally reflect the use of transport capital, labour, transport oil and material input for the own transport activity. Our data, however, did not provide us with sufficient information to specify the aggregated own transport in such a detailed manner. The cost of own transport is instead modelled as

$$(60) \qquad PT^O_j = (ZKF^R_j \cdot PF^R_j + PK^R_j) ZK^R_j \cdot ZTF^R_j + ZTF^S_j \cdot PF^S_j.$$

The first term in the parenthesis is the cost of autodiesel and gasoline (input of fuel multiplied with the fuel price) per unit of capital goods used in own transport, and the second term in the parenthesis is the user cost of capital related to own transport equipment. These terms are multiplied with the input of capital goods in own transport per unit of own transport produced measured by the use of autodiesel and gasoline (ZK^R_j), times the input of own transport per unit of aggregate commercial transport (ZTF^R_j). The last term is the cost of marine fuels per unit of input of aggregate commercial transport. All the input coefficients are base year calibrated and price independent. However the model user may implement "guesstimates" of the evolution path for these variables based on other studies.

3.4.2 Data

Demand for transport
In 1988, transport, as defined in the previous section[17], amounted to approximately 122 billion Nkr according to the Norwegian national accounts, see table 3.5. Of this, 55 per cent were road transport and 22 per cent post and telecommunication. Air transport and sea transport amounted to approximately 10 per cent each, while only a minor part were rail transport.

Table 3.5. Total demand for transport. 1988. Million Nkr

	Road transport	Air transport	Sea transport	Rail transport	Post/tele-communication	Total transport
Primary industries	896	11	2 059	28	123	3 117
Manufacturing industry	6 654	2 060	1 617	524	3 085	13 940
Oil activities, ocean transp.	169	1 037	783	6	872	2 868
Construction	2 766	91	346	118	1 318	4 639
Wholesale and retail trade	6 822	294	451	84	6 489	14 139
Other service industries	10 951	3 422	2 436	323	7 332	24 464
Goverment services	1 329	1 071	485	292	1 390	4 567
Privat consumption	36 713	2 200	783	1 449	5 687	46 832
Gross investment	-	333	1 295	-	-	1 627
Export	-	2 539	1 549	158	1 217	5 462
Total	66 301	13 056	11 805	2 983	27 513	121 656

Almost 40 per cent of the total value of transport demand is residential demand, while demand from the Wholesale and retail trade sector and Other private services together amounted to approximately 30 per cent of the transport demand. The residential sector is dominating the road transport by nearly 60 per cent of the total, while Wholesale and retail trade and Other private services top the list of demand for post and telecommunications. In value terms the Manufacturing industry is the fourth largest sector in demand for both road transport, air transport, sea transport and post and telecommunications and the second largest in demand for rail transport.

[17]This includes commercial transport and energy costs and user costs of capital for own transport. Energy costs consist of both gasoline and diesel. Gasoline cost comes directly from the national accounts, while diesel is part of the fuel oil commodity in the national accounts which also includes heating oil. The separation between diesel and heating oil is based on keys from the Norwegian energy accounts.

Total demand for transport amounts to less than 8 per cent of total Norwegian gross production, see table 3.6. Total demand for transport in the production sectors amount to less than 5 per cent of total gross production.

Table 3.6. Total transport demand as share of gross production

	Road transport	Air transport	Sea transport	Rail transport	Post/telecommunication	Total transport
Primary industries	0.0227	0.0003	0.0521	0.0007	0.0031	0.0789
Manufacturing industries	0.0224	0.0069	0.0054	0.0018	0.0104	0.0469
Oil activities, ocean transp.	0.0027	0.0168	0.0127	0.0001	0.0141	0.0465
Construction	0.0271	0.0009	0.0034	0.0012	0.0129	0.0454
Wholesale and retail trade	0.0695	0.0030	0.0046	0.0009	0.0661	0.1441
Other industries	0.0437	0.0136	0.0097	0.0013	0.0292	0.0975
Goverment services	0.0294	0.0237	0.0107	0.0065	0.0308	0.1011
Privat consumption[a]	0.1190	0.0071	0.0025	0.0047	0.0184	0.1517
Gross investment[a]	-	0.0020	0.0077	-	-	0.0097
Export[a]	-	0.0119	0.0072	0.0007	0.0057	0.0255
Total	0.0418	0.0082	0.0074	0.0019	0.0174	0.0768

[a] As part of total consumption, gross investment and exports.

Composition of commercial and own transport

Total transport in 1988 is found to be approximately divided into one half commercial transport and one half own transport, see table 3.7. As explained before, own transport is calculated from the cost side where only the capital cost and the costs of transport fuels are included. This underestimates the level of own transport, but calculations done by Alfsen (1993) shows that this may be negligible. All rail transport and post and telecommunication are commercial transport, while only 20 per cent of total road transport is commercial transports.

The demand for commercial and own transport varies among sectors. In Primary industries approximately 15 per cent of the total transport demand is for commercial transport. In the residential sector almost 30 per cent is commercial transport. In the Construction sector, Wholesale and retail trade and Other private services approximately one half is commercial, in Manufacturing industry about 85 per cent and in Oil activities, Construction and Government services almost all transport activities are commercial.

From table 3.5 and 3.7 we find that the largest share of commercial transport is found in the Post and telecommunication sector with approximately 45 per cent of total commercial transport. The shares of road transport and air transport are close to 20 per cent each of the total value of commercial transport.

The total value of own transport is calculated to be near 59 billion Nkr in 1988

Table 3.7. Share of commercial transport in total transport. 1988

	Road transport	Air transport	Sea transport	Rail transport	Post/tele-communication	Total transport
Primary	0.23	1.00	0.03	1.00	1.00	0.14
Industries	0.60	1.00	0.98	1.00	1.00	0.84
Oil activities, ocean transp.	1.00	1.00	0.79	1.00	1.00	0.94
Construction	0.32	1.00	0.78	1.00	1.00	0.58
Wholesale and retail trade	0.10	1.00	0.78	1.00	1.00	0.56
Other industries	0.24	0.38	0.44	1.00	1.00	0.52
Goverment services	0.90	0.99	0.94	1.00	1.00	0.96
Privat consumption	0.09	1.00	1.00	1.00	1.00	0.29
Gross investment	-	1.00	1.00	-	-	1.00
Export	-	1.00	1.00	1.00	1.00	1.00
Total	0.20	0.84	0.68	1.00	1.00	0.52

out of which nearly 90 per cent were produced on roads. Most of the own produced sea transport takes place in Fisheries and in Other private services.

3.5 Power production, transmission and distribution

Nearly hundred per cent of the electricity consumed in Norway today is domestically produced in hydro power stations. Approximately 80 per cent of the total available hydro power reserves in Norway are already utilized. Further economic growth and increased prices of fossil fuels due to international environmental concerns make it reasonable to expect future growth in the demand for electricity. Long term marginal cost of investments in new hydro power capacity are, however, increasing. Sooner or later Norway may therefore introduce fossil fuel thermal power plants in the domestic electricity production system. Although natural gas as a fossil fuel may be taxed for environmental reasons in the future, production of electricity in gas power plants may still be profitable compared to hydro power production. This will have a great impact on emissions of several compounds to air in Norway. Thus, the development of the electricity market will be an important theme in all future energy–environment analyses.

Norway's electricity market has traditionally been strongly regulated. This regulation resulted in electricity price discrimination among different user groups. New capacity were introduced when the average price in the consumer group with the highest price matched the long term marginal cost. In 1991 a deregulation of the electricity market took place by the introduction of a new energy law[18], leaving investments in new power production capacity to the

[18] Ot. prp. nr. 73 (1988-1989): Om lov om produksjon, omforming, overføring, omsetning, fordeling og bruk av energi m.m. (Energiloven), i.e. The law on production, transformation, transmission, distribution and use of energy, etc. (The energy act).

market. Since, on average, the "willingness to pay" are much less than the long-term marginal cost, investment in new production capacity in Norway is very low today.

One main objective of the deregulation of the electricity market is to increase the economic efficiency in electricity use, which implies a reallocation of power among end users to secure that the value of the marginal productivity of electricity are more equal among sectors. Except for approximately 30 per cent of the domestic electricity market, which consists of long term contracts with the energy intensive industry, the deregulation is effective in the sense that industries have started to negotiate contracts with different producers according to price differences. Although common access to the transmission grid has been a major task, it so far seems as if transmission tariffs to a certain extent has obstructed the market.

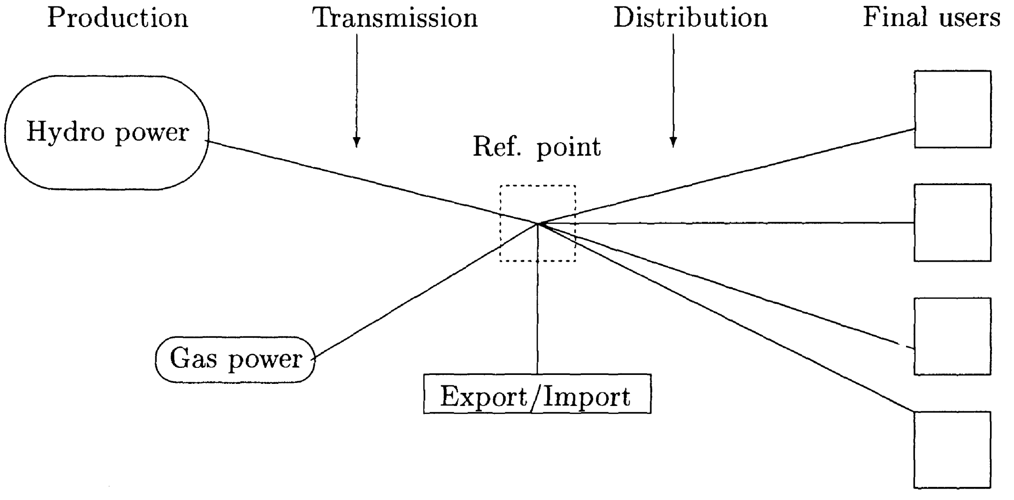
Due to excess production capacity in the Norwegian electricity sector, a deregulation of the export of Norwegian electricity has also been initiated. However, since the Swedish and Danish markets are not yet deregulated, the Swedish Waterfall company obstruct Norwegian participation in the Scandinavian spot market by not allowing third party access to the Swedish transmission grid.

Figure 3.3 gives a brief overview of the Norwegian electricity market taking into account a possible introduction of gas power plants in the future. The supply of electricity is organized in four production sectors; production of hydro power, production of thermal power (natural gas), transmission services and distribution services.

There are 643 hydro power plants in Norway. A national transmission grid connects these producers to the distribution grids. A central institution (Statnett) manage the power transport in the transmission grid. The transmission system is by law open for common carrier access at regulated non-discriminating tariffs. The cost of distribution services and thereby tariffs differs between sectors due to differences in distribution length and time varying capacity constraints[19]. Some large firms in the energy intensive industry are directly connected to the transmission grid. The rest of the final users have to purchase distribution services from the distribution companies. Since the regional distribution companies represent natural monopolies in supplying distribution services, their tariffs are controlled by the authorities. Due to the administrative costs, only large firms so far negotiate contracts directly with

[19]The tariff structure is build up through an access tariff, a tariff on capacity constraints and an energy transportation tariff. The theoretical background for the tariff system is presented in Bye, Johnsen and Strøm (1991a) and (1991b).

Figure 3.3. The electricity market



power plants and the transmission and distribution networks. Consumers have to deal with distribution networks that negotiate with power plants and the transmission company on their behalf.

3.5.1 The submodel for the electricity market

In section 3.3, the electricity demand was specified as a function of electricity prices[20], fuel oil prices and total sectoral activities. The purchaser prices of electricity delivered to sector j can be written

$$(61) \qquad PE_j = \left\{ t_{Vj} + (1 + H_{VEj}) \sum_{i \in \{E,D\}} \Lambda_{ij}[B_i] \right\} (1 + t_{Mj}),$$

The purchaser prices are composed of the equilibrium basic price of electricity (B_E) and the price of distribution services (B_D) weighted by their respective value shares in the base year (i.e. Λ_E and Λ_D). Since B_E represent the price of firm power, and surplus power is assumed to have a lower quality, the Λ_E for sectors using surplus power are adjusted downwards to reflect their willingness to take some delivery risk if they are compensated with lower prices. The variables H_{VEj} define price discrimination, and are determined on a sectoral

[20]The electricity market model in this section is described in more detail in Johnsen (1991, 1992).

level by calibration of the model in the base year. The price discrimination factor varies among sectors in the base year, and in some sectors the deviation between the purchaser price and the equilibrium price is up to 50 per cent. Even after deregulation of the market, some of the discrimination between consumers exists, in particular due to the long term contracts that favour the energy intensive industries. The non-refunded value added tax rate t_{Mj} and the electricity tax rate t_{Vj} also vary among sectors.

The electricity commodity is composed of the two factors; energy and effect. The composition varies among different consumers. Some consumers use electricity on average 4500 hours per year, while other consumers use electricity on average 8000 hours per year. This places certain restrictions on the energy and effect capacity both at the power plants and in the transmission system. Some sectors or demand categories demand electricity deliveries without any interruptions, while others may be shut down when electricity production capacity constraints are reached or when prices of capacity exceed a certain level. In addition some consumers demand extensive use of the transmission system for long distances, while other users demand less transmission capacity. In a perfect market consumers should face the total costs of meeting their demand. In the model an equilibrium price of electricity that balances demand and supply is determined in a reference point somewhere between the distribution and transmission system, see figure 3.3. At this reference point all electricity demand is transformed to a homogenous commodity.

The quantity of electricity demanded by a sector, EK_j, is net of transmission and distribution losses. Total demand at the power plant, ED, is the sector aggregated net demand corrected for transport losses

(62) $$ED = \sum_j \frac{EK_j}{(1-\tau_j^d)(1-\tau_j^t)},$$

where τ_j^d and τ_j^t are distribution and transmission losses, respectively. The demand for electricity in the reference point (EE), i.e. at the start of the distribution net, equals end user demand with the physical losses in the distribution net added

(63) $$EE = \sum_j \frac{EK_j}{(1-\tau_j^d)}.$$

The equilibrium condition in the electricity market at the reference point may then be written as

(64) $$(X^V + X^I + X^G)\Theta = EE,$$

where X^V is the hydro power production, X^I is net import of electricity, X^G is the production of gas thermal power and Θ is a vector of transmission losses taking into account different transmission lengths for the different sources.

The equilibrium price of electricity at the power plant; B_i for a hydro power plant ($i = H$) and a gas power plant ($i = G$), adjusted by the unit transmission cost B_T (transmission losses included) times the (average) distance from the plant to the reference point μ_t, equals the equilibrium price at the reference point (B_E)

$$B_i + \mu^i B_T = B_E, \quad i = H, G. \tag{65}$$

In the model, unit transmission costs is calibrated to the average transmission cost from existing hydro power plants, i.e. μ^H are normalized to unity for new hydro power plants. For gas power plants μ^G is calculated as the location ratio between gas power plants and the average hydro power plant. Suppose that a gas pipe line from the North Sea to Sweden is established. Then a gas power plant may be localized either at the west coast or in the central east region. The pipe line cost is then included in the gas purchaser price while power transmission cost is reduced compared to transmission cost from a hydro power plant.

3.5.2 Power production costs

The long run marginal cost for new power production capacity may be specified as

$$LMC_j = c_{jK} PK_j^X + \sum_{i=L,V,R,G} c_{ji} Pi_j + Z_{TS}^j, \quad j = H, G, \tag{66}$$

where the first term on the right hand side is the capital cost of new projects and the last term is short run marginal cost. c_{jK} is the capital unit input coefficient and PK_j^X is the user cost of capital services including a real interest rate of 7 per cent. Because of decreasing returns to scale, the capital input coefficient is increasing with production capacity in hydro power plants ($j = H$)[21]. Norwegian Water Resources Administration (NVE) have detailed cost-estimates for new hydro power projects. An increasing capital input coefficient is constructed from these data. In gas power plants ($j = G$) a constant capital/capacity ratio is assumed.

The short run marginal cost in hydro power production consists of labour costs (c_{HL} -labour input coefficient multiplied with labour unit cost PL_H) and materials cost ($c_{HV} PV_H$), while Z_{TS}^H is a sectoral tax.

[21] Johnsen (1992) discussed this in more detail.

The short run marginal cost for gas power plants differs from the short run marginal cost in hydro power plants in that the two additional inputs, natural gas (G) and pipeline transport (R), are included and that the labour and materials input coefficients differs. In this sector, natural gas is the main cost component. The gas price is assumed to include any environmental taxes on emissions (CO_2, NO_x, etc.) which follows the general specification of environmental taxes in the model.

3.5.3 Transmission and distribution costs

The unit cost of transmission services is given by

$$(67) \qquad B_T = \sum_{i=K,L,V} c_{Ti} P i_T + Z_{TS}^T + \frac{\tau^t}{(1-\tau^t)} B_E.$$

As in the electricity producing sectors, the unit costs includes capital, labour and material costs and sectoral taxes, i.e. the two first terms. The last term is the cost of transmission losses per unit of electricity transmitted, i.e. τ^t is the physical loss factor in the transmission grid. Similarly the unit cost of distribution services is given by

$$(68) \qquad B_D = \sum_{i=K,L,V} c_{Di} P i_D + Z_{TS}^D + \frac{\tau^d}{(1-\tau^d)} (B_E + B_T),$$

where τ^d is the physical loss factor in the distribution network, and $(B_E + B_T)$ is the unit value of electricity in the distribution net.

3.5.4 Base year calibration

Tax rates, price discrimination parameters, the equilibrium price of electricity at the reference point and unit costs of transmission and distribution services are determined by calibration of the model in the base year (1988), see Johnsen (1992). Observed prices, quantities of electricity production and consumption, net profit and total tax amounts are input data to the calibration.

The rate of return to capital is set equal to 7 per cent in the transmission and distribution sectors. The rate of return in the hydro power producing sector is consequently residually determined. The new energy law states that tariffs in the transmission and distribution net should be cost based. Although this may be in conflict with the optimal capacity utilization argument, one possible conclusion is that periodic tariffs also should cover expected long term returns on capital. Another argument may be that short term marginal cost in production is so low that full capacity utilization in the transmission system is always optimal, i.e. network utilization will be the same and thereby tariffs should not change although purchaser prices change[22].

[22]For a more extensive discussion of different possible assumptions on the markets influence

Table 3.8. Cost elements in the purchaser prices for some sectors. Nkr/kWh. 1988

Sector	PEK_j^a	H_{Rj}^b	H_{V70j}^c	H_{VEj}^d	Λ_{E73j}^e	B_{73}^f	Λ_{EEj}	B_E^g
Export	0.083			-0.13	0.33	0.15	0.33	0.135
Consumption	0.419	0.19	0.035	0.12	0.99	0.15	0.99	0.135
Pulp and paper	0.124		0.027	-0.40	0.33	0.15	0.83	0.135
Metals	0.099		0.035	-0.47	0.00	0.15	0.99	0.135
Wholesale and retail trade	0.363		0.034	0.20	0.96	0.15	0.96	0.135
Defence	0.408	0.19	0.036	0.08	1.00	0.15	1.00	0.135

a. Purchaser prices observed in the energy account.
b. Computed, total value added tax observed in the national accounts.
c. Computed, total electricity tax observed in the national accounts.
d. Computed in the calibration of the model.
e. Computed from percent loss and the sectors use of surplus and firm power.
f. Total costs (including losses) is covered in the distribution sector.
g. Equilibrium price at the reference point.

Table 3.8 shows the elements of the purchaser prices in the model for some of the electricity consuming sectors, using an assumption of a 7 per cent return to capital in the transmission and distribution sectors.

Table 3.9 reports base year values of input coefficients and input prices in four production sectors. The short run marginal cost in hydro power production is 0.02 Nkr/kWh in the base year (alternative future cost of the water supply excluded). The marginal cost of new capacity in the cheapest forthcoming hydro power project is about 0.07 Nkr/kWh. The long run marginal cost in hydro power production is sharply rising to approximately 0.40 Nkr/kWh, see figure 3.4. Only very small projects can be realized to the lower cost.

In gas power production, the short run marginal cost in the base year equals approximately 0.16 Nkr/kWh (including a gas price of approximately 0.65 Nkr/Sm^3). The long run marginal cost of gas power plants is approximately 0.23 Nkr/kWh, which implies a capital cost of 0.065 Nkr/kWh. These figures illustrates the difference in cost structure between hydro and gas power; capital costs dominating the hydro power production while the cost of gas dominates the gas thermal power cost.

The distribution service sector is the most labour and materials input intensive of the four electricity producing sectors. The power loss in the distribution network is about 8 per cent while in the transmission network it is about 2 per cent. The unit costs of transmission and distribution services depend on the physical losses and the unity power value, i.e. on the equilibrium price of electricity. These costs are computed simultaneously in the base year calibration of the model.

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on the rate of return in these two sectors, see Johnsen (1992).

Table 3.9. Base year input coefficients and input prices. 1988

Variable	Units	Hydro power	Gas power	Transmission	Distribution
c_{jK}	Capital units/kWh	1.02	0.65	0.33	0.73
c_{jL}	Man-hour/GWh	7.30	5.10	3.20	0.30
c_{jV}	Nkr/kWh	0.01	0.01	0.003	0.04
c_{jR}	Sm^3/kWh		0.20		
c_{jG}	Sm^3/kWh		0.20		
PK_j	Nkr/capital unit	0.06[a]	0.10	0.10	0.10
PL_j	100 Nkr/man-hour	1.46	1.46	1.45	1.46
PV_j	Price index	1.00	1.00	1.00	1.00
PR_j	Nkr/Sm^3		0.08		
PG_j	Nkr/Sm^3		0.65		
τ_{72}	Per cent			0.02	
τ_{73AF}	Per cent				0.08[b]
SMC_j	Nkr/kWh	0.02	0.16		
LMC_j	Nkr/kWh	0.07[c]	0.23		
B_j	Nkr/kWh			0.05	0.15

[a] Due to surplus capacity, the return to capital in the hydro power sector was only 3.6 per cent in 1988.

[b] This is the percentage loss in deliveries to households. The losses are lower in some of the industry sectors.

[c] The long run marginal cost in hydro power production is sharply rising from this starting point. It is only very small projects that can be realized to this low cost.

Figure 3.4. Long term marginal cost for new hydro power plants. 1988-Nkr/kWh

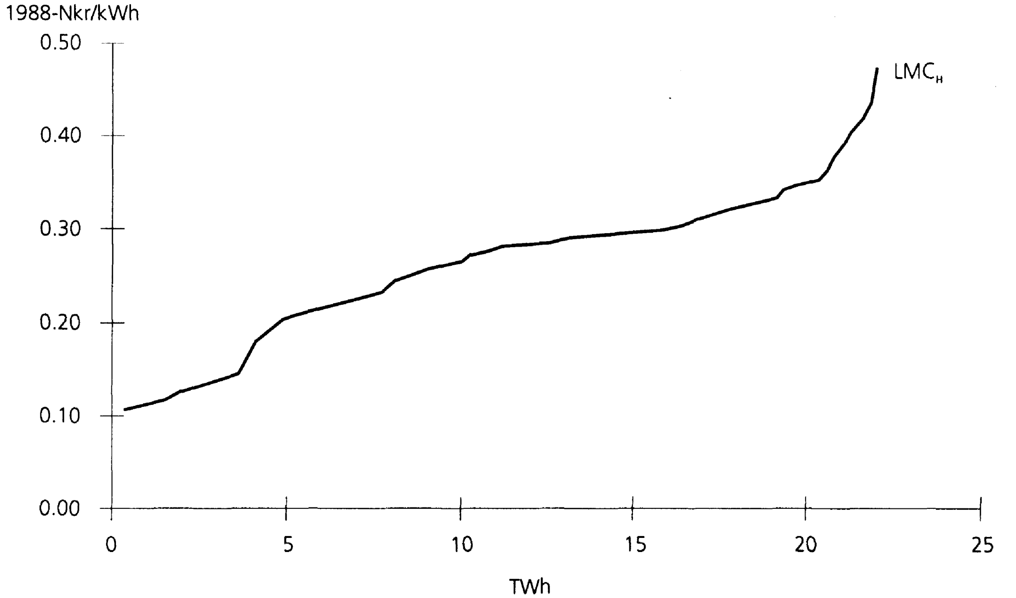


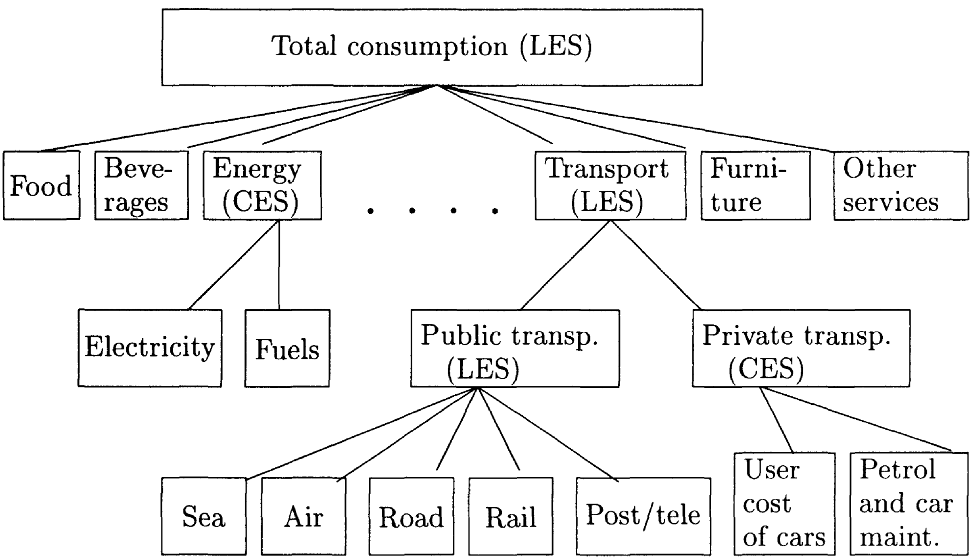
Figure 3.4 shows the long term marginal cost for new power plants up to a total new production capacity of 25 TWh in Norway. From the figure we can conclude that investments up to a total of approximately 10 TWh may be profitable, considering today's willingness to pay for electricity in the Norwegian market (given the regulation of the energy intensive market). Up to 20 TWh may be profitable within a foreseeable future, in particular if international carbon taxes on fossil fuels are implemented.

3.6 Consumption

3.6.1 General structure

The consumer demand functions for the 22 consumption goods in MSG-EE are derived from a specified utility tree[23], see figure 3.5. At the upper level, MSG-EE specifies a linear expenditure system (LES) for 22 commodities. Motivated by the applied analyses for which the model is designed, special attention is paid to the transport and the energy aggregate commodities. In spite of the relatively small fraction of total consumption, these goods are important when determining energy use and polluting emissions.

Figure 3.5. The utility tree in the complete demand system



In 1988 the budget share of energy consumption was approximately 6 per cent according to the Norwegian national accounts, while public transportations

[23] For a detailed presentation of the consumer system see, Aasness and Holtsmark (1993).

share was slightly less than 5 per cent, see table 3.10. The electricity share was approximately 85 per cent of the energy consumption. As shown in the table, personal transport expenditure are twice as high as public transport expenditures.

Table 3.10. Energy, public transport and total consumption, 1988

Consumption categories	Mill. Nkr	Per cent
Energy:	18 305	6.1
-oil	2 259	0.7
-electricity	16 046	5.2
Public transportation:	14 477	4.7
-sea	1 081	0.4
-air	2 200	0.7
-road	3 634	1.2
-rail	1 450	0.5
-post/telecommunication	6 112	2.0
Total	65 564	21.3
Total private consumption	308 604	100.0

In the consumption model, the transport aggregate is based upon a three-level utility tree, see figure 3.5. At the lower level there is substitution between air transport, sea transport, road transport, rail transport and post and telecommunication. At the intermediate level there are substitution between public and private transport, and at the top level there are possibilities for substitution between transport and other consumer goods. For energy, the basis is a two-level utility tree, where there is substitution between electricity and fuel at the lower level.

The utility tree is based on the assumption of non-homothetic weak separability, for instance it opens for the possibility of different Engel elasticities in the lower level transport aggregate. The aggregate demand system is derived from rational consumer behaviour in 13 household groups. The Stone-Geary utility structure is a Gorman polar form which permits perfect aggregation over household specific demand functions. The number of households, the number of children and the number of adults are important variables in the aggregate demand functions. The model is calibrated exploiting both micro- and macro-econometrics.

3.6.2 The top level LES

The consumption (C_j) for the 22 commodities at the upper level LES system of the model is specified as follows

$$C_j = \gamma_{j0}N + \sum_{i=0,1,2} \gamma_{ji}A_i + \beta_j \frac{W-M}{PC_j} + C_j^E, \tag{69}$$

where γ_{j0} is the average minimum consumption for a household and N is the number of households. The parameter γ_{ji} reflects additional consumption for a household with children and one or more adults, and A_1 is the number of children and A_2 is the number of adults. The marginal budget share for commodity j, β_j is multiplied with total expenditure W by M, which is an aggregate of minimum consumption expenditure over households, see Aasness and Holtsmark (1993), PC_j is a price index for commodity j, and C_j^E is an error term. For $j = U, T$, we get the energy and the transport aggregate, respectively. The γ_{Ti} parameter is then an aggregate of the minimum demand for transport at the upper level and a non-homothetic parameter at the lower level for public transport. In table 3.11 the estimated parameter values are presented. A main result is the large estimated minimum expenditures for almost all commodities, something which imply relatively small substitution possibilities between the top level LES commodities. From an energy point of view, it may also be interesting to note that the relative large fixed minimum consumption for that commodity may reflect increasing returns to scale in the households use of energy.

Table 3.11. Parameter values in the top level LES

Commodity group		Minimum consumption[a] Fixed	Extra child	Extra adult	Marginal budget share
Code	Name	γ_0	γ_1	γ_2	β
00	Food	6 164	8 344	9 382	0.060
11	Beverages and tobacco	3 270	1 228	1 062	0.067
U	Energy[b]	6 316	999	1 355	0.017
14	Transport[c]	-3 916	2 244	2 893	0.067
15	Other goods	-621	1 271	1 934	0.032
21	Clothing and footware	-1 236	2 956	4 011	0.066
22	Other household goods	904	567	222	0.015
23	Other goods for recreation activities	1 159	898	1 296	0.048
31	User cost of cars	-6 438	1 079	6 354	0.073
41	Funiture etc.	1 636	554	544	0.061
42	Durabel consumer goods	317	405	392	0.023
50	Rents	7 157	3 107	-1 095	0.151
61	Public transports[c]	2 052	-797	1 723	0.037
63	Entertainment, education etc.	-303	347	1 630	0.016
64	Various household services	1 329	566	-148	0.010
65	Other services	-1 510	1 043	2 236	0.120
66	Tourism abroad	-1 530	37	891	0.138
	Sum	14 750	24 851	34 683	1.000

[a] Measured in 1988 Nkr.
[b] A CES aggregate, see table 3.12.
[c] Based on sublevels LES, see table 3.13 and 3.14.

3.6.3 Energy consumption

The residential energy use in MSG-EE consists of two energy commodities; Electricity (E) and Fuel oils (F^X) (excluding transport oils). This energy group, energy for stationary combustion and technical purposes, is a CES-aggregate of the two inputs. This reflects a rather simple specification of the household's energy demand. The dual price function for energy, PU, in MSG-EE is then given by

$$(70) \qquad PU = \left[\omega_U PE^{1-\sigma_U} + (1-\omega_U)\left(PF^X\right)^{1-\sigma_U}\right]^{1/(1-\sigma_U)} .$$

PU is a CES function of the electricity price (PE) and the fuel oil price (PF^X), and ω_U and σ_U are estimated share coefficients and elasticity of substitution, respectively. The demand functions for electricity (C_E) and fuel (C_{F^X}) may be written as

$$(71) \qquad C_j = C_U\, \omega_U \left(\frac{PU}{Pj}\right)_U^{\sigma} + C_j^E, \quad j = E, F^X,$$

where C_U is total energy and C_j^E is an error term. From table 3.12 we find that the estimated distribution parameter is approximately equal to the base year expenditure share, see table 3.10. The elasticity of substitution is set to 0.5, which is comparable to findings in other studies.

Table 3.12. Parameters in the sub level CES for Energy

Commodity group Code	Name	Distribution parameter ω
12	Electricity (ω_U)	0.868
13	Fuels ($1-\omega_U$)	0.132
	Elasticity of substitution (σ_U)	0.5

3.6.4 Consumption of transport services

The residential sector uses own cars for transportation (private transport) and demands public transport. Public and private transport is modelled as a LES aggregate in MSG-EE. The expenditure on public and private transport (C_{PTj} for j = public transport, private transport) is then formulated as

$$(72) \qquad C_{PTj} = \gamma_{PTj}N + \sum_{i=0,1,2} \gamma_{PTij}A_i + \beta_{PTj}\frac{W_T - M_T}{P_{PF_j}} + C_j^E,$$

where γ_{PTj} and γ_{PTij} for public transport is an aggregate of minimum consumption at the intermediate level and the bottom level, respectively. Parameter estimates are shown in table 3.13. The main result is the large substitution possibilities between private and public transports. It is also worth mentioning that the number of children and adults have a positive effect on the demand for private transport, but a negative effect on the demand for public transport. One way of interpreting this, is that more persons in a car will reduce the individual cost, while public transport costs per person is more or less constant.

Table 3.13. Parameter values in the intermediate level LES for Public transport

Commodity group	Minimum consumption[a] Fixed γ_0	Extra child γ_1	Extra adult γ_2	Marginal budget share β
Private transport	-3 877	1 298	394	0.783
Public transport	3 623	-1 213	-368	0.217
Sum	-254	85	26	1.000

[a] Measured in 1988 Nkr.

Public transport is split into five transport commodities, sea transport (C_S), air transport (C_L), road transport (C_V), rail transport (C_B) and post and telecommunication (C_P). The demand functions are formulated as follows;

$$C_j = \gamma_{j0}N + \sum_{i=1,2} \gamma_{ij}A_i + \frac{\beta_j}{PC_j} \left(W_{PTk} - M_{PT0}N - \sum_{i=1,2} M_{PTi}A_i \right) + C_j^E, \quad (73)$$

for k = public transport. Similar to the intermediate level LES for transport, the bottom level estimated parameters for total minimum consumption are small, and reflects large substitution possibilities, see table 3.14.

Table 3.14. Parameter values in the bottom level LES for Public transport

Commodity group		Minimum consumption[a]			
		Fixed	Extra child	Extra adult	Marginal budget share
Code	Name	γ_0	γ_1	γ_2	β
75	Road transport	0	423	847	0.049
76	Air transport	0	-170	-341	0.238
77	Railway, tramway and subway transport	0	183	366	0.021
78	Transport by boat and ferry	0	54	107	0.055
79	Postage, telephone and telegram	0	-433	-865	0.637
	Sum	0	57	114	1.000

[a] Measured in 1988 Nkr.

Private transport expenditure is allocated to the user cost of cars (i.e. rent and depreciation of the capital), petrol and car maintenance. From a CES structure the demand functions becomes

$$C_j = C_{PTj}\omega_{PTj} \left(\frac{PC_{PTj}}{PC_j} \right) + C_j^E, \quad (74)$$

for j = petrol and car maintenance, user cost of cars. The estimated distribution parameter, ω_{PTj}, reflects the high budget share for the user cost of cars, see table 3.15. The low elasticity of substitution may reflect that other attributes than investment cost and petrol prices are important when selecting type of car. It also may reflect a limitation law at the micro level, i.e. the elasticity of substitution in macro is an aggregation effect which may be small since the differences in car technology as an average over the population of cars is rather small.

Table 3.15. Parameter values in the bottom level CES for Private transport

Commodity group		Distribution parameter
14	Petrol and car maintenance	0.392
31	User cost of cars	0.608
	Sum	1.000
	Elasticity of substitution	0.1

3.6.5 Total elasticities

Table 3.16 presents elasticities in the total consumer demand system. Of special interest in our context is the low Engel elasticities for the energy commodities and the high Engel elasticities for petrol and car maintenance and user cost of cars. The public transport Engel elasticities are on average below unity, but vary with the highest for air transport and lowest for rail, tram and subway transport. It is also noteworthy that the household elasticity of private transport is negative, which may reflect a high Engel elasticity and that smaller households spend relatively little on private transport. In contrast, more households means more energy consumption for stationary combustion.

Table 3.16. Elasticities for the average household and macro demands in the complete demand system

Commodity group			Budget share	Engel elasticity	Household elasticity	Child elasticity	Adult elasticity	Direct Cournot elasticity	Direct Slutsky elasticity
Codes		Name	w_i	E_i		P_{i1}	P_{i2}	e_{ij}	s_{ii}
00		Food	0.193	0.310	0.602	0.503	0.563	-0.193	-0.133
11		Beverages, etc.	0.066	1.016	0.767	-0.093	-0.272	-0.499	-0.433
U		Energy[a]	0.063	0.263	2.119	0.132	0.175	0.865	0.882
	12	Electricity	0.055	0.263	2.119	0.132	0.175	-0.183	-0.169
	13	Fuels	0.008	0.263	2.119	0.132	0.175	-0.452	-0.450
14		Petrol, etc.	0.046	1.467	-2.353	0.174	0.168	-0.692	-0.624
15		Other goods	0.036	0.898	-0.673	0.185	0.321	-0.429	-0.397
21		Clothing, etc.	0.075	0.871	-0.644	0.248	0.324	-0.437	-0.371
22		Other househ. goods	0.017	0.900	0.898	0.163	-0.256	-0.419	-0.404
23		Goods for recr. act.	0.046	1.056	0.214	-0.095	-0.120	-0.507	-0.458
31		User costs of cars	0.065	1.128	-2.553	-0.163	0.832	-0.550	-0.477
41		Furniture etc.	0.045	1.341	0.363	-0.300	-0.491	-0.635	-0.575
42		Durabels	0.018	1.273	-0.024	-0.129	-0.318	-0.591	-0.568
50		Rents	0.112	1.347	0.966	-0.083	-0.803	-0.673	-0.522
61		Public transport[a]	0.045	0.817	0.733	-0.520	0.172	0.604	0.641
	75	Road transport	0.013	0.144	0.129	0.384	0.983	-0.168	-0.166
	76	Air transport	0.006	1.404	1.260	-1.310	-0.535	-1.424	-1.415
	77	Rail transp., etc.	0.005	0.143	0.128	0.386	0.985	-0.168	-0.167
	78	Sea transport	0.004	0.546	0.490	-0.156	0.499	-0.627	-0.625
	79	Post, telecom.	0.017	1.359	1.220	-1.250	-0.481	-0.990	-0.966
63		Education, etc.	0.024	0.664	-0.499	-0.025	0.656	-0.314	-0.298
64		Various services	0.013	0.755	1.992	0.347	-0.533	-0.351	-0.341
65		Other services	0.073	1.647	-0.991	-0.379	-0.378	-0.781	-0.661
66		Tourism abroad	0.063	2.183	-1.244	-0.763	-0.877	-0.997	-0859

[a] This aggregate is measured in expenditure at current prices, which explains the positive direct elasticities.

Table 3.17 reports Slutsky elasticities for the energy and transports commodities. We note that increased prices of petrol leads to a relatively substantial decrease in the stock of cars. The income effect and the substitution effect draws in the same direction. We also see that a 1 per cent increase in purchaser prices of cars will reduce the use of petrol more than the same relative increase in petrol prices. In the transport aggregate we find that the substitution effect dominates the income effect. Another interesting aspect is that air transport and post and telecommunication are the most income elastic goods. From the Slutsky elasticities we also find considerable substitution possibilities between the clean postage and the polluting air transport. It is also noteworthy that with increasing prices of bus and railway transport, the income effect dominates the substitution effect so that private transport decreases. Increased prices of the other public transport services results in increased private transport, because the substitution effect dominates the income effect.

Table 3.17. Slutsky elasticities for selected goods in the demand system[a]

Commodity group		sj.12	sj.13	sj.14	sj.31	sj.75	sj.76	sj.77	sj.78	sj.79
12	Electricity	-0.175	0.049							
13	Fuels	0.325	-0.451							
14	Petrol, etc.			-0.309	-0.324	0.007	0.033	0.003	0.008	0.088
31	User cost of cars			-0.208	-0.424	0.007	0.033	0.003	0.008	0.088
75	Road transport			0.023	0.035	-0.178	0.016	0.001	0.004	0.042
76	Air transport			0.198	0.307	0.028	-1.452	0.012	0.032	0.371
77	Railway, etc.			0.022	0.035	0.003	0.016	-0.178	0.004	0.042
78	Sea transport			0.083	0.128	0.012	0.058	0.005	-0.651	0.155
79	Post, tele.			0.192	0.299	0.028	0.135	0.012	0.031	-1.185

[a] For a detailed presentation of the complete Slutsky elasticities, see Aasness and Holtsmark (1993).

4. Growth potential, energy demand and air pollution in the baseline scenario

E. Holmøy and B. Strøm

4.1 The choice of focus

According to the Ministry of Finance (1993, p. 99), the purpose of long run projections based on general equilibrium models

> "...is not to make detailed forecasts about the distant future, but rather to exploit systematically the available information about the demographic trends and the resource constraints in order to
>
> 1. Assess the growth potential under given assumptions about the supply and utilization of labour and technological progress.
> 2. Shed light on the long run consequences of decisions already made or under consideration.
> 3. To reveal long run trends which are relevant for the short- and medium-term decision making."

In the context of this book, the long run baseline (or reference) scenario presented in this chapter, serves mainly as a background for the analysis carried out and described in the rest of the book; the issues of carbon taxation and economic growth (chapter 5), the effects of a liberalized national and Nordic market for electricity (chapter 6), and transport issues (chapter 7). These sensitivity calculations are all based on reference scenarios that are minor variants of the scenario presented here. The description of the baseline scenario in this chapter will therefore not be complete[24]. Additional relevant aspects and

[24] By and large, the baseline scenario is equal to the one presented in the Government's Long Term Programme (Ministry of Finance, 1993).

details of the baseline scenario will, when necessary, be described in the chapters to come.

Still, we will in this chapter give examples of issues related to the three aspects of model simulations put forward by the Ministry of Finance. As an example of the first aspect, the baseline scenario will quantify the impact on production and consumption caused by stagnation in the growth of the labour force. The second aspect is illustrated by the projected development of energy demand and emissions to air resulting from the incentives implied by the existing tax structure. Of crucial importance for emissions to air, is the use of fossil fuels. A concrete example of the third aspect is the question of whether or not to introduce power production based on natural gas into the Norwegian electricity system.

4.2 Development of key exogenous variables

Most essential among the exogenous variables for the simulations of the MSG-EE model are those related to technical change and resource constraints. When the growth of capital is determined endogenously, these constraints are represented by the growth in productivity, labour supply and the possibilities for further exploration of natural resources like petroleum reserves and the hydro power potential. Another essential constraint is the target with respect to the development of foreign debt, which imposes an intertemporal constraint on the aggregate consumption possibilities. The precise quantification of the foreign debt accumulation will reflect normative priorities on the possible intertemporal aggregate consumption paths. Accordingly, the baseline scenario is not a neutral description of what is likely to happen in the future, but rather a plan derived from an instrument-target approach to economic planning. With this interpretation in mind, we turn to a survey of the assumptions made about key exogenous variables outside government control.

4.2.1 Labour supply

Demographic projections for Norway indicate important changes in the share of the population belonging to the labour force. The number of persons between 16 and 74 years of age will grow only very slowly compared to historical trends, in particular after year 2010. On the other hand, after about year 2015, the share of persons older than 73 years old will grow rapidly, see table 4.1.

The effective supply of labour is further determined by the participation rate and the average working hour per employee. Both of these variables have to be determined outside the model. For the baseline scenario, the assumptions regarding the effective labour supply were based on demographic projections calculated by the micro simulation model MOSART developed at the Statistics Norway, see Andreassen (1993).

Table 4.1. Historical and projected future development of the labour force and number of pensioners in Norway. 1000 persons

	1970	1980	1991	2010	2030
Old age pensioners	335	520	616	580	820
Disability pensioners	120	160	239	360	370
Widow/widower pensioners	58	57	77	65	70
Total pensioners	523	737	932	1 005	1 260
Labour force	1 653	1 940	2 126	2 380	2 340
Pensioners in per cent of the labour force	32	38	44	42	54

The present unemployment in the labour market is assumed to be gradually eliminated before year 2000. This contributes to an increase in the employment level equal to 0.5–0.7 per cent each year over the period 1990–2010. The average working hour is assumed to decline by 9 per cent from 1990 to 2010 and then to remain constant throughout the simulation period. This implies a break in the historical rate of reductions in working hours. All together, these assumptions implies that the labour supply of man hours will increase by approximately 5 per cent from 1990 to 2010, and then be reduced by 1 per cent from 2010 to 2030.

4.2.2 Total factor productivity (technical change)

For the mainland industries (i.e. outside the off shore petroleum activity), the total factor productivity is assumed to grow by an average annual rate of approximately 1 per cent throughout the simulation period. This growth rate is higher than experienced in the 1980s, but below the average observed for the 1970s (see Holmøy *et al.*, 1992).

4.2.3 The petroleum sector

The baseline projection assumes that the production of petroleum increases from about 132 million tonnes oil equivalents (mtoe) in 1992 to 165 mtoe in year 2000. The increase in the production of crude oil will stagnate near the end of the century, thereafter production will gradually decrease as the reserves are depleted. In a period around year 2000 increased gas production will make up for the reduction in crude oil production, but thereafter the total production from the petroleum sector will decline steadily, reaching a level of 87 mtoe in year 2030.

4.2.4 International markets

The baseline scenario assumes an average annual growth in GDP of 2.5 per cent in the Norwegian trading partners up to year 2000. From then on, the growth rate is assumed to be lowered to 2 per cent because of slower growth in the international labour force. For a comparison, the GDP growth rate for the trading partners has averaged around 2.2 per cent over the period 1970–1990.

Traditionally, trade volumes have grown faster than GDP. Also the completion and extension of the internal market in the European Union is likely to lead to a stronger growth in Norwegian export markets. Thus, the annual growth in the export markets are assumed to average about 4 per cent per year up to year 2000. Thereafter, the annual growth rate is assumed to decline gradually to 2.5 per cent due to slower economic growth and because the potential for further gains from international trade and specialization are supposed to be diminishing.

The increase in world market prices is assumed to be moderate for the whole simulation period. Consumption prices abroad are assumed to grow with 3 per cent per year, while the annual increase in the prices of imports to Norway averages about 2.5 per cent.

Essential to Norway is the development in prices of petroleum products. Measured in 1993 prices, the world market price on crude oil is assumed to stay constant at 130 Nkr per barrel throughout the simulation period. The price of natural gas is assumed to follow the price of crude oil.

Norway is assumed to participate in free international capital markets, implying that the real rate of interest is determined internationally. After a slight reduction until year 2000, the long-term real interest rate is assumed to stay constant at an annual rate of 3 per cent.

4.2.5 The external balance

The current account is positive in the whole simulation period. Up to year 2010 the current account constitutes on average 3.4 per cent of GDP, reflecting that the composition of the national wealth shifts from petroleum reserves to net financial claims on the rest of the world. Net financial wealth will constitute approximately 60–70 per cent of GDP in year 2010. The average current account/GDP ratio is considerably lower in the period 2010–2030, the net wealth/GDP ratio being reduced to around 40 per cent in year 2030.

According to the discussion of the different closure rules in chapter 2, such a development requires a specific development in the average domestic wage rate in order to be consistent. Thus, under the above assumptions, the wage rate is allowed to increase by 4–5 per cent on an annual basis. This implies an average annual increase in the real wage rate of 1.5 per cent from 1990 to 2010, and 1.8 per cent from 2010 to 2030. This is below the historical trend; from 1970 to 1990 the real wage rate increased on average by 2 per cent per year. According to these assumptions, the international competitiveness[25] will improve by 10 per

[25]Measured by average wage cost per unit of production in Norway relatively to that of the

cent during the 1990s. From then on, the relative international competitiveness will remain unchanged for the rest of the simulation period.

4.3 Simulated growth in production and consumption

One of the most conspicuous results from the long–term projection is that the growth potential for the Norwegian economy is moderate relative to historical trends. The average annual growth rate of GDP was almost 5 per cent in the 1970s. Through a more or less steady decline, the baseline scenario calculates a growth rate close to 1 per cent at the end of the simulation period, see table 4.2. For a comparison, the corresponding annual growth rate for the OECD countries as a whole is assumed to be around 2.3 per cent in the period 2000–2030.

Table 4.2. Historical and simulated future development in major supply and demand components. Average annual growth in fixed prices. Per cent

	1970-1980	1980-1990	1990-2015	2015-2030
Man hours	0.08	-0.05	0.14	-0.10
Real capital	4.5	3.1	2.1	1.3
Total factor productivity	2.0	0.5	1.0	0.9
GDP	4.7	2.5	1.7	1.1
GDP, mainland	3.7	1.6	1.8	1.3
GDP, manufacturing industries	1.5	0.3	1.6	1.8
Net disposable real income	4.0	1.3	2.1	1.7
Exports	5.4	5.0	2.1	1.5
Exports net of petroleum products	2.8	5.2	2.7	2.1
Imports	3.4	2.4	2.6	1.6
Private consumption	3.6	1.8	2.4	1.6
Government consumption	5.3	3.2	1.5	0.1
Gross investment in mainland industries[a]	5.3	-0.8	2.1	1.2

[a] Including dwellings.

Before commenting further on the simulation results, we briefly present a framework for identifying the sources of economic growth along a growth path.

4.3.1 A growth accounting framework

The following framework provides an approximate account of the sources behind real GDP growth for the total economy. Because real GDP is the dominant component in real national income, and since the time path of national income restricts the consumption possibilities in an intertemporal perspective, the framework is relevant, though not exhaustive, for identifying the sources behind consumption growth.

MSG-EE adopts the national accounting definition of GDP. Measured in basic

trading partners.

prices, national GDP is the sum of value added in fixed basic prices in each industry. In order to interpret the results from the simulation, it is instructive to relate the GDP growth rate to developments in more fundamental variables. Define Q and L as real value added and labour input, respectively. Let $\widehat{Q}$ and $\widehat{L}$ denote the relative change in these variables. A subscript j indicates that the variable is related to industry j. Let q denote the labour productivity defined as $\frac{Q}{L}$. From the definition of GDP (in fixed prices) as $Q = \sum_j Q_j$, it is straightforward to decompose the GDP growth rate in the following way:

$$\widehat{Q} = \widehat{L} + \widehat{q} + m^L\left(\frac{q_j}{q}, \widehat{Q_j}\right) \equiv \widehat{L} + \widehat{q} + m^L\left(\frac{q_j}{q}, \widehat{L_j} + \widehat{q_j}\right). \tag{75}$$

Here, $\widehat{q}$ is the average of the industrial labour productivity growth rates weighted by the industrial employment shares, and m^L is the covariance operator based on the same weighting scheme. The last term in equation (75) accounts for the effect on aggregate real value added growth from disproportionate industrial growth in employment and labour productivity. A positive covariance implies that real value added on average grows faster in industries with a labour productivity above the average level. Quantified with annual data, equation (75) is a first order approximation which improves the smaller are the changes in the variables.

Value added in current and fixed prices have clear definitions as gross production less intermediate inputs. However, the existence of real value added as a well defined volume index requires the production technology to be separable into real value added and other intermediate inputs. This simplifying, but restrictive, assumption is not imposed on the industry technologies in MSG-EE. However, using it as an approximation and additionally abstracting from the presence of sectorial taxes, makes it possible to decompose the growth in labour productivity according to the well known growth accounting formula:

$$\widehat{q_j} = \Theta_{Kj}\widehat{k_j} + t_j, \tag{76}$$

where $\widehat{k_j}$ is the growth rate of the capital/labour ratio, and Θ_{Kj} is the cost share of capital in value added which reflects the marginal elasticity of capital in the real value added production function under competitive producer behaviour. The term t_j is the Hicks-neutral technical change rate. The first term in equation (76) represents the impact of increased capital intensity on value added growth.

Defining P_Kj and P_Lj as the factor prices of capital services and labour respectively, and defining units such that the price of value added equals unity, the labour productivity level can be written as:

(77) $$q_j = P_{Kj}k_j + P_{Lj}.$$

Taking equations (76) and (77) into account, it is possible to decompose the GDP growth rate according to the following formula:

$$\begin{aligned} \widehat{Q} &= \widehat{L} + t + \Theta_K \widehat{k} + \Theta_K m^K \left(\frac{P_{Kj}}{P_K}, \widehat{L_j}\right) \\ &+\Theta_K m^K \left(\frac{P_{Kj}}{P_K}, \widehat{k_j}\right) + \Theta_L m^L \left(\frac{P_{Lj}}{P_L}, \widehat{L_j}\right), \end{aligned} \tag{78}$$

or alternatively

$$\widehat{Q} = \widehat{L} + t + \Theta_K \widehat{k} + \Theta_K m^K \left(\frac{P_{Kj}}{P_K}, \widehat{K_j}\right) + \Theta_L m^L \left(\frac{P_{Lj}}{P_L}, \widehat{L_j}\right), \tag{79}$$

where P_K and P_L are the average price indices of capital services and labour, and t is the weighted average[26] of the industrial technical change rates.

The first three terms on the right hand side of equation (79) attribute GDP growth to the following aggregate sources:

1. growth in labour supply,

2. average Hicks-neutral technical change, and

3. average capital deepening.

The latter depends on the average cost share of capital, which reflects its aggregate marginal elasticity. Of these three effects, only the labour supply is strictly exogenous in MSG-EE. In the growth accounting framework, the average technical change is also exogenous, since these growth rates are exogenous at the industry level. However, over time a second order effect will emerge because the weights used for the average rate will vary due to a disproportionate growth in industrial value added. Whether the aggregate capital deepening is exogenous depends on the choice of closure rule. Even if K is exogenous, the growth contribution from capital deepening will vary over time due to the second order effect generated by changes in the aggregate cost share of capital.

The last two terms in equation (79) account for the growth effect due to the reallocation of labour and capital. If, for example, the covariance m^L (m^K) is positive, a reallocation of labour (capital) increases the effective supply of labour (capital) services because the average marginal labour (capital) productivity is increased.

[26] The weights are the industrial shares of total real value added.

Compared to equation (79), equation (78) decomposes the gain from the reallocation of capital into two sources of industrial capital growth: 1) changes in employment for a fixed capital/labour ratio, and 2) changes in the capital/labour ratio for a fixed employment level. The potential role of these effects clearly depends on the industrial differences in the prices of labour and capital services.

The growth in the industrial capital/labour ratios depend on the endogenous evolution of relative factor prices and the estimated possibilities for factor substitution. At this point, it is important to remember that the actual growth in the capital/labour ratios are interrelated with the rate of technical change. The reason is that technical progress brings about a reduction in unit costs and prices of produced factors, such as capital goods. Thus, technical change has an indirect growth effect as well as a direct one, since it causes labour productivity to grow through capital deepening.

4.3.2 Accounting for growth in the baseline scenario

The accounting framework laid out above provides a clearer understanding of the underlying sources of the moderate growth perspectives reported in table 4.2. However, there are several reasons why the sum of the components in the growth accounting formula (79) does not reproduce the simulated GDP growth exactly. One reason is that the formula represents a local approximation to the simulated growth, and over time the weights in the formulas change and reduce the accuracy of the approximation. In order to reduce this problem we have separated the simulation period into two subperiods, 1989–2015 and 2015–2030. This particular choice is motivated by the fact that the decrease in the labour force starts in the years 2013–2015. Thus, the division into these periods is also needed to show how the demographic changes are transmitted into the growth performance.

Table 4.3 represents the empirical counterpart to the growth accounting formula (79), with the figures being transformations of the relevant simulated results. The figures (in table 4.3) reveal that the approximate quantification of formula (79) is able to account for almost all the simulated GDP growth. This suggests that the decomposition in table 4.3 can be used with confidence when assessing the contribution to growth from different sources.

The figures in table 4.3 clearly show that the projected GDP growth can almost entirely be attributed to increased labour productivity. The growth in labour supply is weak or decreasing over the whole simulation period. This represents a continuation of past trends.

What can be said about the sources behind the increase in labour productivity?

Table 4.3. Accounting for GDP growth in the simulated projection. Average annual percentage growth

	1989-2015	2015-2030
1. Growth in total man hours	0.14	-0.10
2. Growth in labour productivity (2.1+2.2)	1.85	1.43
2.1 Technical change	1.00	0.90
2.2 Growth contribution from capital deepening	0.85	0.53
2.2.1 Marginal elasticity of capital	0.43	0.37
2.2.2 Average capital deepening	1.98	1.42
3. Growth contribution from reallocation of labour and capital (3.1+3.2)	-0.23	-0.18
3.1 Growth contribution from reallocation of capital	-0.26	-0.20
3.2 Growth contribution from reallocation of labour	0.03	0.02
Sum of contributions (1+2+3)	1.76	1.15
- Simulated GDP growth	1.68	1.11
= Approximation error	0.08	0.04

In MSG-EE, growth in total factor productivity (TFP) is the fundamental exogenous source. In addition, there may be productivity changes due to variations in relative factor prices which are not caused by TFP. The impact of TFP on GDP is spread through the following channels, which are identified by the growth accounting framework: 1) a direct effect, 2) an indirect effect via capital deepening, 3) indirect effects coming through gains from reallocations of labour and capital.

The figures in table 4.3 suggest that the direct effect on GDP growth from TFP growth (line 2.1) is of the same magnitude as the induced effect from capital deepening (line 2.2) in the first subperiod. Moreover, these two effects dominate the losses from reallocation of labour and capital (line 3), which account for - 0.23 per cent of the GDP growth in this period. There is a striking change in the relative importance of these sources when we compare the average growth rates in the two subperiods. The growth in overall labour productivity drops by about 0.4 percentage points to 1.4 per cent per year in the last subperiod. According to the growth accounting framework, the most important "reason" is the strong reduction in capital deepening, while the changes in the contributions from technical change and reallocations are much less significant.

Capital deepening (line 2.2.2) averages 2.0 per cent per year in the first subperiod and only 1.4 per cent in the last one. We find that the corresponding growth contribution is reduced from 0.9 to 0.5 per cent. This reduction is also due to a moderate reduction of the average marginal elasticity of capital.

A closer examination of factor reallocation reveals that it is the reallocation of capital that is important along the simulated growth path. Capital tends to move from industries offering a high return into industries where the marginal productivity is below average. The single most important factor movement is the reduction in the capital stock in the extremely profitable petroleum sector. The capital stock in fixed prices falls by 17.6 per cent (0.72 per cent per year) between 1989 and 2015 and by -39.7 per cent (3.11 per cent per year) between 2015 and 2030. The importance of this reduction can be better understood by considering the contribution from these changes to the covariance between capital changes and real returns to capital. In the period 1989–2015, this covariance averages - 0.63 per cent per year, of which the element associated with the petroleum sector contributes -0.47 per cent. The picture is by and large the same in the second subperiod although the average reduction of the capital stock is greater. The explanation is that the resource rent in oil and gas depletion, which is included in the return to capital in the model, falls over time as the most profitable oil fields are drained. The resource rent in the expanding production of natural gas is much smaller than in crude oil production. One can argue that this element of decreasing returns to scale should be attributed to a decrease in the technical change rather than capital returns. However, the point of the discussion in this section is to trace how the model works, not to question its concepts and structure.

4.3.3 Consumption possibilities

Disposable real income grows at the same rate as GDP in the subperiod 1990–2015 and slightly faster than GDP during 2015–2030. The reason for this difference is the interest income on the accumulated current account surpluses. As noted above, these surpluses reflect, to some extent, that the petroleum reserves are drained, and that the reduction of the petroleum wealth is not included in the calculation of disposable real income.

The projected scenario implies a shift from government to private consumption. The former is basically exogenously determined and is assumed to grow much more slowly than it did during the past 20 years. The rationale for this assumption is the concern for a balanced public budget in the long run. The ability to pay for government consumption decreases because of 1) lower income from the petroleum sector, 2) moderate growth in the direct and indirect tax base, 3) preferences for keeping the tax rates stable in light of the recent tax reform and international tax competition, 4) a strong increase in the amounts of transfers to pensioners. However, the slowdown of government consumption growth is not sufficient to avoid a public deficit in the last 20 years of the simulation period. But government financial wealth still constitutes 4.8 per cent of GDP in 2030 due to accumulation in the years up to 2010. The structure of government income and expenditures is examined in greater detail below.

The annual private consumption growth averages 2.4 per cent in the period 1990–2015 and 1.6 per cent in the period 2015–2030. Thus, private consumption is projected to grow in line with the historical trend. In per capita terms, private consumption in 2030 exceeds its 1990-level by 105 per cent. It is mainly reduced savings, through lower investment in the petroleum sector and net exports, that make such an increase possible. Investment in the petroleum sector is exogenously determined in MSG-EE, and the reduction reflects that the reserves are drained.

4.4 Energy demand in the baseline scenario

4.4.1 Will gas power supplement hydro power in the future?

Today, Norwegian electricity demand is met by hydro power technology. However, expansion of the hydro power capacity is increasingly costly when waterfalls are developed in an optimal order. On the other hand, expansion of gas power capacity exhibits nearly constant returns to scale. Therefore, if electricity demand continues to grow, gas power will eventually become profitable on the margin. However, the relative profitability of the two technologies does not only depend on the aggregate electricity demand. It is also affected by the simulated equilibrium prices of the input factors employed in the two sectors. In particular, the costs associated with gas power production also include a CO_2 tax and the cleaning of NO_x emissions.

According to the projections, hydro power will continue to be the most profitable technology for electricity production in the simulation period. But this conclusion is not at all robust because the simulations indicate that the long run marginal costs are approximately the same for hydro and gas power production at the end of the simulation period. In 2030 all available waterfalls will have been developed, and the production has increased to 141 TWh, or 16 per cent over its 1990 level. Therefore, stronger growth in electricity demand, a lower natural gas price and a lower CO_2 tax are examples of changes that will make gas power profitable at least at the end of the simulation period.

To identify reasons for the increase in electricity demand, it is instructive to decompose the aggregate growth. Total electricity demand (E) has three main sources: Household consumption (C_E), input demand from the production sector (E_X) and net export (E_A). Net export of electricity is relatively small compared to the other main demand components and are exogenous in MSG-EE. We can decompose growth in electricity demand as follows:

$$(80) \qquad \widehat{E} = \lambda_H^E \widehat{C_E} + \lambda_X^E \left[\sum_j \lambda_j^E \widehat{e_j} + \widehat{L} + m^L \left(\frac{e_j}{e} - 1, \widehat{L_j} \right) \right] + \lambda_A^E \widehat{E_A},$$

where λ_i^E, $i = H, X, A$ is the share of component i in the total electricity demand, $e = \frac{E}{L}$ is the electricity intensity which is defined for both industries and the total production sector, and j indicates sector. As before a hat above a variable indicates the relative change rate of the variable.

Household consumption of electricity is determined in two-steps. First, a given demand for energy is allocated to electricity and fuels (F) according to a homothetic CES preference structure. Second, energy demand is a function of total consumption expenditure and the ideal price index for energy, according the top level Stone-Geary preference structure. The growth in household electricity demand can therefore be written:

$$\widehat{C_E} = -\sigma_H^U \Theta_{HF}^U \left(\widehat{P_C^E} - \widehat{P_C^F}\right) + \eta^U \hat{V} - \widehat{P_C^U}, \tag{81}$$

where σ_H^U is the elasticity of substitution between electricity and fuels in household consumption and Θ_{HF}^U is the cost share of fuels in household energy expenditure. Furthermore, η^U is the Engel elasticity of energy, V is total household consumption expenditure and P_C^U is the ideal price index for energy.

Also in industries where input composition is endogenous, is the electricity demand determined in a two-step procedure. In these industries, the growth rate of the industrial electricity intensity can therefore be written:

$$\hat{e_j} = -\sigma_j^U \left(\widehat{P_j^E} - \widehat{P_j^F}\right) + \widehat{u_j}, \tag{82}$$

where u_j is the energy intensity in industry j and the other symbols have analogous definitions to those for the household. The industrial energy intensity is a function of the factor prices of labour, capital, energy and other material inputs.

The decomposition gives the results presented in tables 4.4[27] and 4.5. The approximation error is negligible in the first subperiod, but relatively significant in the second one. Households consume 28-29 per cent of total demand measured in physical units, so that the evolution of private consumption is important to the aggregate growth rate. However, the simulated contribution is significantly smaller than would have been the case if electricity consumption maintained its volume share of aggregate private consumption, which grow at an average annual rate of 2.4 and 1.6 per cent in the two subperiods. The decomposition of the growth in electricity consumption by households reveals that substitution of electricity for fuels is not an important reason for the redirection of household demand away from electricity. The main reasons are

[27]The starting point for the first subperiod was changed from 1989 to 1990 in the growth accounting for electricity demand, because of a sharp drop in the net exports from 1989 to 1990. This makes 1989 a very untypical year compared to the whole simulation period.

the low Engel elasticity of energy and that the price index for energy consumption increases relative to the aggregate consumer price index.

Table 4.4. Accounting for aggregate electricity demand in the simulated projection

	1990-2015	2015-2030
1. Contribution from household consumption (1a*1b)	0.23	0.18
1a. Share of total demand, per cent	27.80	29.10
1b. Growth in household consumption of electricity (1b1+1b2)	0.81	0.63
1b1. Substitution of electricity for fuels	-0.04	-0.04
- Elasticity of substitution	0.50	0.50
- Change in the energy price index relative to the electricity price	-0.08	-0.08
1b2. Growth in household consumption of energy	0.85	0.67
2. Contribution from input demand in production sectors (=2a1*2b)	0.40	0.25
2a1. Share of total demand, per cent	64.6	63.2
2a2. Simulated growth in electricity input in production sectors (=2b+2b4)	0.63	0.37
2b. Growth in electricity input in production sectors (2b1+2b2+2b3)	0.62	0.39
2b1. Growth in total employment	0.14	-0.10
2b2. Growth in average electricity intensity	1.22	0.70
2b3. Covariance between reallocations of labour and electricity intensities	-0.74	-0.21
2b4. Approximation error (2a2-2b)	0.01	-0.02
3. Contribution from net export demand	-0.00	0.00
3a. Share of total demand	7.60	7.70
3b. Growth in net exports of electricity	-0.00	0.00
Sum of contributions (=1+2+3)	0.13	0.43
- Simulated growth in total electricity demand	0.65	0.52
=Approximation error	-0.02	-0.09

The use of electricity in the production sectors, absorbing nearly two thirds of total GWh consumption, is simulated to grow slower than electricity consumption by households. It is interesting to see that an aggregate model would have produced the opposite result. In the period 1989–2015 the growth in total employment and in the average electricity intensity implies a growth rate in electricity demand equal to 1.36 per cent. However, the growth pattern is characterized by a strong tendency for labour to be reallocated into industries which are less electricity intensive than the average intensity. This negative reallocation effect is estimated to be equal 0.74 percentage points in the first subperiod. In the last subperiod reallocations are much less important, and the covariance falls to -0.21. On the other hand, reduced negative impact from such reallocations is not enough to prevent the growth in electricity use in production sectors to decline over the whole simulation period. Both the drop in labour

Table 4.5. Accounting for growth in electricity intensity in industries with endogenous input composition

	1989-2015	2015-2030
Share of total electricity demand, per cent	33.30	32.30
1. Average substitution effect, change in the electricity/energy ratio (-1a.*1b.+1c.)	-0.02	-0.02
1a. Average elasticity of substitution	0.25	0.25
1b. Average change in the price of electricity relative to energy	0.13	0.08
1c. Average exogenous substitution	0.01	0.00
2. Covariance between elasticities of substitution and relative price changes	0.02	0.01
3. Growth in the average energy intensity	1.43	0.60
4. Covariance between electricity-energy ratios and growth in energy intensities	0.11	0.35
5. Covariance between reallocation of labour and electricity intensities	-0.69	-0.27
Sum of contributions (1+2+3+4+5)	0.84	0.66
- Simulated growth in average electricity intensity	0.82	0.63
=Approximation error	0.02	0.03

supply and slower growth in electricity intensities contribute to this reduction.

Of particular importance for electricity demand in the production sectors is, of course, the development of the most electricity intensive industries; Manufacture of pulp and paper articles, Manufacture of industrial chemicals and Manufacture of metals. Together, these three sectors used nearly 30 TWh in 1990, representing 31 per cent of the total domestic net demand[28]. As pointed out above, the performance of these industries is strongly influenced by the assumptions about their access to subsidized hydro power deliveries in the future. Under the present conditions, prices of deliveries to these sectors are subsidized relative to the prices paid by other consumers. In the projections it is assumed that the real price of this total contracted volume is kept constant, but additional deliveries to the three industries are assumed to be sold at ordinary market prices. With current technology and prices, production would not be profitable in these industries if they were to pay the ordinary market price for electricity, and this is assumed to be the situation throughout the simulation period. Consequently, an electricity supply equal to 30 TWh is imposed as an effective constraint on the production possibilities of the energy intensive industries. If this constraint were relaxed so that these industries had the option to increase their electricity demand at the existing favourable prices, then these industries would respond to the improved international competitiveness and to increased world market demand by expanding more than in the simulated scenario. Compared to the reported simulations, the

[28]Net demand excludes power losses in the transmission and distribution systems.

covariance capturing the effect of reallocations of labour would then have been larger. This would in turn have increased the equilibrium price of electricity, and the critical point where marginal expansion is based on gas power would be reached within the simulation period. Again, the relative detailed industry classification in the MSG-EE model is seen to be indispensable both for understanding the aggregate results and for making the simulations of relevant policy issues possible.

4.4.2 Demand for fossil fuels

The same accounting framework can be employed to analyse the demand for fuel. The treatment of electricity and fuel is symmetric in MSG-EE, so the formal decomposition of electricity demand can be duplicated for fuel. Tables 4.6 and 4.7 shows the empirical counterpart to the decomposition.

Table 4.6. Accounting for aggregate demand for fuel in the simulated projection

	1989-2015	2015-2030
1. Contribution from household consumption (1a*1b)	0.07	0.15
1a. Share of total demand, per cent	15.3	17.4
1b. Growth in household consumption of fuel	0.44	0.85
1b1. Substitution of fuel for electricity	0.25	0.29
- Elasticity of substitution	0.50	0.50
- Change in the energy price index relative to the fuel price	0.50	0.59
1b2. Growth in household consumption of energy	0.24	0.26
2. Contribution from input demand in production sectors (=2a1*2b)	0.59	0.02
2a1. Share of total demand	72.2	75.1
2a2. Simulated growth in fuel input in production sectors (=2b+2b4)	0.88	0.04
2b. Growth in fuel input in production sectors (2b1+2b2+2b3)	0.82	0.03
2b1. Growth in total employment	0.14	-0.10
2b2. Average growth in fuel intensities	1.15	0.25
2b3. Covariance between labour growth and fuel intensities	-0.46	-0.12
2b4. Approximation error (=2a2-2b)	0.06	0.01
3. Contribution from net export demand	-0.32	-0.02
3a. Share of total demand	13.6	7.5
3b. Growth in net exports of fuel	-2.53	-0.26
Sum of contributions (=1+2+3)	0.34	0.15
- Simulated growth in total fuel demand	0.39	0.15
=Approximation error	-0.05	0.00

The decomposition reveals rather different trends in the fuel consumption for the three main demand categories. Net export of fuel is significantly reduced during the period 1989–2015 and contributes by -0.32 percentage points to the growth rate of total use of fuels. In the last 15 years of the simulation period, net export accounts for a negligible part of aggregate growth. Similar to the

Table 4.7. Accounting for growth in fuel intensity in industries with endogenous input composition

	1989-2015	2015-2030
Share of total fuel demand	0.46	0.46
1. Average substitution effect, change in the fuel/energy ratio (-1a.*1b.+1c.)	0.08	0.08
1a. Average elasticity of substitution	0.25	0.25
1b. Average change in the price of fuel relative to energy	-0.30	-0.33
1c. Average exogenous substitution	0.00	0.00
2. Covariance between elasticities of substitution and relative price changes	0.02	0.01
3. Growth in the average energy intensity	1.43	0.60
4. Covariance between fuel-energy ratios and growth in energy intensities	-0.14	-0.50
5. Covariance between reallocations of labour and fuel intensities	-0.41	-0.15
Sum of contributions (1+2+3+4+5)	0.97	0.04
- Simulated growth in average fuel intensity	1.00	0.04
=Approximation error	-0.03	0.00

electricity demand, household consumption of fuel grows significantly slower than the volume index of aggregate private consumption, mostly because of the low Engel elasticity of energy consumption. However, over time, household consumption becomes more polluting as the share of fuel in total energy consumption increases. The growth rate of fuel consumption over the period 2015–2030 is nearly twice that in the first subperiod, although energy consumption grows at an almost constant rate.

On the other hand, the use of fuel in the production sectors levels off during the period 2015–2030, after growing by 0.82 per cent on average up to 2015. This discrepancy in fuel use for the household and production sectors is a consequence both of slower growth in the total production capacity and of a cleaner technology. The former capacity effect is due to the decline in labour supply and contributes by 0.14 - (-0.10) = 0.24 percentage points to the reduction of the average growth rate of fuel demand. A cleaner technology can be inferred by the growth rate of the average fuel intensity, which is significantly below the growth rate of the aggregate capital intensity and which declines over the simulation period. The reduction in the growth rate of the average fuel intensity contributes by 1.15 – 0.25 = 0.90 percentage points to the reduction of the average growth rate of fuel demand in the production sectors.

However, the sum of these aggregate effects overestimates the simulated growth rate of fuel demand in both subperiods. This is seen by the negative covariance between industrial labour growth and fuel intensities which indicates that in both periods labour is reallocated into the less fuel intensive industries. This effect is particularly important in the first subperiod when it alters the growth rate of fuel demand by 0.46 percentage points. It should be noted that the growth in the average fuel intensity is not driven by substitution from electricity to fuel. Rather, the important change in the input composition is the variations in energy intensities as defined by the energy/labour ratio. This can be seen by comparing the growth rates of average fuel and electricity intensities in tables 4.4–4.5 and 4.6– 4.7. Total input of electricity in the productions sectors grows by 0.63 and 0.37 per cent in the periods 1989–2015 and 2015–2030, respectively. The corresponding growth rates for total input of fuel are 0.82 and 0.03. Thus, to a large extent, the slowdown of the growth in electricity intensities is accompanied by a parallel development in the growth rates of fuel intensities.

However, the simulated growth rates also indicate that there is a tendency within the industries to replace electricity by fuel in the first subperiod, but this substitution is drastically reversed in the second period. It turns out that changes in the ratio between the prices of electricity and fuel does not play any important role in this respect. In both periods, this relative price increases, mainly because of decreasing returns to scale in further development of the hydro power capacity. However, this ratio affects the energy composition only in industries where such substitution possibilities have been estimated econometrically. Such industries absorb 46 per cent of the total fuel use in both subperiods. Even in industries with price dependent energy composition, the estimated elasticity of substitution is as low as 0.25 on average. Consequently, the total impact of relative prices on energy composition within the industries is almost negligible.

4.5 Emissions to air

Norway has signed several international treaties regarding emissions of several air pollutants. Additionally, Norway has unilaterally set its own targets for air pollution which are more ambitious than required under international agreements. Table 4.8 summarizes the emission targets.

Table 4.8. Some international obligations and national targets for emissions to air in Norway

	International obligations (per cent reduction)	National targets (per cent reduction)	Year of comparison	Proposed year of fulfilment
CO_2		Stabilization	1989	2000
SO_2 [a]	30	50	1980	1993
NO_x	Stabilization	30	1987	1994
NMVOC	30	30	1989	1999

[a] According to the so called Helsinki protocol. This has later been superposed by the Oslo protocol stipulating a 76 per cent reduction by year 2000.

It is widely recognized that there are strong links between economic activity and emissions to air of polluting compounds. As pointed out in chapter 2, a separate block taking these links into account has been incorporated into MSG-EE. Consequently, the model can be used to project future air emissions in a way that is consistent with the simulated economic projections. A natural question is then whether the projections imply that the official emissions targets will be met or to what extent they will be violated.

The simulated projections of emissions of SO_2, NO_x, NMVOC and CO_2, summarized in table 4.9, show that SO_2 emissions are estimated to be rather stable at the 1989-level, which is well below the target for these emissions. Emissions of NO_x decline over the simulation period, but not enough to meet the announced target. NMVOC and CO_2 emissions continue to grow in the first subperiod. In the last one, these emissions decline, especially the petroleum related NMVOC. For both compounds, however, the emissions are still above the target levels in 2030, although the gaps are considerably smaller than for NO_x emissions.

Table 4.9. Total emissions to air in the baseline scenario. Thousand tonnes

	1989	2000	2010	2030
CO_2	35 300	40 600	41 000	41 400
SO_2	58.8	46.9	48.2	52.5
NO_x	233.0	220.5	208.5	208.3
NMVOC	274.8	276.2	238.6	194.4

It is obvious from the emission model that the simulated use of fossil fuels is by far the most essential economic activity behind the emissions. Growth in total use of fuels averages 0.39 per cent between 1989 and 2015 and 0.15 per cent between 2015 and 2030, which is modest compared to the corresponding GDP growth rates, see tables 4.2 and 4.5. In this sense, one might conclude that the Norwegian economy gets cleaner over the simulation period, but the speed of this process is still too slow to meet Norway's ambitious emission reduction targets.

5. Economic impacts of a CO_2 tax

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5.1 Introduction

Analyses of the costs of reducing carbon dioxide (CO_2) emissions have attracted growing attention. Several studies have focused on the GDP losses connected with reaching different goals for CO_2 emission in USA (Barns *et al.*, 1992, Jorgenson and Wilcoxen, 1992 and Manne and Richels, 1992). In the Norwegian projects SIMEN (Bye *et al.*, 1989) and KLØKT (Moum, 1992), stabilization of CO_2 emissions and consequences for economic growth in Norway were analysed. In the SIMEN study the taxes on fossil fuels were substantially increased in order to obtain a stabilization of Norwegian emissions of CO_2. The SIMEN study focused on unilateral stabilization of CO_2 emissions at the 1987 level by the year 2000 and the corresponding GDP loss. The KLØKT project analysed stabilization of CO_2 emissions in Norway in 2000 and in 2025 under two different regimes; a unilateral Norwegian stabilization and a global stabilization regime.

In the OECD Model Comparison Project (Dean and Hoeller, 1992) a relationship between reductions in world CO_2 emissions and world GDP losses was established based on simulations carried out on the participating models. The studies conclude that the marginal GDP loss is increasing as a function of emission reductions.

In line with these studies, we aim in this chapter to study the relationship between reductions in CO_2 emissions and GDP losses for the Norwegian economy using the MSG-EE model. The model is simulated over the period from 1988 to 2020. In order to obtain different CO_2 reduction levels, we implement a number of different CO_2 tax paths. We analyse and compare our results with the results from the previous international studies.

It should be noted that whether the CO_2 tax is introduced unilaterally or as part of a multilateral agreement, has a severe impact on the relationship between emission reductions and GDP losses in Norway. The main reason for this is that a multilateral agreement probably will lead to a decrease in the crude oil and natural gas prices which will seriously affect Norway as a petroleum exporting country. In the analysis presented here, we will assume *unilateral* Norwegian CO_2 reductions, but we will also briefly discuss the consequences of a multilateral agreement to reduce the emissions. Another potentially important limitation of this study, is that we will neglect any changes in technical progress due to increased CO_2 taxation.

In the rest of this chapter, we first give a brief presentation of the baseline scenario employed in the analysis. The baseline scenario is similar to the one discussed in detail in chapter 4, however with some modifications. These are discussed in the next section. Thereafter we discuss the effects of a CO_2 tax high enough to stabilize the CO_2 emissions at the 1989 level. We report on changes in macroeconomic variables, sectoral output and emissions by source and sector. Then, by varying the CO_2 tax rate, a relationship between various CO_2 emissions reductions and GDP reductions is presented and discussed. In section 5.3 our results are compared to a set of similar international studies. Section 5.4 concludes.

5.2 Reductions in CO_2 emissions and GDP

5.2.1 The baseline scenario

In order to establish a relationship between reductions in the CO_2 emissions and the corresponding GDP reductions, we take as a starting point a baseline scenario similar to the scenario described in chapter 4. However, in this chapter the model simulations cover the period from 1988 (the base year) to 2020. Also, in contrast to the scenario in chapter 4, the price of crude oil in real terms (deflated by the consumer price index) increases slowly from 20 US$ per barrel in year 2000 through 24 US$ in year 2010 to 26 US$ in year 2020. The simulation presented in chapter 4 assumed that the crude oil price was kept constant in real terms.

To get an idea of the potential for CO_2 reductions, we report in table 5.1 the CO_2 emissions in the (modified) baseline scenario. Overall we find an increase in total emissions from 34.3 million tonnes CO_2 in 1988 to close to 46 million tonnes in year 2020, representing an annual average growth in emissions of 0.9 per cent. The emission level in 2020 is some 5 million tonnes above the level reported in chapter 4. The main reason for the higher emission level in the present baseline scenario is the presence of thermal gas power, which was absent in the scenario presented in chapter 4. This, in turn, is mainly due to a higher crude oil price in this scenario than in the scenario described in chapter 4. A higher oil price will increase the demand for electricity, and since the supply of low cost hydro power is limited, see chapter 6, this demand is met by investments in gas thermal power.

Table 5.1. CO_2 emissions by aggregate industry and type of source in the baseline scenario. Base year levels in million tonnes CO_2 and average annual percentage growth, 1988-2020

	Stationary		Mobile		Process		Total	
	Level 1988 Mill. tonnes	Ann. growth Per cent	Level 1988 Mill. tonnes	Ann. growth Per cent	Level 1988 Mill. tonnes	Ann. growth Per cent	Level 1988 Mill. tonnes	Ann. growth Per cent
Primary prod.	0.2	-3.3	2.0	-0.1	0.2	0.0	2.4	-0.2
Energy int. prod.	1.7	-1.3	-	-	5.4	0.4	7.1	0.0
Other manuf.	3.0	-0.6	0.3	1.3	1.0	-1.4	4.3	-0.6
Power prod.	0.1	14.6	-	-	-	-	0.1	14.6
Construction	0.1	-1.5	0.5	-0.2	-	-	0.6	-0.4
Trade	0.2	-1.5	1.0	1.2	-	-	1.2	0.9
Petroleum prod. and ocean transp.	4.6	-0.7	1.7	0.3	-	-	6.3	-0.4
Road transport	-	-	2.0	0.4	-	-	2.0	0.4
Air transport	-	-	1.1	2.4	-	-	1.1	2.4
Sea transport	-	-	0.1	1.3	-	-	0.1	1.3
Rail transport	-	-	1.3	0.6	-	-	1.3	0.6
Post and telecommunic.	-	-	0.2	1.8	-	-	0.2	1.8
Other	0.8	-1.0	0.9	1.1	-	-	1.7	0.3
Households	1.8	0.9	4.1	1.2	-	-	5.9	1.1
Total	12.5	1.2	15.2	0.9	6.6	0.1	34.3	0.9

Although increasing at an average annual rate of 1.2 per cent, stationary CO_2 emissions decreases in many of the sectors in the baseline scenario. The most important exception is thermal power generation. Natural gas based thermal power becomes favourable in the last part of the simulation period, and CO_2 emissions from this sector increase rapidly to about 7 million tonnes CO_2 in year 2020. Stationary CO_2 emissions from the households also increase throughout the simulation period. Both substitution from (hydro power based) electricity to fossil fuels and growth in energy consumption explain this fact. In the production sectors a trend towards increased electricity/fuel ratio is assumed, see section 3.3.1. Thus, the CO_2 emissions from stationary combustion in these sectors decline. In 1988, more than 35 per cent of stationary CO_2 emissions came from the oil and gas industry. In the baseline scenario, the corresponding percentage has dropped to about 20 in 2020, which represents about 8 per cent of total CO_2 emissions.

Emissions of CO_2 from mobile sources increase due to increased activity levels in the economy. Emissions in the road transport sector, and from the households' use of motorcars, accounted for about 40 per cent of the total emissions from mobile sources in 1988. These and other mobile emissions may be reduced by cuts in the general activity level or by changes in the sectoral composition of the economy generated by changes in relative sectoral costs. In the residential sector both income and relative prices of transport influence mobile emissions. No fuel substitution is assumed in neither commercial nor sectoral own produced road transport, see chapter 3.

Only a few manufacturing sectors have process emissions of CO_2. The most important process emissions are generated in the metal industry, which accounted for about 13 per cent of total CO_2 emissions in 1988. These emissions are price sensitive through their link to the use of intermediate materials in the sectors.

5.2.2 Reduction scenarios

The stabilization scenario
First, we will examine the economic effects of a CO_2 tax by comparing the baseline economy with a scenario where the Norwegian CO_2 emissions in year 2020 are stabilized at 1989 levels by use of a domestic CO_2 tax (stabilization scenario). In the next subsection, the relationship between CO_2 emissions and GDP growth with different levels of the CO_2 tax will be discussed. All simulations are carried out under the condition that the total capital stock is endogenously determined while the foreign debt follows the path in the baseline scenario[29]. In table 5.2, changes in some macroeconomic variables from the stabilization to the baseline scenario in 2020 are shown.

Table 5.2. CO_2 emissions stabilization scenario: Deviation in some macroeconomic variables from the baseline scenario in year 2020

	Per cent
Gross domestic product	-0.5
Import	0.1
Private consumption	1.2
Gross investments	-1.6
Government expenditure	0.0
Export	-1.9
Capital stock	-0.4
Wage	0.7

A tax of the order of 50 US$ per tonnes CO_2 is required in order to stabilize the emissions in year 2020 at the 1989 level. The resulting increase in fuel prices is transmitted through the cost functions and the input–output structure to higher prices of domestically produced input factors. The prices of capital goods increase and lower the demand for investments, thus reducing economic

[29]That is, the simulation adopt closure rule no. 2 according to the terminology of chapter 2.3.

growth. In the simulation, gross investments are reduced by 1.6 per cent in year 2020, and the capital stock has decreased by 0.4 per cent compared to the baseline scenario at the end of the simulation period. The gross domestic product (GDP) is reduced by 0.5 per cent. However, this substitution effect is modified by an increase in the wage rate, which is necessary in order to restore the trade balance. In the new equilibrium, the wage rate is 0.7 per cent higher and production is 0.5 per cent lower than in the baseline scenario.

An increased domestic price level increase the export prices by on average 2 per cent and reduces the export volume by 1.9 per cent. Import shares increase, but the decrease in the activity level makes the total import volume nearly constant. In total, the import volume increases with only 0.1 per cent. With unchanged import prices, the trade balance restriction, which is formulated in nominal terms, is thus satisfied.

The export industry is a large carbon emitter, and the CO_2 tax changes the sectoral composition of economic growth somewhat. Since the export industry is assumed to experience higher autonomous technological progress than most other sectors, the shift from production for exports to production of goods and services for the domestic market will also reduce the overall growth rate of the economy.

The reduction in gross investments and export are larger than the production decrease. This makes an increase in private consumption of 1.2 per cent possible.

Table 5.3 shows the emissions in the stabilization scenario and deviations from the baseline scenario in year 2020. The large reduction in emissions from the power generation sector attracts immediate attention. What happens is that when the CO_2 tax passes a certain level, the thermal production of electricity based on gas is abandoned and partly replaced by hydro power electricity. Due to the large reduction in emissions from the thermal power sector, the need for reductions in the other sectors are moderate and this explains the relatively modest cost of stabilizing the CO_2 emissions in this analysis.

Emission reductions through reduced stationary fuel use vary significantly across sectors. The energy price elasticity is relatively large in sectors producing consumption goods, Pulp and paper, Machinery and equipment, Wholesale and retail trade, Rail transport services and Other private services. Not surprisingly, also the energy intensive industries (Pulp and paper production, Manufacturing of industrial chemicals and Manufacturing of metals) bear heavy burdens with 13–20 per cent reductions in the emissions from stationary energy use. Gross productions are reduced by 11–13 per cent in these sectors. Stationary CO_2

Table 5.3. Emissions of CO_2 by aggregate sector and type of source in the stabilization scenario and deviation from the baseline scenario in year 2020

Industry/sector	Stationary		Mobile		Process		Total	
	2020 Mill. tonnes	Dev. Per cent	2020 Mill. tonnes	Dev. Per cent	2020 Mill. tonnes	Dev. Per cent	2020 Mill. tonnes	Dev. Per cent
Primary prod.	0.1	-7.3	1.9	-0.2	0.2	0.0	2.2	-0.5
Energy int. prod.	0.9	-16.9	-	-	5.5	-11.4	6.4	-12.3
Other manuf.	2.1	-11.8	0.6	-2.3	0.7	5.6	3.4	-6.9
Power prod.	0.1	-98.8	-	-	-	-	0.1	-98.8
Construction	0.1	-1.7	0.5	-0.1	-	-	0.6	-0.4
Trade	0.0	-64.0	1.5	-0.1	-	-	1.5	-4.1
Petroleum prod. and ocean transp.	3.6	0.2	1.8	0.0	-	-	5.4	0.1
Road transport	-	-	2.3	-1.3	-	-	2.3	-1.3
Air transport	-	-	2.4	-2.0	-	-	2.4	-2.0
Sea transport	-	-	0.1	-0.6	-	-	0.1	-0.6
Rail transport	-	-	1.4	-4.0	-	-	1.4	-4.0
Post and telecommunic.	0.1	0.0	0.3	-0.1	-	-	0.4	-0.1
Other	0.6	-7.1	1.4	0.0	-	-	2.0	-2.1
Households	2.2	-10.7	5.7	-4.7	-	-	8.0	-6.5
Total	9.8	-46.8	19.9	-2.2	6.4	-9.4	36.1	-21.3

emissions from private households are reduced by 11 per cent, although, as we have seen, total private consumption increases with 1.2 per cent. Thus, a strong switch to electricity for heating and stationary appliances takes place in the households.

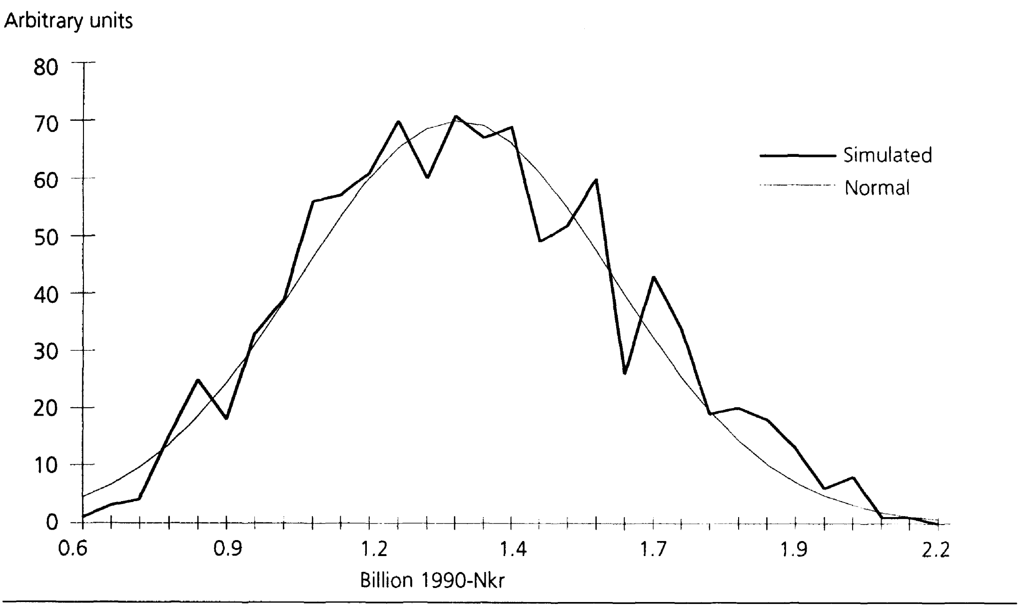
Mobile emissions from the production sectors are closely linked to the production levels due to limited substitution possibilities. Since the structural changes induced by the CO_2 tax mainly reduce the activity levels in sectors with limited demand for transport services, the changes in mobile emissions from the production sectors are small. Substitution effects are, however, possible within the residential sector. The emissions from use of transport fuels in the private households are reduced by 4.7 per cent. Increased consumption counteracts the price effect on transport fuel demand in private households. The rise in private consumption also stimulates the production of road and air transport services.

Process emissions of CO_2 (i.e. emissions not directly related to combustion of fossil fuels) are forecasted by the demand for material inputs, which are becoming relatively cheaper than fossil fuels as a consequence of the tax. Sectors with process emissions of CO_2 are, however, very capital intensive, and the emission levels follow the reduction in production levels quite closely. In total, process emissions in the stabilization scenario are reduced by 9.4 per cent from the baseline scenario in 2020.

Local benefits of CO_2 reductions

Most of the reductions in CO_2 emissions are of course due to less use of fossil fuels. This will also reduce the emission levels of other air pollutants such as SO_2, NO_x, CO and particulate matter. Furthermore, the volume of road traffic will be changed. All of these changes will carry with them changes in external effects related to damage to nature, materials and human health from local air pollution and road accidents, congestion, damage to roads and noise related to road traffic. When these effects are valued according to the model described in section 2.6.2, we find that stabilizing the CO_2 emission level implies benefits of the rough order of 1 billion 1988 Nkr. This number is of course highly uncertain; we find that a reasonable range is from 0.5 to 2 billion Nkr, see figure 5.1. Most of the benefits accrue from the reduction in road traffic, which generates more than 50 per cent of the total benefit. Among other categories covered by the model, reduced health damage from NO_x is of most importance. These benefits, which are tentatively estimated to be of the order of almost 20 per cent of the GDP loss, comes in addition to potential benefits associated with a reduced rate of climatic change.

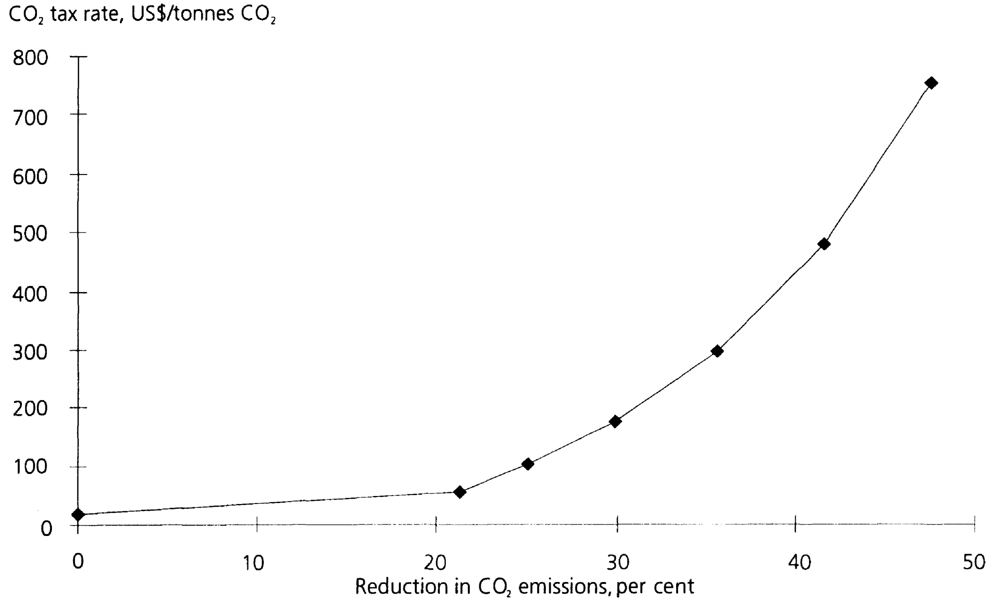
Figure 5.1. Monte Carlo simulation of the local benefit of stabilizing the CO_2 emission level



5.2.3 Other reduction scenarios

In addition to the stabilization scenario, a number of simulations have been carried out with varying CO_2 tax rates. In the baseline scenario, the oil price path and the existing CO_2 tax implies a 3 per cent growth in the prices of fossil fuels on an annual basis. In the reduction scenarios, the CO_2 taxes increase by from 10 to 60 per cent annually from 1994 to 2000, and with 7 per cent annually from 2001 to 2020. Before we comment on the macro economic results, let us first take a look at the relationship between the implemented tax rates and the reductions in CO_2 emissions shown in figure 5.2.

Figure 5.2. CO_2 tax rate versus CO_2 reductions in year 2020



We notice from the figure that the tax rate necessary to obtain gradually tightening CO_2 goals is increasing and at an increasing rate. This is due to gradually diminishing macro substitution possibilities in the economy. In the first tax phase gas thermal power plants with heavy emissions are substituted by hydro power plants with no emissions. This substitution is rather cheap since the marginal cost of these different plants are approximately equal. In the next phase some of the stationary fuels are substituted by electricity on the demand side. From then on the substitution possibilities are more limited because materials are generally less flexible as inputs than fuels in the sectoral cost functions. For mobile sources the only substitution possibility is through the flexibility in the residential sector and through structural changes.

The possibilities for substituting either polluting input factors with less polluting factors, or activity in polluting sectors with activity in less polluting sectors, reduces the tax burden. Thus, diminishing substitution possibilities with increasing tax rates will increase the marginal GDP-loss of the tax. Since the tax increases capital cost, and thereby reduces investments and economic growth, reduced substitution possibilities increases the marginal effect of the tax on economic growth. This again implies that the relationship between reductions in CO_2 emissions and reductions in GDP induced by CO_2 taxes, is also increasing on the margin, see figure 5.3 and table 5.4.

Figure 5.3. CO_2 reductions and GDP losses in year 2020

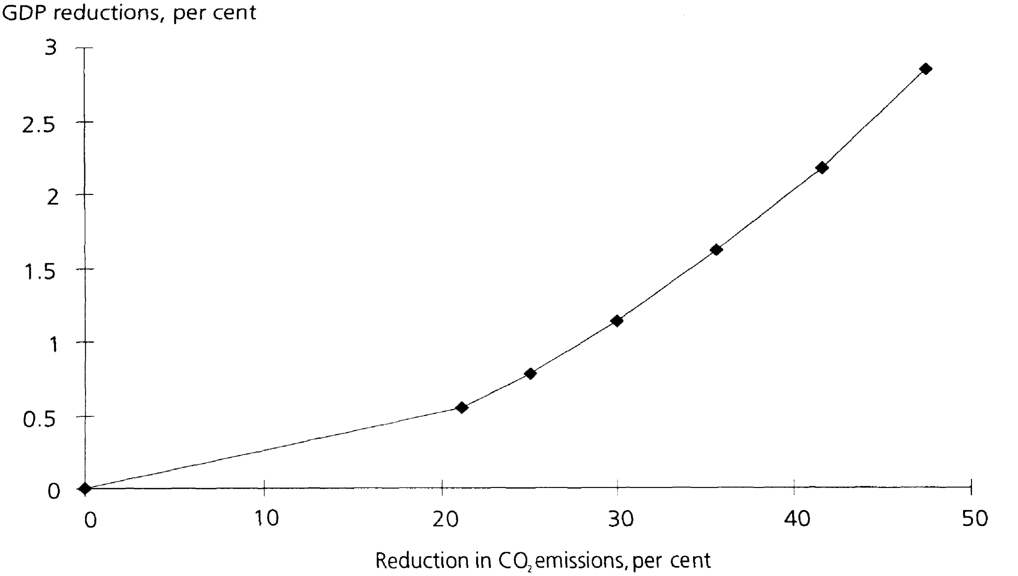


Table 5.4. Percentage reductions in CO_2 emissions and GDP in year 2020 as function of CO_2 tax rates measured in 1990-US$ per tonnes CO_2

CO_2 tax rates US$/tonnes CO_2	CO_2 reductions Per cent	GDP reductions Per cent
19	0	0
55	21.2	0.6
101	25.0	0.8
176	29.9	1.1
296	35.6	1.6
479	41.7	2.2
753	47.5	2.9

The relative low cost even for large emission reductions, is due to the relative small cost share for fossil fuels in the Norwegian economy. The heaviest tax scenario (753 US$ per tonnes CO_2[30] in year 2020) yields a 48 per cent reduction in emissions and a 2.9 per cent loss in equilibrium GDP relative to the baseline level in year 2020. The emission reduction from the 1989 emission level is then about 35 per cent.

From the above discussion, it is clear that the cost of reducing CO_2 emissions will depend heavily upon the emission level and the overall substitution possibilities in the baseline scenario. Of prime importance here is how the supply of primary energy is provided and how electricity is generated. Furthermore, the general industrial structure and the cost shares of polluting input factors in the economy matters a great deal. So do the transport infrastructure facilities, the dependence on transport services and, last but not least, the environmental policy implemented in the baseline scenario.

5.3 Comparison with international studies

Various economic models have been developed to examine the costs of reducing emissions of CO_2 internationally. The OECD Model Comparison Project (Dean and Hoeller, 1992) gives a comprehensive review of six global models in this area. The six models have been standardized by specifying key economic assumptions for the baseline scenario of unconstrained CO_2 emissions growth, and a set of common simulations for reducing CO_2 emissions. Jorgenson and Wilcoxen (JW) have studied this topic within a US setting in several papers (see for instance Jorgenson and Wilcoxen 1989, 1990 and 1992). The JW model is an econometrically estimated intertemporal general equilibrium model of the US economy. All models measure the costs of reducing emissions of CO_2 as reduction in GDP.

5.4 GDP losses and CO_2 emission reductions

The OECD model comparison project reports the relationship between reductions in CO_2 emissions and GDP losses (several pairs of corresponding values) for the world as a whole. Figure 5.4 shows graphs representing this relationship measured as reductions from the baseline scenarios in 2020 for the world and for Norway (MSG-EE).

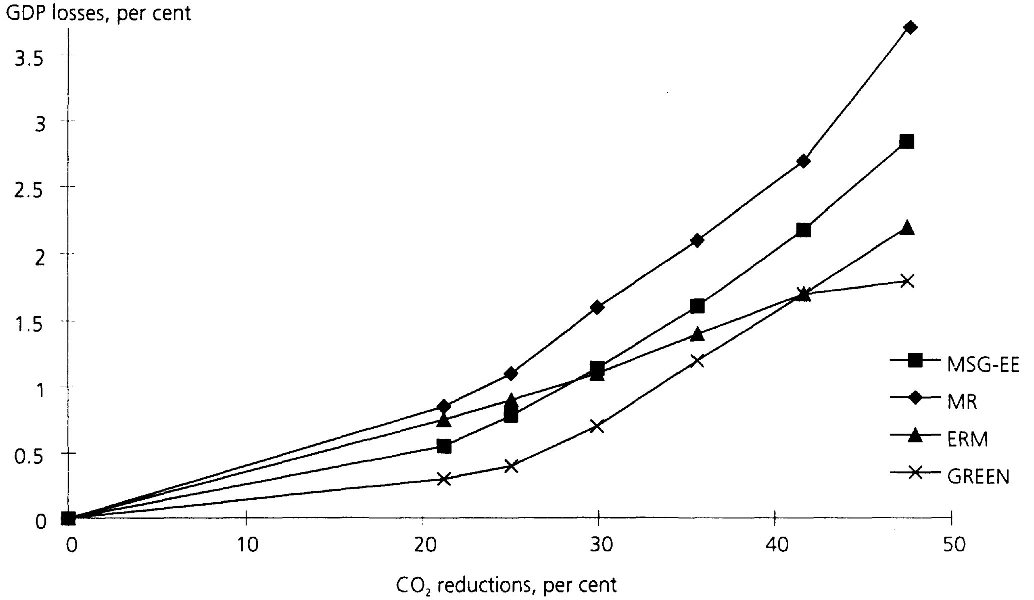
The models represented in the figure, besides MSG-EE, are:

- MR: Manne-Richels Global 2100 Model (Manne, 1992) which is a forward looking intertemporal model with international trade in carbon rights,

[30] To convert to other common units, note that the weight of CO_2 relative to C is $\frac{44}{12}$, while the density of oil is approximately 0.85 kg/l. Furthermore, one barrel is equal to 159 l.

- ERM: Edmonds-Reilly Model (Barns *et al.*, 1992) which is a partial equilibrium model with a detailed dynamic energy submodel, and
- GREEN (Oliveira Martins *et al.*, 1992) which is a recursive dynamic general equilibrium model with full trade links plus trade in carbon rights.

Figure 5.4. Percentage reduction in GDP and CO_2 emissions relative to baseline scenarios for the world and for Norway (MSG-EE) in year 2020



As we can see from the figure, the Norwegian results are more or less in line with the results calculated by the three OECD models for the world with respect to the magnitude of the effects. In all cases the reductions in GDP can be characterized as being small. Still, the results differ by approximately ±50 per cent, reflecting differences in substitution possibilities, etc., as mentioned above. The estimated Norwegian GDP loss connected with an approximate 50 per cent reduction of the emissions lies between the lowest and the highest OECD estimate for world GDP losses. Like MSG-EE, both MR and ERM suggests that the marginal GDP losses connected with reductions in CO_2 emissions are increasing. As far as the results from GREEN is concerned, the relationship seems more obscure. Up to 40 per cent reduction in the emissions the marginal GDP loss is increasing. After that, however, it seems to be decreasing.

5.4.1 Tax rates and GDP losses when stabilizing the CO_2 emissions

Of the regions covered by the OECD model comparison project, the regions most suitable for comparison with Norway are OECD except the United States and the United States. The growth of emissions in the baseline scenario is an important determinant of costs connected with a stabilization of emissions in the different models. The annual percentage baseline growth of emissions in the OECD area outside US varies from 0.94 (ERM) to 1.35 (MR), while the growth rate for US emissions in the baseline scenario of the JW model is as small as 0.6 per cent. As mentioned, the Norwegian annual growth of emissions is about 0.9 per cent in our baseline scenario.

Table 5.5 reports the required taxes and GDP losses connected with a stabilization of the CO_2 emissions in 2020 at 1990 levels for the OECD countries and for Norway. The tax needed to stabilize OECD emissions lies within the range from 16 US$/tonnes CO_2 (GREEN) to 33 US$/tonnes CO_2 (MR). The corresponding percentage losses in GDP vary from 0.3 (GREEN) to 0.7 (ERM and MR) per cent.

Table 5.5. Stabilization of CO_2 emissions at 1990 levels in 2020 for OECD except the United States and for Norway (MSG-EE). Required taxes and corresponding GDP losses relative to the baseline scenario

Model	CO_2 tax US$/tonnes CO_2	GDP losses Per cent
ERM	31	0.7
GREEN	16	0.3
MR	33	0.7
MSG-EE	52	0.5

The 0.5 per cent GDP loss connected with a stabilization of emissions in 2020 shows that the result for Norway is in line with the results from the OECD model comparison project as far as GDP loss is concerned. On the other hand, the tax required to stabilize emissions in Norway (52 US$ per tonnes CO_2) is significantly higher than the tax required in the OECD countries.

The high tax required in Norway to obtain stabilization of the emissions, indicates that the substitution possibilities in Norway are lower than in the average OECD country. This is reflected in low elasticities of substitution between fossil and non fossil fuels in the MSG-EE model when compared with the other models. Moreover, use of coal for heating purposes is very limited in Norway, see table 5.6. In other OECD countries substantial emission reductions can be obtained by substituting coal with oil or gas. In Norway, use of electricity is based on hydro power and a large share of the fossil fuels is used in the transport sector. Demand for fossil fuels in the transport sector is relatively inelastic compared with demand for fossil fuels for heating purposes.

Table 5.6. Energy requirements per GDP for oil, coal and gas in the US, OECD Europe and Norway in 1988, Mtoe/ billions of US$

	Oil	Coal	Gas
US	0.165	0.094	0.089
OECD Europe	0.152	0.066	0.053
Norway	0.124	0.015	0.026

It would perhaps have been reasonable to expect that the higher tax required in Norway also would lead to a higher GDP loss in Norway than the other OECD countries. As we have seen, this is not the case. The fact that the fossil fuel–output ratio or the cost share of fossil fuel is relatively low in Norway is an important explanatory factor for the relatively low GDP loss.

In order to stabilize emissions at the 1990 level in the United States, the OECD models suggest a CO_2 tax ranging from 18 US$ (GREEN) to 37 US$ (MR) per tonnes CO_2 emitted (table 5.7), all well below the result for Norway. The US GDP loss is between 0.3 per cent (GREEN) and 1.1 per cent (MR). Thus, the estimated Norwegian GDP loss (0.5 per cent) is in line with the result for the US.

Table 5.7. Stabilization of CO_2 emissions at 1990 levels in 2020 for the United States. Required taxes and corresponding GDP losses relative to the baseline scenario

Model	CO_2-tax US$/tonnes CO_2	GDP losses Per cent
ERM	25	0.6
GREEN	18	0.3
MR	37	1.1
JW	5	0.5

Compared with the OECD results, the tax needed to stabilize emissions in the Jorgenson and Wilcoxen dynamic general equilibrium model is surprisingly low, only about 5 US$ per tonnes CO_2 emitted. As mentioned above, this model has low baseline emissions compared with the OECD models. The elasticities of substitution in the JW model are also much higher than in the Norwegian model.

For Norway the KLØKT study carried out in 1992 (Moum, 1992) suggested a 190 US$ per tonnes CO_2 tax to obtain a 20 per cent reduction below the 1988 emission level in 2025. The estimated GDP loss was 3.2 per cent. The KLØKT analysis assumed an international agreement to reduce emissions, while the present study assumes an unilateral action. Multilateral agreement to reduce emissions most likely implies taxes on fossil fuels in the participating countries. This will lead to a downward shift in the world demand for crude oil and consequently cause lower crude oil prices. Since Norway is an oil exporting country, lower demand for oil will have negative impact on Norwegian GDP. On the other hand, the energy intensive industry in Norway will be better off with a multilateral agreement than with unilateral action, since foreign industry will have a disadvantage with high taxes on fossil input, either directly or indirectly through thermal power production. In Norway the power intensive industry is mainly based on hydro power.

5.5 Conclusions

All analyses of the cost of reducing CO_2 emissions are dependent on a number of more or less uncertain factors. For Norway in particular, it matters a great deal whether a CO_2 tax is introduced as an international or a national tax. As mentioned, this is because Norway is a large exporter of petroleum products, and reductions in the world market prices of these products can potentially be very expensive for Norway. Secondly, and working in the opposite direction, Norway has a large exporting power intensive industry based mainly on hydro power. Thus, an international CO_2 tax will favour this industry vis a vis the international competition. For Norway, the cost of emission reductions will also depend on to what extent the simulation incorporates domestic thermal gas power. If this is the case, Norway obtain a greater flexibility in reduction options than would otherwise prevail in a mainly hydro power based energy system. Finally, it may matter how the revenue from the carbon tax is recycled in the economy. In our analysis, the revenue is recycled in a lump sum manner, but recycling by removing or reducing other distortive taxes would presumably lower the cost of the emission tax.

With the assumptions adopted in our study, we find that marginal GDP losses are increasing with increasing reductions in the CO_2 emissions. This result is in line with previous international studies and seems reasonable since the cheaper options to reduce emissions are likely to be taken first. The results also show that the CO_2 tax required to stabilize emissions in 2020 at the 1989 level is relatively high in Norway compared to what seems to be the case in other OECD countries. This reflects that the substitution possibilities for fossil fuels are limited in Norway. For heating purposes use of hydro electric power dominates, and in the transport sector, which in Norway has a large share of total fossil fuel use, the demand for fossil fuel is relatively inelastic.

On the other hand, the Norwegian GDP loss connected with a stabilization of the emissions are of the same magnitude as the average OECD and US GDP losses. One reason why the higher tax in Norway does not lead to a greater Norwegian GDP loss is that the fossil fuel–GDP ratio is relatively low in Norway. The energy intensive industry bear the heaviest burdens when emissions are reduced.

Finally, we may note that the high taxes required to obtain substantial reductions in the Norwegian CO_2 emissions probably will have short term effects on the economy that may be more important than the long term effects described in this paper.

6. The electricity market in Norway

T. Bye and T.A. Johnsen

6.1 Introduction

Nearly 100 per cent of the electricity consumption in Norway is generated by power plants based on hydro power. However, thermal power production based on natural gas may be introduced in the foreseeable future due to decreasing rate of return of investments in new hydro power generation capacity. The amount of new exploitable watercourses is also restricted because of environmental regulations of the remaining water falls. The amount of thermal gas power developed will depend on, in addition to energy prices, the location of gas pipe lines and on the expected air pollution abatement policy. Based on the *baseline scenario* of MSG-EE described in chapter 4, we analyse the development of new electricity generating capacity. Additional issues, such as the impacts of further deregulation of the electricity market, environmental taxes on hydro power, additional CO_2 taxes, or liberation of international trade in electricity, are then explored in a number of alternative scenarios.

Historically, the electricity prices and investments in new hydroelectric capacity in Norway have been regulated by the central Government. The residential sector, primary industries, private and public service sectors and less energy intensive manufacturing industries have been discriminated with respect to electricity prices relative to the energy intensive industries (manufacturing of ferro alloy, aluminium, industrial chemicals and pulp and paper). In 1991 the Norwegian electricity market was partially deregulated. By now, electricity producers participate in a competitive market, while the transmission and the distribution grids as natural monopolies are offered a rate of return regulation[31]. The energy intensive manufacturing industries have, however, kept

[31] Other countries use alternative regulatory instruments as for instance direct price regulation, price cap regulation, yardstick regulation, rate of return regulation or technology improvement

their, largely favourable, long term contracts. Consequently, releasing the total economic benefits of a complete deregulation of the electricity market will still take some time. In the long run the deregulation will have an impact on the relative prices of electricity among sectors, and thereby have consequences for the investments in the generation, transmission and distribution sectors. The economic impact of the deregulation and the effect on the power producing sectors are analysed in the *efficiency scenario*, presented in section 6.3.

Although relative environmentally benign, hydro power production do have negative impacts on the environment. By affecting the flow of water, the water quality may deteriorate, possibilities for outdoor recreation may change, as may the fishing opportunities, to mention just some of the issues. The effects of internalizing some of these environmental costs is the subject of the *protection scenario* presented in section 6.4.

Hydro power generation do not create CO_2 emissions and will therefore not be directly influenced by CO_2 abatement policies. However, indirectly the Norwegian electricity market is influenced by both Norwegian and global climate policies. A CO_2 tax in Norway will increase the fossil fuel prices and induce substitution from demand of fossil fuels to demand of electricity. Increased energy prices will also reduce the total demand for energy (scale effect). If Norwegian export and import of electricity continues to be restricted[32], increasing marginal costs in hydro power generation will, due to scarcity of new exploitable watercourses, lead to increased electricity prices, which will modify the substitution from fossil fuels to electricity. A CO_2 tax will also make thermal gas power generation less profitable compared to hydro power generation. The size of the resulting increase in the electricity price will depend on the shape of the long run marginal cost curve of new hydro power projects and the cost of thermal power.

The Norwegian electricity transmission grid is connected with the Swedish, Danish, Finnish, and Russian transmission grids. In the long run, it may be relevant to study the effects of international trade at a larger scale. In a free trade regime, Norwegian electricity prices will be determined in the "world market". When exporting electricity from Norway, the domestic price will reflect the world market price less transmission costs. When importing, the domestic price will equal the world market price plus transmission costs. A large amount of the existing thermal power generating capacity in neighboring countries are coal fired. An international CO_2 tax on fossil fuels will increase

price regulation.

[32]Today, electricity producers may enter into long term contracts with foreign consumers restricted to a total of 5TWh, i.e. the sum of all long term contracts for all Norwegian producers face this ceiling.

both costs for stationary heating based on fossil fuels and costs in thermal power generation. Relatively low fuel efficiency in thermal power generation abroad compared to the fuel efficiency in decentralized heating systems [33] in Norway, may result in a larger price increase for electricity than for fossil fuels. The substitution effect will then be in favour of fossil fuel use in Norway and the magnitude of the scale effect will determine whether fossil fuel use increase or decrease as a consequence of an increased CO_2 tax. The combination of an international carbon tax and a competitive international electricity market is analysed in the *trade scenario* presented in section 6.5. The discussion in sections 6.3-6.5 is confined to the effects on the electricity market. Section 6.6 presents the macroeconomic effects of the reallocations.

6.2 The structure of the supply side

According to the Norwegian Water Resources and Energy Administration (NVE), the Norwegian exploitable hydro power production potential represents a mean annual production capacity of 175 TWh[34]. A total of 643 existing hydro power plants have installed a generating capacity of about 27 GW. The mean annual inflow of water allows an average energy production in the existing plants of 110 TWh. The domestic demand is less, which together with low export prices, suggests excessive hydro power capacity.

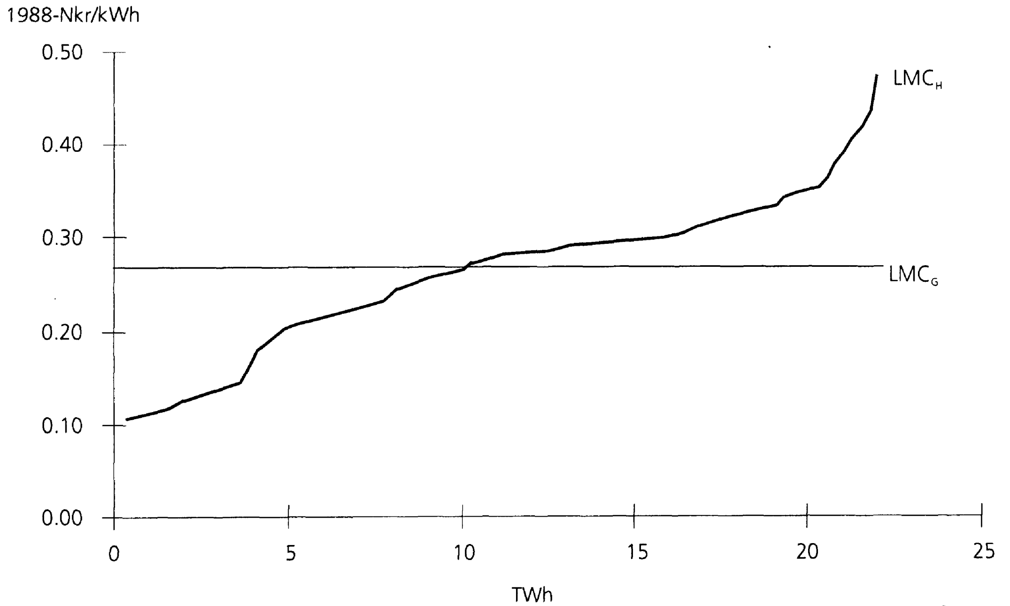
As mentioned, the Norwegian electricity market was deregulated in 1991. At the same time, the stock and the inflow of water to the reservoirs were at an all time high. Consequently electricity prices decreased. Purchaser prices fell less than producer prices because of stable transmission and distribution tariffs, and increasing commodity specific and value added taxes on electricity in this period. Due to low electricity prices, almost no investments in new capacity takes place today.

Based on project specific cost estimates for unexploited hydro power projects in Norway, the remaining water falls are ranked according to increasing cost. This ranking forms the long run marginal cost curve (H) of hydro power generation (NVE, 1988), see figure 6.1. According to this cost curve there are still some relatively cheap projects left in the portfolio of non-developed hydro power projects. Many of the hydro power projects developed under the regulated regime were more expensive than the cheapest projects on this cost curve.

[33]Decentral heating systems which use fuels (oil burners/fireplaces, wood fireplaces) are common in Norway. The fuel efficiency in existing coal fired power plants in Denmark ranges from 30-39 per cent. Stationary heating using fuels in Norway has a fuel efficiency of 70-75 per cent.

[34]The total technical potential is more than twice that high. The total of 175 TWh was calculated in the early 1970's. Since then prices has increased dramatically and the profitable potential may be higher than 175 TWh in the future. However, this is not important in our analyses since we never reach this level in our scenarios.

Figure 6.1. Long term marginal cost (LMC for hydro electric (H) and gas (G) thermal power. Nkr/kWh



Norway has abundant supply of natural gas in the North Sea, but today there are no gas fired power plants in Norway. So far, hydro power capacity has been cheaper to develop. In some instances, however, hydro power projects with higher unit cost than the cost of gas power have been developed under the regulated regime. The focus on environmental policy, especially the aim of reducing emissions of greenhouse gases, has so far excluded the introduction of combined cycle gas turbine generation capacity in Norway.

From figure 6.1 we see that gas based electricity generation (G) limits the hydro power capacity expansion to about 10 TWh through an expected total cost of 0.28 Nkr/kWh . However, important differences in the cost structure between hydro and gas power production should be noted [35]. The cost of thermal gas power is highly dependent on the value of natural gas in the international energy markets and on the unit cost of pipeline transport which in turn is scale dependent. The value of natural gas amounts to almost 45 per cent of total unit cost for thermal gas production of electricity (pipeline cost included). Labour and materials input cost constitute just above 5 per cent of the total cost. Environmental policy instruments, like for instance a CO_2 tax, may drastically increase the gas based electricity production cost. However, technical progress in electricity producing equipment and in construction can be expected to shift

[35]See also section 3.5.

the cost curves in figure 6.1 downwards over time.

Uncertainty about the future development of the energy markets and the irreversibility of investments in power generation capacity may make gas power (low capital input per kWh) expansion more attractive relative to hydro power (high capital input per kWh) capacity expansion. Kobila (1990) considers the choice between investments in hydro and thermal power capacity in the presence of uncertainty in demand and concludes that uncertainty about the future restricts the optimal level of expansion of the hydro power system. Uncertainty concerning the global warming policy is most likely to favour hydro power capacity expansion. These effects of uncertainty are important, but are not yet included in the empirical model presented in this book.

As described in chapter 4, the current CO_2 tax in Norway (150 Nkr per tonnes CO_2 corresponding to approximately 20 US$ per tonnes CO_2) is prolonged in fixed prices up to year 2020 in the baseline scenario. The crude oil price is assumed to be fixed at the 1992-level in real terms throughout the simulation period. There is no international electricity trade in this scenario.

Figure 6.2. Energy purchaser prices in the baseline scenario in the residential sector including taxes measured per unit utilized energy. 1992-Nkr/kWh

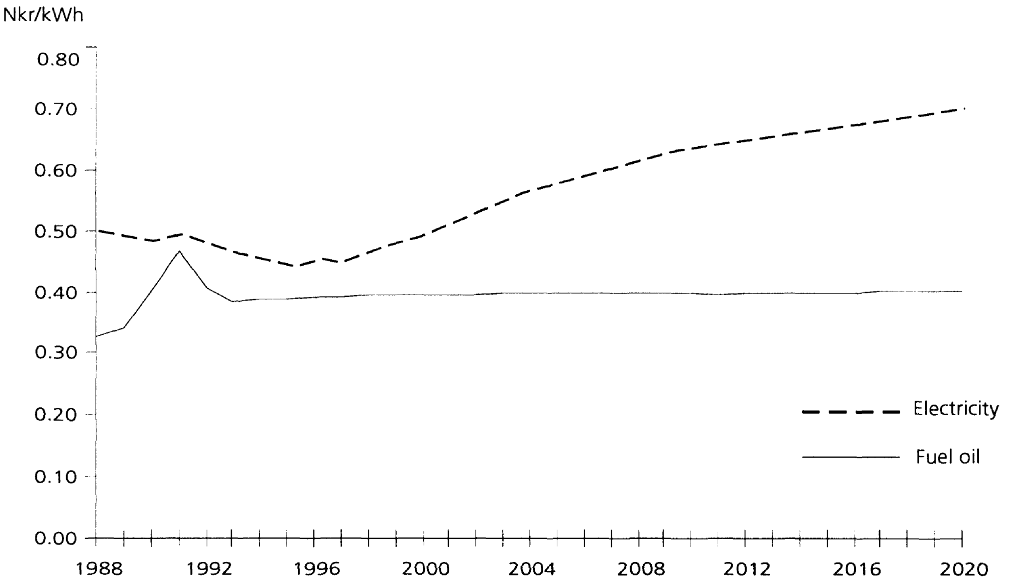


Figure 6.2 reports the historically observed electricity and fuel oil prices from 1988 to 1992 and simulated prices from 1992 to 2020. Due to the assumed constant crude oil price, the domestic prices of fossil fuels are nearly constant over the simulation period. Increasing electricity demand is met by exploiting new hydro production plants with increasing marginal cost, thereby leading to an increasing electricity price. Other aspects of the electricity market in the baseline scenario are described in section 4.4.1. Here, we only reports the energy balance in the baseline scenario, see table 6.1. From the table we see that increasing electricity demand and increasing long term marginal cost of hydro power plants are not sufficient to make Norwegian gas fired thermal power competitive. Thermal gas power must pay the existing CO_2 tax, while no environmental tax (for damage to nature, etc.) is levied on hydro power production.

Table 6.1. Energy balance in the baseline scenario. Electricity supply and demand. Fossil fuel demand for stationary use. Utilized energy, TWh.

	Electricity				Fossil fuels[a]			
	1988	2000	2010	2020	1988	2000	2010	2020
Generation								
- hydro power	108.8	112.3	118.6	123.0				
- gas power	0.0	0.0	0.0	0.0				
Import	1.2	0.0	0.0	0.0				
Export	6.8	0.0	0.0	0.0				
Domestic use	103.2	112.3	118.6	123.0	18.0	17.1	19.5	20.6
Network losses	8.6	7.6	8.1	8.5				
Energy int. ind.	30.5	30.5	30.5	30.5	1.6	1.6	1.6	1.6
Pulp and paper	6.0	4.8	4.8	4.8	2.0	2.5	1.8	1.3
Other manufact.	10.1	11.8	13.5	14.8	4.7	4.0	5.2	5.6
Services	18.6	24.5	27.3	26.8	3.1	2.8	3.4	3.3
Residential	29.3	33.2	34.4	37.6	6.6	6.2	7.5	8.8

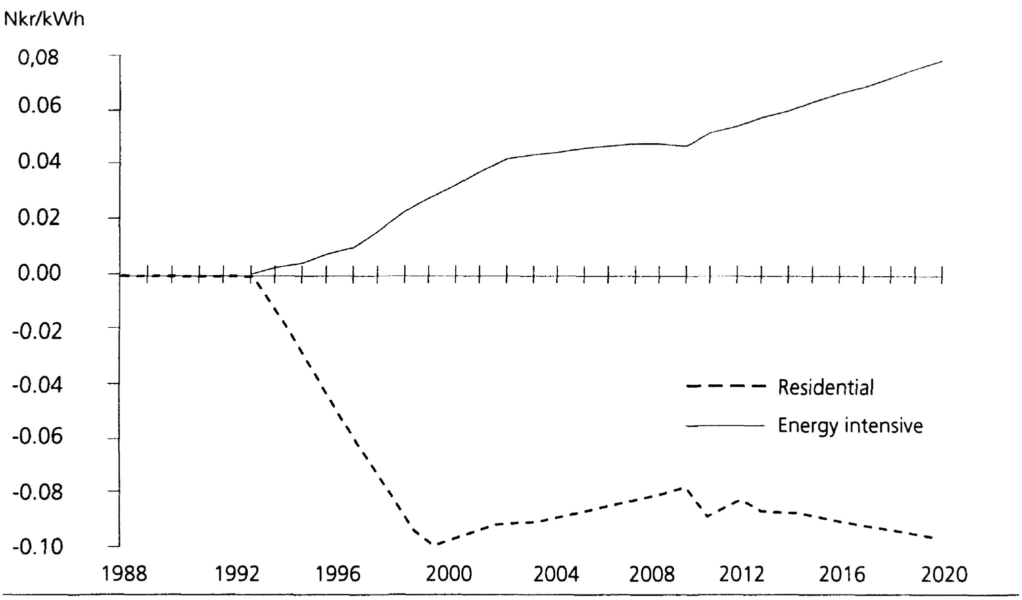
[a] Only stationary use i.e. transportation use not included.

Transmission losses in the base year was 7.8 per cent of total supply of electricity (domestic production plus imports), while it is calculated to be 6.9 per cent in year 2020. Consumption that demands a high rate of transmission and distribution services (non energy intensive industries and the residential sector) grow faster than sectors with less transmission and distribution demand (energy intensive industries and exports). This should by itself increase the transmission loss share. This is, however, more than outweighed by the assumed technical progress in the production of transmission and distribution services.

6.3 A competitive and efficient electricity market

Analyses of the Norwegian electricity market before the deregulation in 1991 concluded that Norway suffered great losses[36] through price discrimination between energy intensive industries and other domestic sectors. The total loss was calculated to be close to 1 per cent of GDP. In their analyses, Bye and Johnsen (1991) also found some discrimination between non-energy intensive industries, but the loss of this discrimination amounted to only 0.05 per cent of GDP. Since the deregulation of the Norwegian electricity market in 1991 did not exclude the long term contracts of the energy intensive industries, most of the benefits from a deregulated market can not be harvested in a short term. However, most of the long term contracts expire in the period 2000-2010 and will then have to be renegotiated, possibly on a competitive basis. In the *efficiency scenario*, we assume no price discrimination and a perfect competitive electricity market.

Figure 6.3. Electricity purchaser prices in the efficiency scenario including taxes. Absolute deviations from baseline scenario. 1992-Nkr/kWh



One important element in the deregulation of the Norwegian electricity market is the effect on export and import of electricity. This may give signals about possible alternative profits from exporting the electricity that today is utilized

[36]Measured as losses in the sum of consumer and producer surplus in the electricity market, see Bye and Johnsen (1991).

in the energy intensive manufacturing industry. In this section we assume, however, that international electricity trade continues to be negligible. Effects caused by development of the transmission grids required for international trade is discussed in more detail in the next section. For an evaluation of the realism of the efficiency scenario, it is important to note that some of the energy intensive firms now signal that they want to participate in the spot market with some of their contracted power.

In the efficiency scenario, the electricity prices are lower than in the baseline scenario for every sector, except for the energy intensive industries, see figure 6.3. Labour and capital is reallocated between sectors and total productivity measured by GDP is increased compared to the regulated baseline scenario (see chapter 6.6 below).

Table 6.2. Energy balance in the efficiency scenario. Deviation from the baseline scenario. Electricity supply and demand. Fossil fuel demand for stationary use. Utilized energy, TWh

	Electricity			Fossil fuels[a]		
	2000	2010	2020	2000	2010	2020
Generation						
- hydro power	-1.8	-4.2	-6.5			
- gas power	0.0	0.0	0.0			
Import	0.0	0.0	0.0			
Export	0.0	0.0	0.0			
Domestic use	-1.8	-4.2	-6.5	-0.9	0.1	0.2
Network losses	0.2	0.1	0.2			
Energy int. ind.	-6.5	-7.1	-11.0	0.0	0.0	0.0
Pulp and paper	0.0	-0.6	-0.7	-0.3	0.4	-0.3
Other manufact.	0.9	0.9	1.6	-0.1	-0.1	0.1
Services	1.8	1.4	1.9	0.1	0.1	0.1
Residential	1.6	1.1	1.5	-0.5	-0.3	-0.3

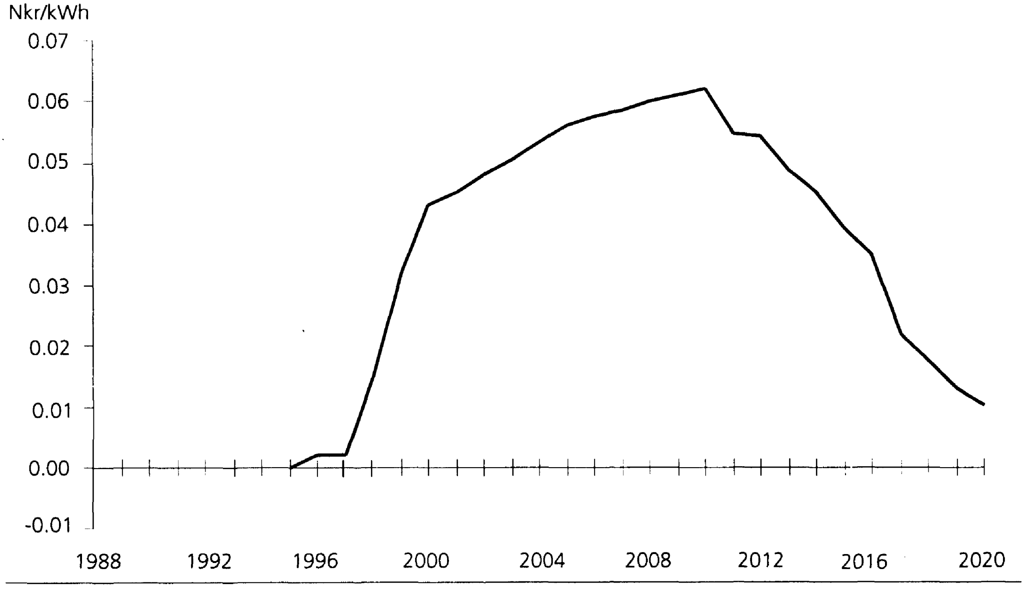
[a] Only stationary use i.e. transportation use not included.

The energy intensive industries (metal production, production of chemicals and pulp and paper production) respond to higher electricity prices by reducing their demand, see table 6.2. The reduction is approximately 60 per cent of the demand in the baseline scenario, i.e. about 11 TWh is made available for the rest of the market. Reduced demand in the energy intensive industry is approximately evenly distributed on reduced need for development of new electricity production capacity and reduced demand in other sectors. Investment costs are thus saved, totaling some 30-35 billion Nkr (0.3 per cent of GDP). The electricity demand in other sectors are increasing due to the lower electricity prices.

6.4 Protection of waterfalls

Throughout the 1970s, the increased concern for possible environmental impacts of further hydro power exploitation made it increasingly important for the Norwegian government to consider all environmental and economic aspects of new hydro power plants. A Norwegian Master Plan for Water Resources was developed where the remaining water falls were ranked according to their economic and environmental net impacts on the Norwegian society. The ranking was carried out by considering 13 so called user interests, such as nature conservation, outdoor recreation, wildlife, fish, water supply, preservation of cultural monuments, agriculture and forestry, reindeer herding, water quality, etc. A potential of about 22 TWh of the undeveloped 65 TWh was classified in a group of water falls that can be developed. Carlsen *et al.* (1992) estimates the implicit shadow prices of the different environmental variables in the Master Plan ranking. They found that adding the total environmental shadow price to economic cost would approximately double the marginal cost of hydro electricity.

Figure 6.4. Electricity purchaser price in the residential sector including taxes in the protection scenario. Deviation from baseline scenario. 1992-Nkr/kWh



The long run marginal costs reported in figure 6.1, includes only economic costs. To illustrate the impact of including environmental costs, we construct a *protection scenario,* where a tax of about 0.05 Nkr/kWh in 1993, 0.075 Nkr/kWh in 2005 and about 0.1 Nkr/kWh in 2020 on exploitation of new waterfalls is implemented, i.e. the investment cost is increased by approximately 25-30 per cent in 2020.

The inclusion of environmental cost is effective in the way that it will restrict the total supply of hydro electricity. As a consequence, the electricity prices are increasing relative to the baseline scenario up to 2010, see figure 6.4.

Gas power plants will be introduced as a back stop technology when prices exceeds cost. The price gap between the protection and the baseline scenario is almost closing when gas thermal power becomes profitable. This reflects that gas thermal power were about to be introduced at the end of the period in the baseline scenario. From table 6.3 we find that gas power generation is approximately 6 TWh in 2020 while total electricity consumption and economic growth is about the same as in the baseline scenario in 2020.

Table 6.3. Energy balance in the protection scenario. Deviation from the baseline scenario. Electricity supply and and demand. Fossil fuel demand for stationary use. Utilized energy, TWh

	Electricity			Fossil fuels[a]		
	2000	2010	2020	2000	2010	2020
Generation						
- hydro power	-1.6	-2.1	-6.4			
- gas power	0.0	0.0	6.4			
Import	0.0	0.0	0.0			
Export	0.0	0.0	0.0			
Domestic use	-1.6	-2.1	0.0	0.2	0.3	0.2
Network losses	-0.2	-0.2	0.0			
Energy int. ind.	0.0	0.0	0.0	0.0	0.0	0.0
Pulp and paper	0.0	0.0	0.0	0.0	0.0	0.0
Other manufact.	-0.4	-0.5	0.1	0.0	0.1	0.1
Services	-0.6	-0.8	0.0	0.0	-0.1	0.0
Residential	-0.6	-0.6	-0.1	0.2	0.3	0.1

[a] Only stationary use. Transportation use not included.

6.5 International electricity trade

Of special interest in analyses of the Norwegian electricity market is the transmission capacity between Norway and other countries. The Norwegian transmission grids has connections to the Swedish, Danish, Finnish, and Russian transmission grid. A new transmission line to Denmark was opened at the end of 1993 and the total annual transmission capacity for exports/imports reaches approximately 25 TWh, which is just above 20 per cent of the domestic hydro power production capacity. New cables to Germany and Holland are under planning/construction.

The power generation capacity in the neighbouring countries are mostly based on fossil fuels or nuclear energy, except for Sweden where close to half of the generation capacity is based on hydro power. The differences in cost structure among the technologies make electricity trade of special interest. In particular, the low cost associated with supply of peak electricity from hydro power generation may make short run trade profitable.

So far, we have treated the demand for export and import of electricity as exogenous. In the *trade scenario* presented in this section, we introduce a "soft-link" between the MSG-EE model and an engineering model of the Nordic and North European electricity market[37] to clear the export market. The engineering model calculates an equilibrium Nordic market electricity price based on the existing production and transmission capacities, costs of new capacity for different technologies and demand curves for each of the regions Sweden, Denmark, Finland and Germany. Export and import in MSG-EE are, through the "soft-linking" procedure, dimensioned to equalize the equilibrium price in Norway and the market electricity price less transmission costs between Norway and the market.

Table 6.4. Assumed fuel efficiency (electricity output to primary input ratio) in different combustion processes in Norway

Technology	Fuel efficiency
Existing coal fired power plant	0.30-0.39
New coal fired power plant	0.45
New natural gas fired power plant	0.50
Stationary heating, kerosene	0.75
Stationary heating, fuel oil no. 1	0.70
Stationary heating, electricity	1.00

In the trade scenario, we also assume the existence of an agreement on an international CO_2 tax. An international CO_2 tax will increase both costs for stationary heating based on fossil fuels and thermal power generation. The fuel efficiencies[38] in existing thermal power generation abroad are relatively low compared to the fuel efficiencies in decentralized heating systems in Norway,

[37] Jarlset et al. (1993).

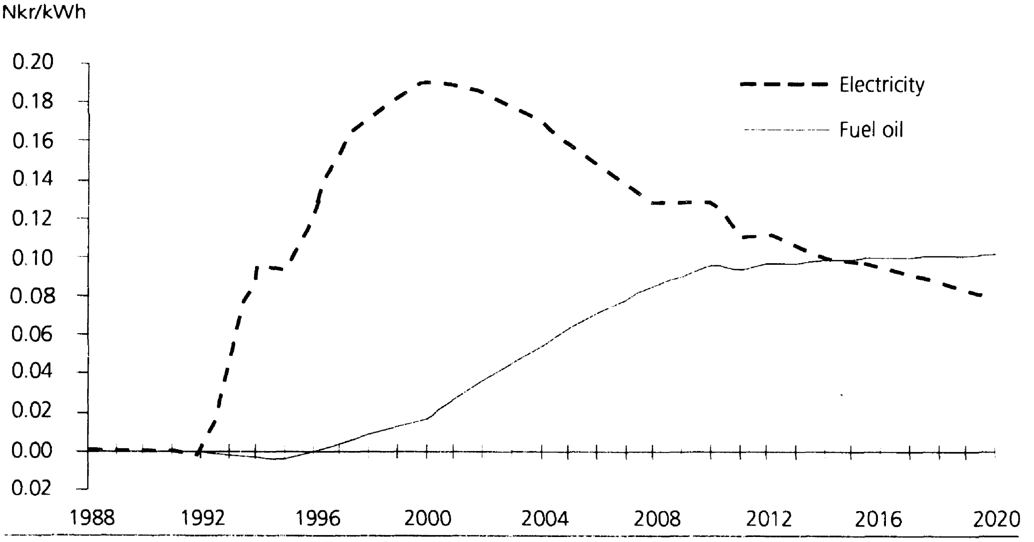
[38] Fuel efficiency (FE) defines the ratio between output of useful physical energy units (O) and total input of physical energy units (I) in a given combustion process, FE = O/I.

which are reported in table 6.4.

Since we assume a competitive Nordic electricity market, the increase in CO_2 tax and the differences in fuel efficiencies, result in a larger price increase on fossil fuel based electricity, and thereby all electricity, than on fossil fuels used for direct heating in Norway.

In the trade scenario we increase the CO_2 tax compared to the baseline scenario. We implement a CO_2 tax equal to 200 Nkr per tonnes CO_2 in year 2000 increasing to 350 Nkr per tonnes CO_2 in 2010 and 2020. We assume that all countries introduce the same tax. Figure 6.5 reports the changes in energy prices from the baseline to the tax scenario.

Figure 6.5. Energy prices in the trade scenario. Absolute deviation from the baseline scenario. Nkr/kWh



Taxing CO_2 in this way increases exports of electricity from Norway with the result that domestic electricity prices increase. Lower CO_2 taxes abroad than in Norway at the outset, and a relatively low fuel efficiency in coal fired thermal power generation (compared to decentralized stationary heating using fossil fuels in Norway), imply a more rapid growth in the electricity price than in the prices of fossil fuels. The substitution effect will then be in favour of fossil fuels for stationary heating. Increased energy costs imply a reallocation of labour and capital in a less productive way than in the baseline scenario and thereby reduces GDP (see section 6.6). The magnitudes of the energy substitution and the scale effects, will determine whether fossil fuel use increases or decreases as a result of the CO_2 tax and international trade in electricity.

The Norwegian domestic electricity demand is lower in the trade scenario than in the baseline scenario due to the higher electricity prices, see table 6.5. The effects on the demand for fossil fuels in Norway are mixed. The demand is higher in the year 2000 in the trade scenario than in the baseline scenario, while the opposite is the case in the years 2010 and 2020. The different sectors are reacting individually to the price changes. In the service sector the scale effect is dominant, which implies reduced fossil fuel consumption both in 2000, 2010 and 2020. In the residential sector the substitution effect is dominant in 2000, but the scale effect is strongest in 2010 and 2020. In the manufacturing sectors the substitution effect dominates over the whole period. The total effect is a mixture of the sectorial effect and this explains the change of sign of the effect along the simulation path.

The Norwegian emissions of CO_2 is reduced at the end of the period in accordance with the change in fossil fuel demand. In addition, other countries have reduced their emissions due to imports of "clean" hydro power from Norway and thereby reduced their own fossil fuel based thermal power production.

Table 6.5. Energy balance in the trade scenario. Deviation from the reference scenario. Electricity supply and demand. Fossil fuel demand for stationary use. Utilized energy, TWh

	Electricity			Fossil fuels[a]		
	2000	2010	2020	2000	2010	2020
Generation						
- hydro power	12.3	14.4	10.0			
- gas power	0.0	0.0	0.0			
Import	0.0	0.0	0.0			
Export	19.1	19.9	14.9			
Domestic use	-6.8	-5.5	-4.9	0.1	-1.9	-2.3
Network losses	0.2	0.4	0.2			
Energy int. ind.	0.0	0.0	0.0	0.0	0.0	0.0
Pulp and paper	0.0	0.0	0.0	-0.2	-0.4	-0.3
Other manufact.	-2.3	-2.1	1.7	-0.1	-0.7	-0.7
Services	-3.0	-3.0	-2.8	-0.2	-0.5	-0.5
Residential	-1.8	-0.9	-0.7	0.7	-0.4	-0.7

[a] Only stationary use. Transportation use not included.

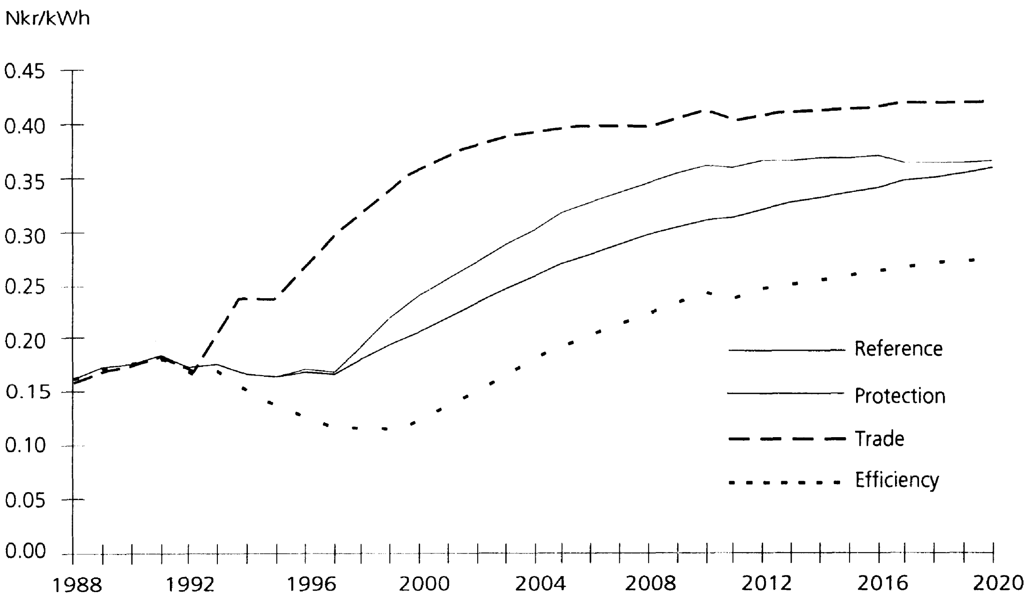
6.6 Macroeconomic effects in the four scenarios

Figure 6.6 reports on the electricity prices in the four scenarios considered in this chapter (the baseline, the efficiency, the protection, and the trade scenario). We find that the electricity prices in Norway in 2020 varies between 0.28

Nkr/kWh (efficiency scenario) to 0.42 Nkr/kWh (trade scenario), i.e. by approximately 50 per cent.

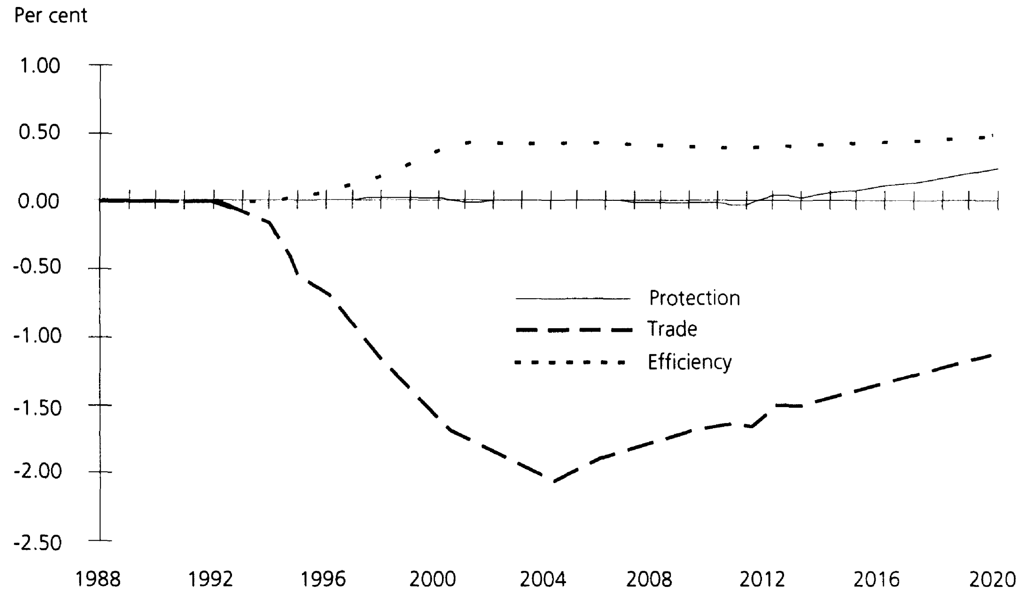
The electricity prices depend on the possibilities for international electricity trade. Whether we run a business as usual scenario (baseline scenario) or implement an environmental tax on hydro power production (protection scenario) does not seem to matter very much for the electricity price and GDP development. The amount of new hydro power projects with costs below the back stop technology (gas power plants) is restricted. Including environmental costs on new investments in hydro production makes gas powered thermal plants a profitable alternative. The minor effect on prices when introducing an environmental tax on water resources imply that gas thermal power is close to be introduced on the margin in the base line scenario in 2020. In the baseline and environment scenarios electricity prices are approximately the average of the price in the free trade scenario and the efficiency scenario.

Figure 6.6. Equilibrium electricity prices in the four scenarios, measured at the border between the transmission and distribution grid, Nkr/kWh



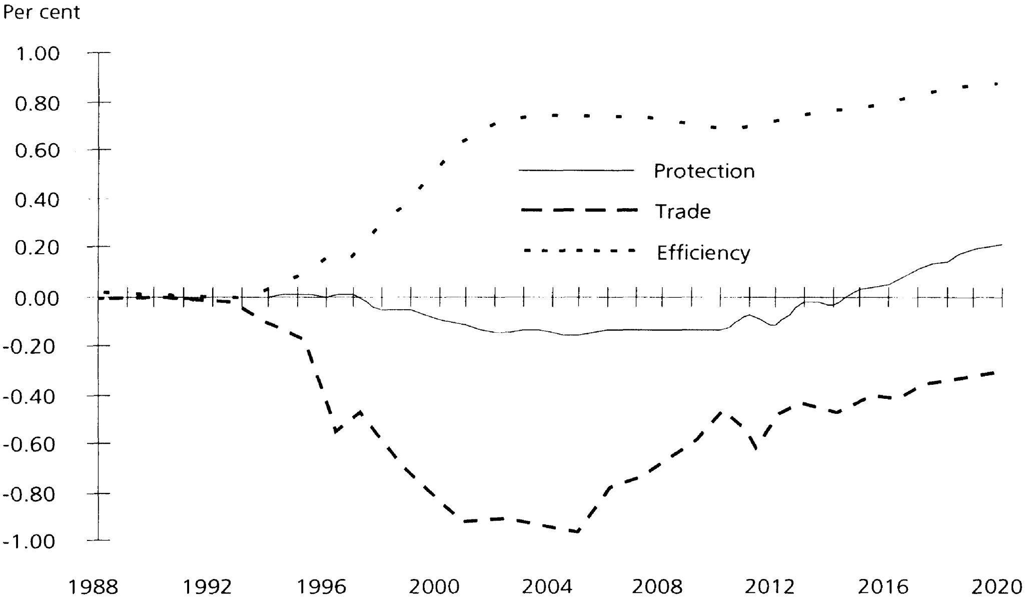
From figure 6.7 we see that the consequences for the Norwegian GDP is slightly positive when moving from the baseline scenario to the efficiency scenario. Thus, GDP increases by 0.5 per cent in year 2020 due to a more productive allocation of the primary inputs labour and capital when the electricity market is deregulated. In the trade scenario, GDP decreases sharply during the first 10 years and recovers somewhat up to year 2020. This is because a European market for electricity combined with higher CO_2 taxes will increase capital costs in Norway and influence the allocation of labour and capital such that total productivity of primary inputs decrease.

Figure 6.7. Gross domestic product. Per cent deviation from the baseline scenario



From figure 6.8 we see that the effects on private consumption (measured in fixed prices) are similar to the effects on GDP, however somewhat more positive. The differences reflect changes in the savings ratio induced by changes in the fixed capital formation. In the efficiency scenario, private consumption increases by close to one per cent in 2020, and in the trade scenario private consumption decreases by 0.3 per cent. When taxing CO_2 emissions, the growth of the energy intensive industries, which also are the main export industries, are reduced. In a long term general equilibrium context, the primary inputs will then be used in production for the domestic market, for instance private consumption commodities. In addition, changes in the terms of trade affect consumption. In our empirical model, export demand is elastic, which means that some of the incremental costs are covered by increases in export prices, while import prices are kept constant. This terms of trade effect, then contributes positive to the changes in private consumption, see Aasness, Bye and Mysen (1995).

Figure 6.8. Private consumption. Per cent deviation from the baseline scenario



7. Transport in a macroeconomic framework

T. Bye and B.M. Larsen

7.1 Introduction

Transport is an important activity in a long stretched country like Norway. In order to avoid excessive costs, transport of both inputs to - and outputs from - economic activity must be as efficient as possible. Effective transport is also important to minimize external effects such as emission of carbon dioxide (CO_2), particulate matter and nitrogen oxides (NO_x).

This chapter will first take a closer look at the development of transport activities in the future as described in the baseline scenario discussed in chapter 4; its total volume and composition (section 7.2). The assumptions of technical progress in transport activities are also discussed in some detail.

Then, in section 7.3, the effects of an increased CO_2 tax on transport activities are analysed. One motivation for this focus is that 60 per cent of total Norwegian CO_2 emissions are due to transport activities. In MSG-EE, technical change is exogenous, i.e. it is not price dependent or dependent upon the rate of economic growth. However, several studies discuss the effects of changes in the tax system on the future development of transport technologies. In the *tax scenario* presented in section 7.3 we implement such "endogenous" technical changes in transport.

7.2 Transport in the long run

According to Rideng (1993), the growth in total transport of freight (measured in tonnes-km) averaged 5.5 per cent annually between 1946 and 1970. From then on, the growth rate has been reduced to 1 per cent per year or less, se table 7.1. Over the same period, the composition of transport on different modes of transport has changed dramatically. Road transport has increased its market share, while sea transport and transport by rail decreased their shares. This is partly due to large structural changes in the Norwegian economy. In addition huge investments in road infrastructure during this period has changed the relative price between road and rail activity since no direct pricing of the infrastructure has taken place. Finally, high income elasticities for private cars has contributed to this change in transport composition. Initially, in the post war period, floating of timber amounted to 6 per cent of total freight transport, but this activity has now ceased.

Table 7.1. Average annual growth rates and market shares for freight transports measured in tonnes-km. 1946-1992. Per cent

	Growth rate	Market shares				
		Road	Rail	Floating	Air	Sea
1946-1960	5.6	12	17	6	0	65
1961-1970	5.5	17	12	4	0	67
1971-1980	1.1	21	10	1	0	68
1981-1990	0.9	31	10	0	0	58
1991	-0.6	42	9	0	0	49
1992	0.2	42	9	0	0	49

Source: Rideng (1993)

According to Rideng (1993), transport of passengers (measured in passenger-km) has increased even faster than freight transport in the whole period after the second world war, with the exception of the last two years, see table 7.2. Changes in the pattern of passenger transport has been similar to the changes in freight transport, however, taking place over a shorter time period. For passenger transport the market share of sea transport and transport by rail declined substantially, while road transport doubled its market share. As for freight transport, road infrastructure investments and consumer behaviour have contributed to this shift, while industrial structural change explains a minor part. Air transport also increased its market share sharply. While the changes in the patterns of freight transports were relatively smooth over the whole post war period, the changes in the pattern of passenger transport took place mostly before 1970. In the period from 1961 to 1991, the average annual growth rate for total passenger transport was 4.5 per cent.

Based on the national accounts, where transport is measured in value terms, commercially produced transport makes up for approximately 60 per cent of the total transport market, mainly due to the fact that both post and telecommunication services and transport by rail are produced commercially only. In the aggregate of sea, road and air transport, the commercial part is

Table 7.2. Average annual growth rates and market shares for person transports measured in passenger-km. 1946-1992. Per cent

	Growth rate	Market shares			
		Road	Rail	Air	Sea
1946-1960	6.9	45	45	0	10
1961-1970	8.3	75	19	1	5
1971-1980	4.7	88	7	2	2
1981-1990	2.6	88	7	4	2
1991	-0.9	89	5	5	1
1992	-0.1	89	5	5	1

Source: Rideng (1993)

approximately 40 per cent. Road transport amounts to approximately 50 per cent of total transport expenditures, while sea transport represents slightly less than 10 per cent. More than two third of the total demand for transport services is from industrial activities.

In our baseline scenario we have assumed a general Hick's neutral annual rate of technical change in transport of 0.5 per cent. Some specific assumptions on technical change in different transport technologies are, however, made as follows:

- The Norwegian Institute of Transport Economics (TØI) estimates that the most likely average annual rate of technical change in road transport is approximately 1 per cent in the long run, however, somewhat lower for transport of goods than for passenger transport.
- According to TØI (Thune-Larsen, 1991) both increased energy efficiency in air crafts and larger average size of new air crafts will influence the average energy use per passenger-km. Based on TØI's analysis we assume an increase in energy efficiency of 0.9 per cent per year in air transport in the long run.
- There are large differences in energy efficiencies within the Norwegian fleet of ships used for domestic sea transport. If the boats with energy technology below average efficiency were replaced today with boats with the average 1985 energy technology, the energy improvement in the total fleet would be somewhere between 20 and 25 per cent (Thune-Larsen, 1991). We assume that this will happen before year 2020 and therefore introduce an annual rate of technical change in domestic sea transport equal to 0.8 per cent.

- Within both transport by rail and post and telecommunication, we assume a general annual technical change rate of 0.5 per cent.
- The model do not specify an explicit rate of technical change in transport carried out by the residential sector.

Figure 7.1 shows that commercial and own produced transport increase approximately at the same rate over the whole simulation period (1.4 per cent per year). However, this hides the fact that there are large differences in the growth of transport in the different parts of the economy. Thus, in the residential sector commercial transport increases by 1.8 per cent per year, while own transport in the residential sector increases by 2.1 per cent annually. This is due to higher expenditure elasticities in own transport than in commercial transport. In the production sectors annual growth rates for commercial and own produced transport are 1.3 and 0.8 per cent, respectively. By comparison, the growth rate of GDP averages 1.7 per cent per year. The transport intensity in the industry sectors decrease by more than 20 per cent over the projection period. Sectors like Manufacturing of metal products and machinery, Banking and insurance and Other private services, which together use a large part of the total commercial transport, grow faster than other sectors. This contributes to the relatively larger increase in the production of commercial transport compared to the own production of transport in the industries.

Figure 7.1. Simulated demand for commercial and own produced transport. 1988-2020. Indices, 1988=1

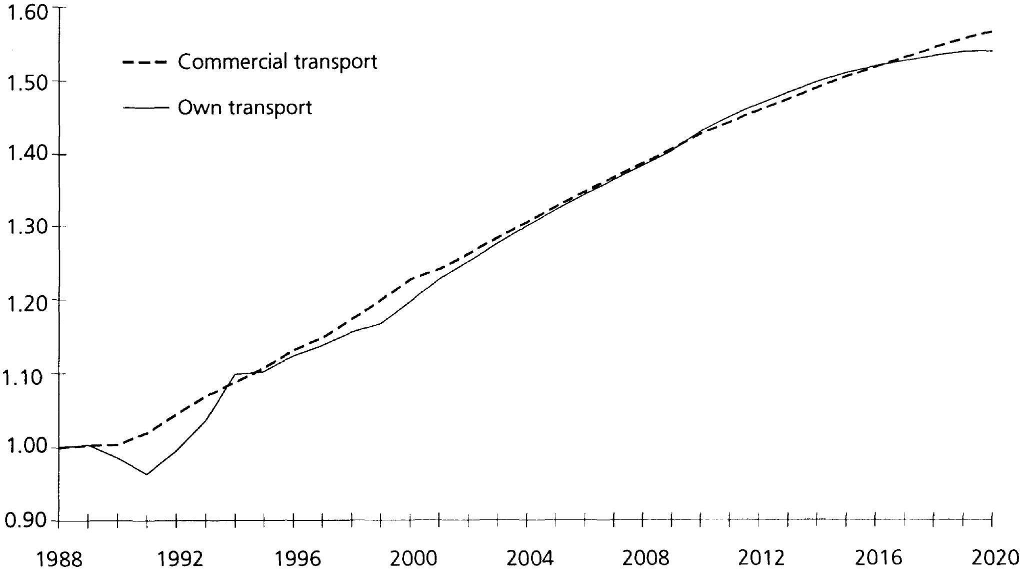
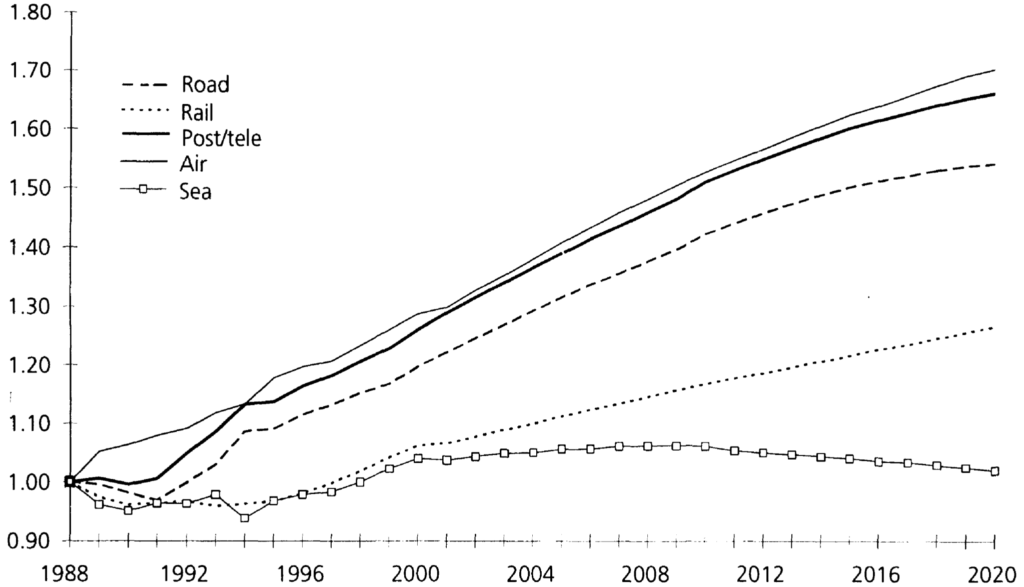


Figure 7.2. Simulated demand for transport by type. 1988-2020. Indices, 1988=1



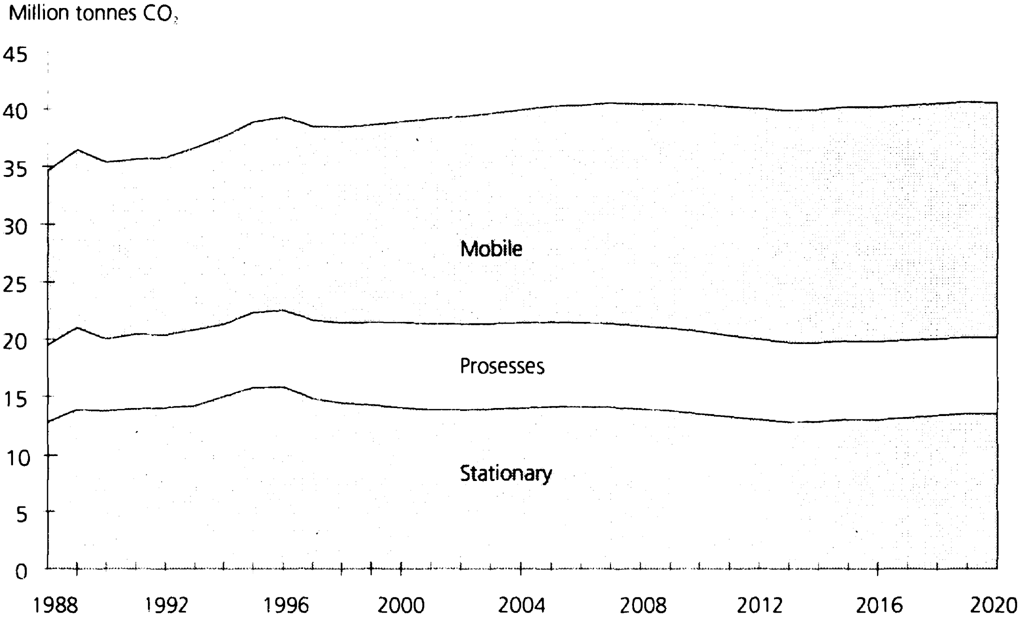
Air transport and *Post and telecommunications* both show an increase of close to 70 per cent over the simulation period, see figure 7.2. This is mainly due to the high income elasticity in the residential sector and a somewhat higher economic growth rate in the private service sectors than in the manufacturing industries. *Road transport* increases by just over 50 per cent, which is equal the increase in total transport activities over the simulation period. Rail transport increases mainly due to increased private consumption. The growth rate is smaller than total consumption growth, however, because of relatively small income elasticities. Sea transport is almost stabilized at the base year level. The main reason for this is the decrease in off shore petroleum activities after the turn of the century.

Transport demand in the residential sector increases by twice as much as the demand for transport in industries. This is due to high income elasticities for most transport categories in the residential sector and a 0.5 to 1.5 per cent annual rate of technical change in own produced transport in the industrial sectors.

7.3 Transports and CO_2 taxes

The share of mobile emissions of CO_2 increases over time in the baseline scenario, see figure 7.3, which illustrates the necessity of focusing on transport activities if we are concerned with future emissions of CO_2 and also other air pollutants. In the MSG-EE model, transport activities and the composition of these activities will be influenced by substitution in the domestic commodity market (which is also influenced by imports), by income effects in the residential sector, and by the elasticities in the export market. The possibility of endogenous "price induced" technical change may also be important for emission reductions.

Figure 7.3. Demission of CO_2 in the reference scenario. 1988-2020. Million tonnes



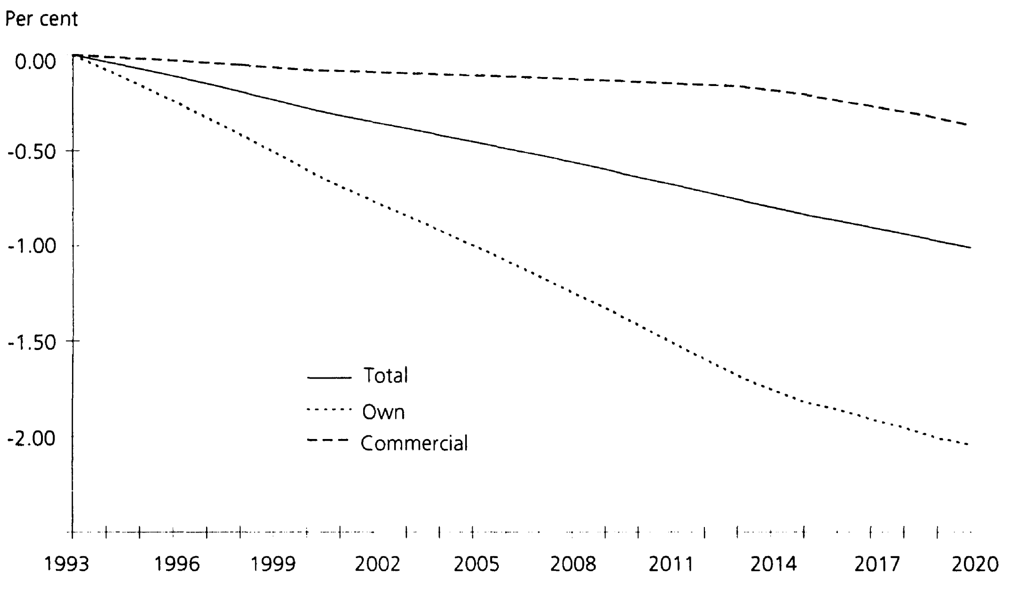
In this chapter we focus on the stabilization scenario from chapter 5, i.e. where the CO_2 tax increases by 10 per cent per year compared to the baseline scenario from 1994 to 2000 and increases annually by 7 per cent from 2000 to 2020. Thus, the tax rate is approximately equal to 380 Nkr per tonnes CO_2 (1990-prices) in 2020. In the baseline scenario a tax of 150 Nkr per tonnes of CO_2 is implemented.

In Thune-Larsen (1991), the potential for increased energy efficiency in road traffic due to the CO_2 tax is estimated to be to 1.8 per cent per year, i.e. 0.8 per cent higher than in the baseline scenario. This estimate is, however, dependent upon whether the tax rate is introduced on a national or an international basis. Introduction of a national tax in a non car producing country like Norway is not likely to have an impact on the technical development in the auto industry. An international tax, however, is likely to accelerate the development of more energy efficient car technologies. Thus, a national tax may lead to a demand side change in chosen technology (moving closer to the front technology), while an international tax will influence technical change both through a demand and supply side effect. In our national tax scenario we have implemented a 0.2 per cent higher annual rate of technical change in the road transport activities than in the reference scenario.

The potential for reducing the energy input in air transport by the introduction of more efficient technologies is less than the potential for more efficient car technologies according to TØI. In the tax scenario we have implemented an additional technical change of only 0.1 per cent per year compared to the baseline scenario.

If every ship in domestic sea transport were replaced with ships employing the best available technology in 1985 before year 2020, the energy efficiency would improve by on average of 1.2 per cent per year in addition to the improvement incorporated in the baseline scenario. In our tax scenario we have assumed a slower replacement rate and have added only a 0.25 per cent technical change in domestic sea transport compared to the reference scenario.

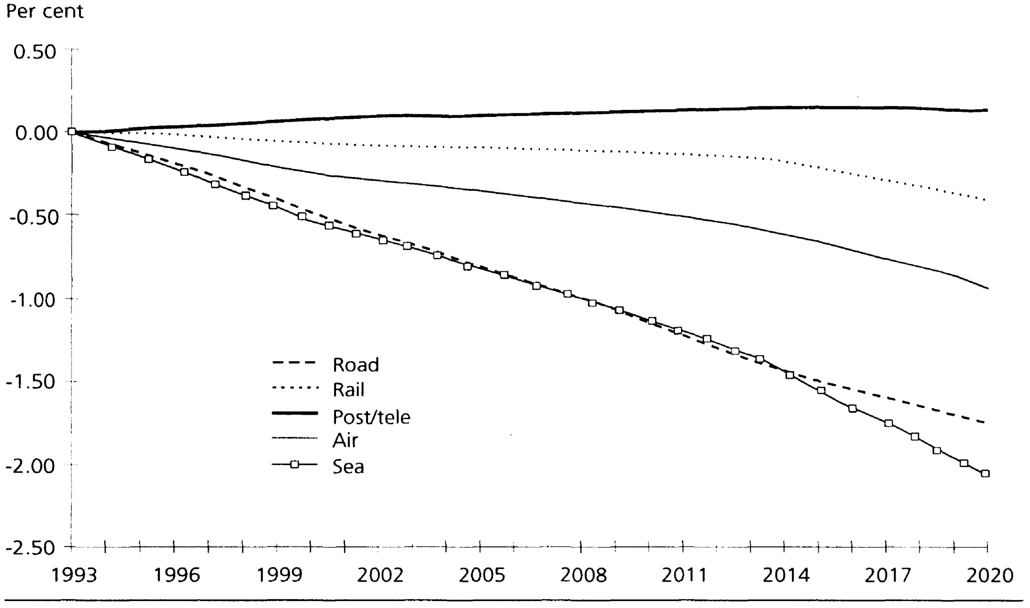
Figure 7.4. Deviation in total transport and commercial and own transport in the tax scenario relative to the baseline scenario. 1993-2020. Per cent



In the sectors *Transport by rail* and *Post and telecommunications* we have not changed the energy efficiencies implemented in the baseline scenario, since the fossil energy input cost shares in these sectors are almost negligible. I.e. the assumed "price inducing" technical change rates are in favour of fossil fuel based transports.

From figure 7.4 we see that demand for own transports is reduced more than commercial transports when the CO_2 tax is increased and transport productivity improved. Commercial transport is reduced less than GDP. Fossil fuel intensive industries experience large cost increases which substitutes demand away from these industries products. Energy intensive industries demands relatively little commercial transport, i.e. large reductions in energy intensive industries and small reductions in less transport intensive industries partly imply an increase in the macro commercial transport intensity. Own transport is reduced more than GDP despite the fact that private consumption, which accounts for a relatively large share of the demand for own transport, increases. Hence, the price effect on own transport from CO_2 taxes in private households more than outweighs the positive income effect.

Figure 7.5. Deviation in transport by type in the tax scenario relative to the baseline scenario. 1993-2020. Per cent



Road and sea transport decrease the most due to the increased tax, see figure 7.5, while rail transport and post and telecommunications are hardly affected.

Increased cost reduces economic activity (GDP) which reduces both road and sea transport, and post and telecommunications. CO_2 taxes increases the cost of fossil fuel both for mobile, stationary and process end uses. Changes in industrial structural due to differences in cost change by end use fuel intensity is in favour of post and telecommunications in the CO_2 tax scenario compared to the reference scenario. Besides, increased private consumption also favours post and telecommunications especially to sea transport.

Figure 7.6. Emissions of CO_2 from transport activities. Deviation from the baseline scenario. 1993-2020. Per cent

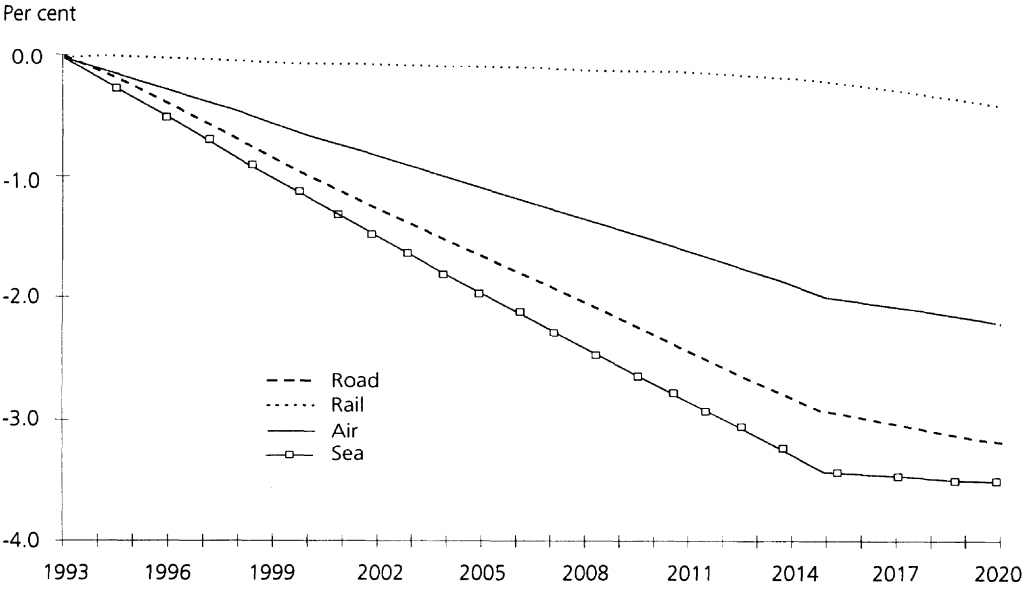


Figure 7.6 shows the decrease in mobile emissions of CO_2 in the tax scenario compared to the baseline scenario. We find that total emissions of CO_2 is reduced by 2.5 per cent relative to the baseline scenario. The composition follows the changes in the transportation structure discussed above.

8. Concluding remarks

The integrated energy - environment - economy model presented in this book is one of a number of extensions to the original Johansen Multi Sectoral Growth (MSG) model (Johansen, 1960, 1974). The extensions have been motivated by progress in economic theory and computational capabilities, but also to a large degree by changes in the questions facing policy makers. During the late 1970s and the early 1980s the profitability of further hydro power capacity expansion, optimal long run pricing of electricity, price discrimination between energy intensive industries and the rest of the economy, and environmental problems linked to hydro power projects and regulations of waterfalls ranked high on the political agenda in Norway. As a consequence the MSG model was extended to capture electricity specific issues in a relatively detailed manner (Bjerkholt *et al.*, 1983). In the 1970s, environmental problems, mainly related to industrial pollution, were controlled through the use of direct regulations. As CO_2 and NO_x related problems became more prominent on the political agenda during the late 1980s, economic instruments became more important as tools for controlling environmental problems. Thus, a detailed emission sub-module were added to the current CGE model, making it possible to carry out studies of environmental taxation, economic growth and energy supply and demand within a consistent general equilibrium framework.

However, several analyses of the economic effects of environmental policies made it clear that the model was in need of further refinements. First, the environmental impacts of transportation of all kinds combined with the large expected growth rate of these activities, pointed to the need for a better and more detailed modelling of the supply and demand of transport services. Second, in 1991 Norway deregulated the internal electricity market, which, thus, created a need for revision of the modelling of the electricity market. In addition, the potential expansion of hydro power capacity in Norway was tightening due to new environmental regulations and steeply increasing marginal cost. Gas thermal power plants thus became viable substitutes for additional hydro power plants. However, use of gas generate emissions of various kinds and thereby put tougher restrictions on the national emission targets for the rest of the economy. Finally, after addressing the problem of the cost of environmental regulations, the problem of identifying the benefits of these regulations was raised.

These issues formed the background for the decision to go ahead with the modelling project reported on in this book. As discussed in chapter 2, the new model, MSG-EE, follows the standard procedure of general applied general equilibrium (AGE) modelling in many respects. Thus, the model focuses on factor substitution within industries, and changes in the industry structure induced by commodity substitution possibilities following price shocks generated by for instance the introduction of environmental taxes. The model is developed to be reasonable realistic in the description of these substitution possibilities, including the possible introduction of gas power plants. Consistency with the national accounts, econometric tests of different behavioural assumption, a detailed representation of a large governmental sector and a reasonable description of the income generation and balancing budgets for different parts of the economy have been emphasized. Furthermore, we have adopted the Armington approach in the modelling of exports, which may be consistent with observed intra industry trade and lack of specialization. This, however, implies that Norwegian producers face a declining export demand curve, and coordinated price setting through a tax increase, enables Norway to capture a terms of trade gain. This property plays an important role in the analyses of the economic effects of for instance carbon taxes as described in chapter 5. The justification for the Armington assumption is questioned in the literature, and the welfare contribution from the terms of trade gain should be emphasized when interpreting the simulation results.

The modelling of transport activities in MSG-EE incorporates several improvements compared to previous versions of the MSG model. First of all, the transport activities are disaggregated to cover road, sea, air, and rail transportation as well as post and telecommunications. Secondly, the production of transport services within almost all industries are recognized, and these own produced transport services together with the supply of commercially produced transport services, constitute a separate (fifth) input factor in the production modelling in the MSG-EE model.

So far, the model does not include intertemporal considerations among consumers or investors, despite the fact that environmental problems typically have long term consequences. Also, the model has not been tested by complete simulations on the history (historical validation of the model) although most of the relations in the model have been estimated on historical data from the early 1960s to the late 1980s. Historical validation of the model is made difficult by the lack of lag structure in the behavioural relations to take care of the partial adjustment both in factor demand, consumer demand and external trade that one expects to take place.

Different versions of the MSG models are applied in different political contexts. The Ministry of Finance applies these models when performing the so called perspective analyses in the Government's Long Term Programme every fourth year. In addition several official committees have been appointed to analyse issues such as for instance:

- the economic impacts of revising the general tax system to be more efficient subject to certain criteria, including environmental effectiveness
- introducing instruments to reduce unemployment and, at the same time, improve the environment.

Lately, also some non-government organizations (NGOs) have taken an interest in formal model based analysis of environmental issues, thus extending both the number of environmental questions addressed by the model and the user group of the model. Hence, the policy relevance of the MSG models is clearly demonstrated.

Of course, the MSG-EE model is not the final answer to demand for suitable analytical tools for policy analyses. In particular the lack of intertemporal optimization can be seen as a weakness in a model aiming at treating long term problems linked to the use of natural resources and the environment. The treatment of the transport sector in MSG-EE can also be characterized as to be of a preliminary nature, since the substitution possibilities among the different types of transport largely are determined exogenously in the model at present. Furthermore, the treatment of international trade by relying on the Armington assumption is perhaps not the optimal choice - other avenues could and should be explored. Finally, the question of the appropriate diasaggregation level and the handling of heterogeneous industries is alwas a difficult question within the field of applied analyses, and further research in this area will probably lead to revisions to the structure chosen in MSG-EE.

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Appendix A: List of production sectors

MSG code	Full name
11	Agriculture
12	Forestry
13	Fishing and breeding of fish, etc.
15	Manufacture of consumption goods
25	Manufacture of intermediate inputs and capital goods
34	Manufacture of pulp and paper articles
37	Manufacture of industrial chemicals
40	Petroleum refining
43	Manufacture of metals
45	Manufacture of metal products, machinery and equipment
50	Building of ships and platforms
70	Hydro power production
71	Thermal power production
72	Power transmission
73	Power distribution
55	Construction, exclusive oil well drilling
81	Wholesale and retail trade
64	Production and pipeline transport of oil and gas
65	Ocean transport, oil and gas exploration and drilling
75	Domestic road transport
76	Domestic air transport
77	Domestic rail transport
78	Domestic sea transport
79	Post and telecommunication
63	Finance and insurance
83	Housing services
85	Other private services
89	Imputed service charges from financial institutions
92S	Defence
93S	Central government education and research
94S	Central government health-care, veterinary services, etc.
95	Other central government services
93K	Local government education and research
94K	Local government health-care, veterinary services, etc.
95K	Other local government services

Appendix B: List of commodities

MSG code	Full name
Commodities from Industries	
11	Agricultural commodities
12	Commodities from forestry
13	Commodities from fishery
16	Processed commodities from agriculture and fishery
17	Beverages and Tobacco
18	Textiles and wearing apparels
25	Various manufacturing products
34	Pulp and paper articles
37	Industrial chemicals
41	Gasoline
42	Fuel oils, etc.
43	Metals
45	Other manufacturing goods
46	Metal products, machinery and equipment
47	Repair
48	Ships
49	Oil production platforms
55	Construction
81	Wholesale and retail trade
66	Crude oil
67	Natural gas
69	Oil and gas pipeline transport
60	Ocean transport
68	Oil and gas drilling
75	Road transport services
76	Air transport services
77	Rail transport services
78	Coastal and inland sea transport services
79	Postal and telecommunication services
63	Finance and insurance services
83	Dwelling services
85	Other Private services
89	Imputed service charges from financial institutions

MSG code	Full name
(List cont.)	
Commodities from government production sectors	
92	Defence
93	Education, research and scientific institutes
94	Health and veterinary services, etc.
95	Other Public Services
Non-competing imports	
09	Food and raw materials
02	Cars, tractors etc.
08	Aircraft
03	Military submarines and aircrafts
04	Oil exploration and drilling
05	Gross expenditures for shipping
06	Imports of services in connection with oil activities
07	Import of goods in connection with oil activities
19	Other non-competing imports
36	Direct purchases abroad by resident households

Appendix C: List of consumption activities

MSG code		Full name
00		Food
11		Beverage and tobacco
U		Energy
	12	Electricity
	13	Fuels
14		Petrol and car maintenance
15		Other goods
21		Clothing and footwear
22		Other household goods
23		Other goods for recreation activities
31		User cost of cars, etc.
41		Furniture and electrical equipment
42		Durable consumer goods
50		Gross rents
61		Public transport services
75		Bus transport, transport by taxi, etc.
76		Air transport
77		Rail, tram, and subway transport
78		Transport by boat and ferry
79		Post, telephone and telegram
63		Entertainment, education, etc.
64		Various household services
65		Other services
66		Direct purchases abroad by resident households

Appendix D: List of household groups

MSG code	Full name
351	Single people of age 65+
352	Single people below the age of 65
353	Two people at least one of whom is 65 or older
354	Two people who both are younger than 65
355	Single parents with one child
356	Single parents with two or more children
357	Couples with one child
358	Couples with two children
359	Couples with three or more children
360	Three adults without children
361	Three adults with one child
362	Three adults with two or more children
363	Four adults with or without children
364	People in institutions

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