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Oppgave mangler foreløpig	Data not yet available	...
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Mindre enn 0,05 av den brukte enheten	Less than 0.5 og unit employed	0,0
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Abstract

Leif Brubakk, Morten Aaserud, Wilma Pellekaan and Fritz von Ostvoorn

SEEM - An Energy Demand Model for Western Europe

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This report documents an energy demand model for 13 West-European countries believed to be of particular interest for Norwegian energy exports. Each country is treated as a separate block in a demand model, i.e. we are not concerned with the supply of primary energy. Supply of thermal electric power is however modelled. In each country there are six demand sectors: Power production, Manufacturing industries and Services industries, Households, Transportation and Other sectors. All sector models can be thought of as variants of the fuel share approach, except from demand in the sector Other activities which is exogeneously given. Parameters in the model were partly calibrated, using estimates reported in the literature, and partly estimated by Statistics Norway and ECN - Policy Studies. The estimation results are reported in an appendix.

Keywords: Energy demand, sector models, power production.

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Contents

1. Introduction*

This report documents the structure and parametrisation of the Sectoral European Energy Model, SEEM. The model calculates future demand for coal, oil, natural gas and electricity in each of 13 West European countries. The fuel demand is specified for 5 sectors; industry, services, households, transport[1] and power production.

The establishing of the SEEM model has taken place in two periods. In 1990-1992 Statistics Norway, partially funded by the Norwegian oil company Statoil, developed the first version of SEEM, covering the fuel demand in the above 5 mentioned sectors in 9 countries. The countries included the four major energy consumers in West Europe, Germany (West), France, UK and Italy, the Netherlands as an important gas country, and the four major Nordic countries Denmark, Sweden, Finland and Norway. These countries consumed about 80 per cent of the OECD Europe total energy use in 1989. Choice of sector model specifications and method of parametrisation was based on utilisation of international literature and previous estimation at Statistics Norway. A summary documentation of the first SEEM model version was given in Birkelund et al. (1993).

In this report the SEEM model version 2.0 is fully documented. This version is a result of the project "Energy scenarios for a changing Europe", partly funded by Statoil and the Dutch Ministry of Planning. The project was carried out by the Netherlands Energy Research Foundation ECN[2] and Statistics Norway in 1994 and 1995. The aim was to study energy demand effects of continued European political and economic integration on the one hand and the effects of fragmentation on the other. The analysis results will be published in 1995.

During the project, models for Spain, Belgium, Austria and Switzerland were included in the SEEM model. Furthermore, former East Germany was included in the German country model. The 13 countries modelled are, or could be, important countries for Norwegian and Dutch energy exports in the future. Furthermore, the transport, power and (partly) the household sector models were respecified. This was done for the following reasons:

* We thank Pål Boug and Dag Kolsrud for useful comments. A special thank to Tony Veiby for excellent work with tables and figures.

[1] Fuel demand for transport purposes has been grouped into one sector.
[2] Energieonderzoek Centrum Nederland.

First, we wanted to make SEEM more unified and transparent. In the SEEM version 1.0 the household energy demand were modelled as a Discrete Continuous Choice process, as in Dagsvik et. al (1986), for the choice of heating system and fuel demand given the system chosen sector model. The model was quite complex and data demanding. Also, the transport model in the first SEEM version had a complex and not very user friendly structure. In SEEM version 2.0 *all* sector models are based on a step wise factor or fuel share approach. For an elaborated description of this approach, see Longva et. al (1983). In the first step the demand for production factors (or consumer goods) aggregates are functions of the aggregate prices and sector activity (or income). In the next steps, the cost minimising fuel shares of the aggregate are determined from relative fuel costs. This approach reduces the parameters to be estimated or calibrated, which is important when data are limited. Thus, the approach has been frequently used in economic modelling. *Second,* the new specifications for the transport and power generation sector allows us to use data for different transport and power production technologies from the EFOM (Energy Flow Optimisation Model) database. *Third*, as opposed to the SEEM version 1.0 substitution possibilities between power produced by fossil fuels, nuclear sources and renewables are modelled.

Finally, two more new aspects of the SEEM version 2.0 should be mentioned. First, the base year for the calibration and simulations has been updated from 1988 to 1991. Second, the new version of SEEM has been implemented in software Portable TROLL instead of MODLER. The PC software MODLER imposed some limitations when running SEEM. For instance, all countries could not be simulated at the same time due to capacity problems, making simulations with interactions between countries difficult. Thus, when the much more powerful software TROLL became available on PC and work stations, it was decided to implement SEEM version 2.0 in Portable TROLL.

Simulations with the *first* SEEM model resulted in two papers published in international journals. Birkelund et al. (1994) analysed the impacts on the West European energy markets and CO2 emissions of a carbon/energy tax as proposed by the Commission of the European Community in 1992. The tax effect was studied under two different assumptions on the investment behaviour in the thermal power production sector; In the planning based regime the new capacity in such production was based on national plans, favouring domestic produced coal, as reported to IEA. In the cost based regime the new capacity was based on relative costs, favouring natural gas. In Alfsen et al. (1995) the impacts of the EC carbon/energy tax on SO2 and NOx emissions and acid rain in Europe under the two above mentioned power sector regimes, were discussed. SEEM energy scenarios for each country were linked with IIASA's[3] model RAINS (Regional Acidification Information and Simulation) which calculates SO2 and NOx emissions by country and the resulting transport and deposition of sulphur and nitrogen in Europe. A major conclusion in both studies was that a change towards more cost efficient, i.e. natural gas based, thermal power production reduced emissions more than imposing the EC carbon/energy tax.

[3] Institute for International Applied Systems Analysis, Austria.

The above analysis illustrates that the SEEM model is a quite powerful and flexible tool for studying important energy and environmental issues in Europe. To have such a detailed, consistent and empirically based energy-environment model is important for Norway and the Netherlands for several reasons: One is that both countries are major exporters of oil and gas. Norway might also become a major exporter of electricity in the near future. Thus, knowledge of European energy markets is beneficiary for both business and government. In 1994 the export of oil and gas contributed to about 33 per cent of total Norwegian exports and about 10 per cent of Dutch exports. Also, Norway and the Netherlands both are among the most eager countries for international agreements on measures to reduce international pollution. 95 per cent of acid rain in Norway comes from emissions to air outside Norway. For the Netherlands the figure is 45 per cent. One needs a modelling tool for evaluating these effects, like the cost efficiency, of measures in consideration. An energy demand model form the basis of such analysis'.

The above mentioned aspects have influenced the choice of model and method of parametrisation. First, the model was to focus on the energy markets in, and emissions from, *each* of the countries which are important for Dutch and Norwegian energy exports and West European emissions to air. Several other models have treated Western Europe as one block when analysing energy and environmental issues. Examples are the global models Global 2100 (Manne and Richels (1992)), GREEN (Burniaux et al. (1992)) and ECON-ENERGY (Haugland et al. (1992)), and the European model presented in Agostini (1992). Second, to study market behaviour, cost efficiency of policies measures, etc. an economic model approach with cost minimising agents should be used, as opposed to the more technological approach used when developing models like MARKAL (see Fisbone et al. (1983)) - a model implemented for many West European countries. Third, we wanted a parametrisation based, preferably on econometric relations. However, due to data and resource limitations only some of the model relations in this SEEM version were estimated. The rest of the relations have been calibrated. Fourth, the model should be transparent, simple to use and update, and possible to implement and simulate on a Personal Computer.

It is clear that there might be some conflicts between these aspects, especially with respect to the resource/input foundation of the project: time, funding, personnel, computer tools and software, and available data. On this background we have used the "top down" approach when modelling SEEM, in the sense that we have formulated the model directly on the sector level. However, the macro producer or consumer that we study is assumed to have a behaviour based on micro considerations. In fact, the neoclassical micro model often seems more meaningful on the sector level than on the level of individuals. Especially, smooth substitution possibilities appear more realistic on a sector level. These substitution possibilities are premises for cost minimisation and utility maximisation, which are major assumptions when deriving the fuel demand functions. The major alternative to the "top down" approach is the "bottom up" approach which is far more data and resource demanding, and leaves the modeller with considerable aggregation problems.

In the present report, chapter 2 gives an outline of the structure and the relations in SEEM. First, we give a sketch of the total energy model for a country. Then, the general framework for all the sector models is presented, followed by a documentation of each sector model. In chapter 3, the data sources used for the parametrisation is described, while the estimation and calibration itself is documented in chapter 4. Chapter 5 offers some final remarks, while the appendix provides an overview of the sector model equations, parameter estimates and elasticities.

2. The model

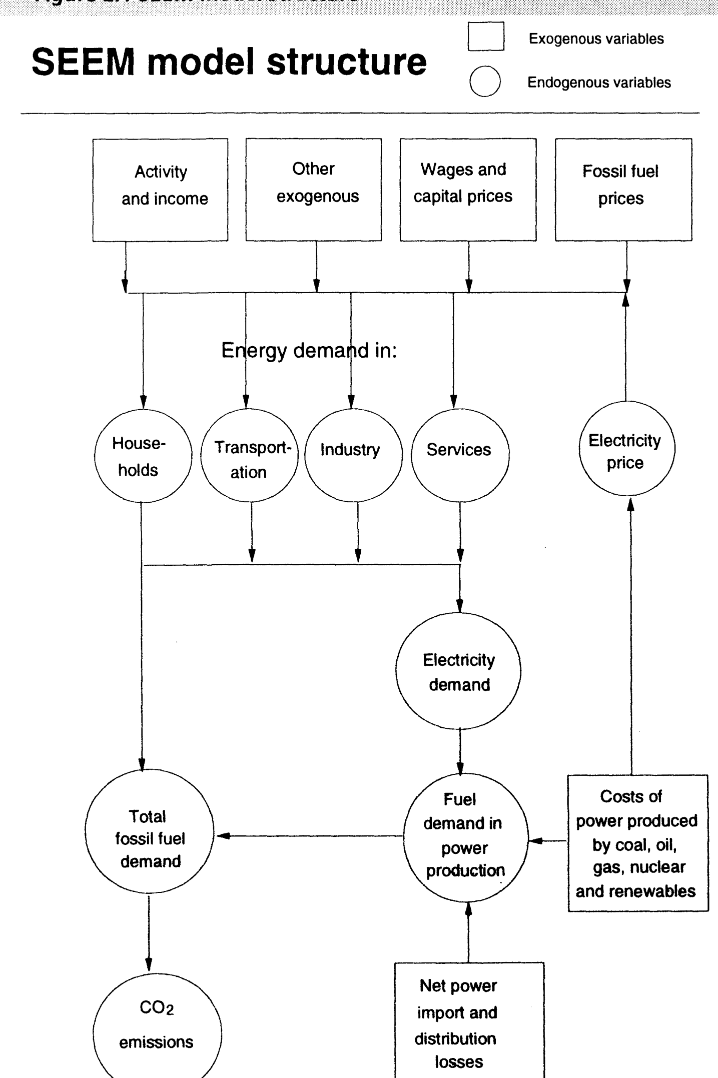
2.1 The structure of each country model

The SEEM model comprises 13 West European countries; the five major energy consumers Germany, France, UK, Italy and Spain, the Netherlands, Belgium, Austria, Switzerland, and the four Nordic countries Denmark, Sweden, Finland and Norway. These countries are chosen for a number of reasons. First, these countries consumed about 90 per cent of the OECD Europe total energy use in 1992. Second, the model includes countries of special interest for Norwegian and Dutch future energy exports. The countries included in SEEM account for around 90 per cent of Norway's oil and gas exports as of 1994 and 87 per cent of the Netherlands' petroleum exports in 1994.

In SEEM each country is treated as a separate block, i.e. trade between countries is not modelled. The SEEM model is not concerned with supply of primary energy. Supply of electric power is however modelled. In each country there are five sectors: manufacturing industries and service industries (here referred to as industry and services), households, transport and power production.

Figure 2.1 depicts the structure of each country model block. The model has a fully recursive structure. First the demand for coal, oil natural gas and electricity in the end user sectors (industry, services, households and transport) is determined from exogenous information on activity levels, income, technology and labour,

Figure 2.1 SEEM model structure



capital and fuel prices. The necessary production of power is determined by adding end user demand for electricity, net power import and distribution losses. Electricity is produced by thermal power plants using coal, oil or natural gas as inputs, nuclear power plants or by plants using renewables (hydro etc.). The plants share of the electricity generation depends on their relative costs in producing the power. Independent of the level of power production, the model calculates the electricity generation price based solely on fuel and capital prices. Thus, constant marginal costs is assumed in electricity production. Adding the use of fossil fuels in the end user sectors to fossil fuel inputs in thermal power production, total demand for each fossil fuel is derived by country. In a submodel demand for coal, oil and natural gas are converted into estimates of CO_2 emissions.

2.2 A general framework

The different sector models are all nested within the same general framework, which will be presented in the following. This representation draws upon the early works of Sato (1967), Brown and Heien (1972) and Berndt and Christensen (1973). The underlying starting point is an objective function denoted

(2.1) $$Y = F(\mathbf{x})$$

where $\mathbf{x}=(x_1,....,x_n)$ is a vector of goods. For example in the case were F is a production function, $\mathbf{x}$ will be inputs of different types of capital, labour, fuels etc.. The set of arguments[4] $N=\{1,....,n\}$ can be partitioned into s subsets $(N_1,...,N_s)$ and correspondingly $\mathbf{x}$ can be partitioned into s subvectors $\mathbf{x}=(\mathbf{x}_1,....,\mathbf{x}_s)$ where $x_i \in \mathbf{x}_s$ if $i \in N_s$. Following our example (assuming N to be a set of factor input indices), the set of factor inputs could be partitioned into subsets labelled capital, labour, energy etc., where the subset capital would consist of different kinds of capital, the subset energy would consist of different fuels and so forth. Assuming weak separability of the subvectors,[5] F will take the following form

(2.2) $$Y = F(X_1,...., X_s)$$

where

(2.3) $$X_i = X_i(\mathbf{x}_i), \quad i = 1,..., S$$

the function X_i, i = 1,...,s, could be regarded as an aggregate index for the elements in $\mathbf{x}_i$. Thus, if $N_r \in \{N_1,...,N_s\}$ is a subset constituted by coal, oil, natural gas and electricity (with a corresponding subvector $\mathbf{x}_r$), X_r could be viewed as an energy aggregate index.

With the objective function of the form (2.2), efficiency in production or consumption can be obtained by step-wise optimisation.

The first step

First, the optimal levels of the aggregates are derived. How this is done, will depend on wether F is i) a production function or ii) a utility function.

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[4]Strictly speaking, this is a set of indices.

[5]Weak separability of a function F means that the marginal rate of substitution between any two elements in the subvector $\mathbf{x}_i$ is independent of any elements outside of $\mathbf{x}_i$ (see e.g. Varian (1984)).

i) If F is a production function, we assume the optimal level of the X's to be found by solving the following cost minimisation problem

(2.4) $$min(\sum_{i=1}^{s} P_i X_i) \quad s.t. \quad Y = F(X_1(\mathbf{x}_1),\ldots, X_S(\mathbf{x}_S))$$

where P_i is a price index for the aggregate X_i.

ii) In some sectors of the SEEM model, like the household sector, demand is derived from the consumer side of the economy. (2.2) will then express household utility, and the optimal level of the X's are found by maximising this utility (with respect to the X's) subject to a budget constraint

(2.5) $$max\{Y = F(X_1(\mathbf{x}_1),\ldots, X_S(\mathbf{x}_S))\} \quad s.t. \quad \sum_{i=1}^{s} P_i X_i = HE$$

where HE denotes household expenditure and Y is interpreted as the level of utility.

Both optimisation problems result in demand functions for the aggregates of the following form

(2.6) $$X_i = f_i(P_1,\ldots,P_s,Z), \quad i = 1,\ldots,s$$

where Z is either the level of production (i.e. Z=Y) or household expenditure (Z=HE), depending on the sector at hand.[6]

The second step

Independent of this first step (due to the separability assumption), we can derive demand equations for the x_j's conditional on the level of the corresponding aggregates. These conditional demand equations are obtained by minimising expenditure on goods in the subset N_i for a given level of the corresponding aggregate X_i, i.e.

(2.7) $$min \sum_{j \in N_i} p_j x_j \quad s.t. \quad X_i = X_i(\mathbf{x}_i), \quad i = 1,\ldots, s$$

where p_j is the price of x_j. Restricting the aggregate functions X_i in (2.3) to be homothetic, the solution to (2.7) can be expressed as follows

(2.8) $$x_j = S_j(\mathbf{p}_i) X_i, \quad j \in N_i, \quad i = 1,\ldots, s$$

Here $\mathbf{p_i}$ is the price vector corresponding to the subvector $\mathbf{x_i}$. It is clear from (2.8) that the ratio (or "share") x_j/X_i, given by the S_j function, is independent of the level of the aggregate X_i. This property follows directly

[6] In the industry and services sector and the part of the transport sector concerning freight transport, Z will be some relevant measure of the level of activity. In the household sector and the passenger transport sector, Z measures consumption expenditure.

from the homotheticity assumption. Throughout this documentation, (2.6) will be referred to as the *upper level* (or the 1. level) whereas (2.8) is referred to as the *lower level.*[7] Defining P_i (which we above referred to simply as the price of X_i) as the unit cost of making use of X_i in either production or consumption, depending on the sector in focus, it will take the form

$$(2.9) \qquad P_i = h_i(\mathbf{p}_i)$$

where

$$h_i(\mathbf{p}_i) = \sum_{j \in N_i} p_j S_j(\mathbf{p}_i), \qquad i = 1,\ldots, s$$

This expression is obtained by substitution (2.8) in the first term of (2.7) and then dividing by the aggregate X_i.[8] Due to the homotheticity assumption this price index will not depend on the level of the aggregate X_i. The model given by the equations (2.6), (2.8) and (2.9) is the underlying general model. All the different sector models will be special cases of this more general specification (with a slight exception for the electricity model).

In general, we do not explicitly specify the objective function F,[9] but simply postulate that the demand equations in (2.6) can be expressed as log-linear functions. Although, in the cases where the upper level demand functions are assumed to be obtained from cost minimisation (corresponding to (i) in the first step above), the log-linear form would be consistent with Cobb-Douglas objective functions.

The specific form of the conditional demand functions in (2.8) (the lower level) will depend on the functional form of the aggregate functions X_i given on a general form in (2.3). Below, we consider the two specifications used in the SEEM model, viz. the Cobb-Douglas and the CES (Constant Elasticity of Substitution) functional forms

Since focus here is on energy demand, all equations following from the general framework which are irrelevant for determining final demand for the different energy carriers, are left out of the model. For example, on the upper level in the industry sector we only specify the demand function for the energy aggregate X_r (referred to above). Thus, demand equations for the labour and capital aggregates are not included. In each sector model, there will be an aggregate index of special interest when deriving final demand for the different fuels. With a slight abuse of notation, this aggregate index will be denoted X_r in all sector models and its interpretation will depend on the sector at hand (this will be further discussed later). As mentioned above, the aggregate X_r (given by (2.3)) is either specified as a Cobb-Douglas or a CES function. These two special cases will be described in more detail in the following two sections.

[7]As will be clear later, the lower level in the household and services sector is further divided into two levels. These two levels are referred to as the 2. and 3. level (or the lower levels)

[8]i.e.:

$$P_i = \frac{\sum_{j \in N_i} p_j x_j}{X_i} = \frac{\sum_{j \in N_i} p_j S_j(\mathbf{p}_i) X_i}{X_i} = \sum_{j \in N_i} p_j S_j(\mathbf{p}_i), \qquad i = 1,\ldots\ldots, s$$

[9]Except for the industry sector, where we assume the macro production function to be of the Cobb-Douglas form.

2.2.1 The Cobb-Douglas case

We have chosen the Cobb-Douglas specification as the functional form for the aggregate X_r in the industry and transport sector. An advantage of the Cobb-Douglas functional form is that the parameters (the α's (see below)) have the interpretation of being cost-shares (given the homogeneity assumption) and can therefore be computed with a rather limited information set. In general, the Cobb-Douglas specification was chosen in sectors where only a limited data set was available or estimation of other functional forms turned out to be difficult.

In the Cobb-Douglas case, assuming linear homogeneity, the energy aggregate will take the form

$$(2.10) \qquad X_r = A\prod_{j\in N_r} x_j^{\alpha_j}, \qquad \sum_{j\in N_r}\alpha_j = 1$$

where N_r is the set of different energy carriers or energy related components. A and α_j are parameters. The restriction on the α's ensures that the aggregate function is linear homogenous.

To provide some examples, in the industry sector the set N_r consists of coal, oil, gas and electricity. Thus, X_r can be interpreted as the input of energy, while the x's are inputs of coal, oil, gas and electricity, respectively. In the transport sector, X_r refers to passenger kilometres and the x's are passenger kilometres "produced" by gasoline cars, diesel cars, gas cars, diesel busses and trains, respectively. It is thus clear that the interpretation of X_r differs between the sector models. Sector specific differences will be given more attention later.

Assuming that X_r is given by (2.10), the demand functions corresponding to (2.8) will take the form

$$(2.11) \qquad x_j = A_j p_j^{-1}\left(\prod_{i\in N_r} p_i^{\alpha_i}\right)X_r, \quad j\in N_r, \quad N_r \in N$$

A_j is a constant and p_j the price per unit of x_j. We note that (2.11) implies that the share S_j (referred to in eq. (2.8)) in the linear homogenous Cobb-Douglas case is given by

$$(2.12) \qquad S_j = A_j\ p_j^{-1}\left(\prod_{i\in N_r} p_i^{\alpha_i}\right), \qquad j\in N_r$$

From (2.12) it is clear that the share of input x_j solely depends on relative prices and not on the level of the aggregate X_r. For example, in the industry model the optimal input of coal relative to the energy aggregate only depends on the price of coal relative to the other fuel prices.

The price index corresponding to X_r, which is stated on a more general form in (2.9), is now given by

$$(2.13) \qquad P_r = B\prod_{j\in N_r} p_j^{\alpha_j}$$

where B is a constant.

2.2.2 The Constant Elasticity of Substitution (CES) case

In both the household model and the services model, the CES specification is chosen for the aggregate X_r, which in these two models is a function of coal, oil and gas and can thus be interpreted as a fossil fuel aggregate.

In the Cobb-Douglas case the elasticity of substitution between the components in the aggregate is equal to one. This puts rather strong restrictions on the substitution possibilities. The CES functional form opens up for an elasticity of substitution different from one, although constant as indicated by the name. In the case of more than two components included in the aggregate, X_r, *the one-level* CES specification implies equal direct partial elasticities of substitution between every pair of components (x_i,x_j), $i\neq j$, $i,j\in N_r$. For example, this would imply the same elasticities between oil and gas, oil and coal and gas and coal in the case where the energy aggregate was constituted by oil, gas and coal. To allow for more flexible substitution possibilities, we choose what is referred to in the literature as the *two-level* CES function (see e.g. Sato (1972)).

Let $N_r=\{N_k,N_m\}$. In the case where N_r includes three elements (e.g. oil, gas and coal), one of the subsets of N_r must include two elements[10] (e.g. oil and coal). We let N_m be the subset including two elements and X_m to be the corresponding subaggregate. The two-level CES function, assuming homogeneity of degree one, can be expressed on the following form

(2.14) $$X_r = \left[\delta_r\left(\frac{X_k}{\delta_r}\right)^{\frac{1-\sigma_r}{\sigma_r}} + (1-\delta_r)\left(\frac{X_m}{1-\delta_r}\right)^{\frac{1-\sigma_r}{\sigma_r}}\right]^{\frac{\sigma_r}{1-\sigma_r}}$$

(2.15) $$X_m = \left[\delta_m\left(\frac{X_e}{\delta_m}\right)^{\frac{1-\sigma_m}{\sigma_m}} + (1-\delta_m)\left(\frac{X_f}{1-\delta_m}\right)^{\frac{1-\sigma_m}{\sigma_m}}\right]^{\frac{\sigma_m}{1-\sigma_m}}$$

where x_e and x_f are the components in the subaggregate and σ_r and σ_m are the elasticities of substitution between X_k and X_m, and between x_e and x_f, respectively. Following our example, X_k, x_e and x_f could be interpreted as gas, oil and coal demand, respectively. Hence, X_m would be an index for coal and oil use. The δ's are distribution parameters.

The partitioning of X_r into the subaggregates, X_m and X_k, allow us to proceed in two steps to derive the conditional demand functions for the elements X_k, x_e and x_f. Following the procedure referred to as the second step in the general outline of the model framework (Ch. 2.1), we start by deriving the conditional demand equations for X_k and X_m.

(2.16) $$X_k = \delta_r X_r P_r^{\sigma_r} P_k^{-\sigma_r}$$

(2.17) $$X_m = (1-\delta_r) X_r P_r^{\sigma_r} P_m^{-\sigma_r}$$

[10]Of course given that N_k and N_m are non-empty

Independent of this step, we can derive demand functions for x_e and x_f conditional on the level of the subaggregate, X_m, using the same procedure. Given that the subaggregate take the form (2.15), we obtain the following conditional demand functions for x_e and x_f.

(2.18) $$x_e = \delta_m X_m P_m^{\sigma_m} p_e^{-\sigma_m}$$

(2.19) $$x_f = (1-\delta_m) X_m P_m^{\sigma_m} p_f^{-\sigma_m}$$

We note that the fuel shares (e.g. x_f/X_m) also in the CES case solely depend on relative fuel prices. The price indexes P_r and P_m, corresponding to (2.9), are given by

(2.20) $$P_r = \left[\delta_r P_K^{1-\sigma_r} + (1-\delta_r) P_m^{1-\sigma_r}\right]^{\frac{1}{1-\sigma_r}}$$

(2.21) $$P_m = \left[\delta_m p_e^{1-\sigma_m} + (1-\delta_m) p_f^{1-\sigma_m}\right]^{\frac{1}{1-\sigma_m}}$$

2.3 The industry sector

2.3.1 Introduction

The industry sector could in principle be divided into subsectors according to differences in energy intensities. One possibility would be to simply distinguish between energy intensive and non-intensive industries. Due to problems in obtaining inter-industry data, this approach is not used in the SEEM model. The industry sector is treated as one sector.

As mentioned above, the energy aggregate in the industry sector is constituted by coal, oil, gas and electricity and is assumed to be represented by a Cobb-Douglas function. The choice of a Cobb-Douglas specification was mainly made for convenience, making calibration more tractable. More flexible functional forms, like Generalized Leontief (GL) functions, were estimated, but the results were not very promising (see Drevdal (1992)).

2.3.2 The industry model

Figure 2.2 displays the structure of the industry model. Fuel prices (through the energy price index), the production level, other factor costs and technological improvement determine the demand for energy. Energy demand is then split into demand for the different fuels in accordance with the optimal fuel shares, determined by fuel prices and substitution possibilities.

Output in the industry sector is assumed to be produced by capital, labour and energy. The industry sector production function, or objective function, is assumed to take the Cobb-Douglas form

(2.22) $$Z = A X_K^{\beta_K} X_L^{\beta_L} X_r^{\beta_r}$$

Z = industry production

X_K = capital input

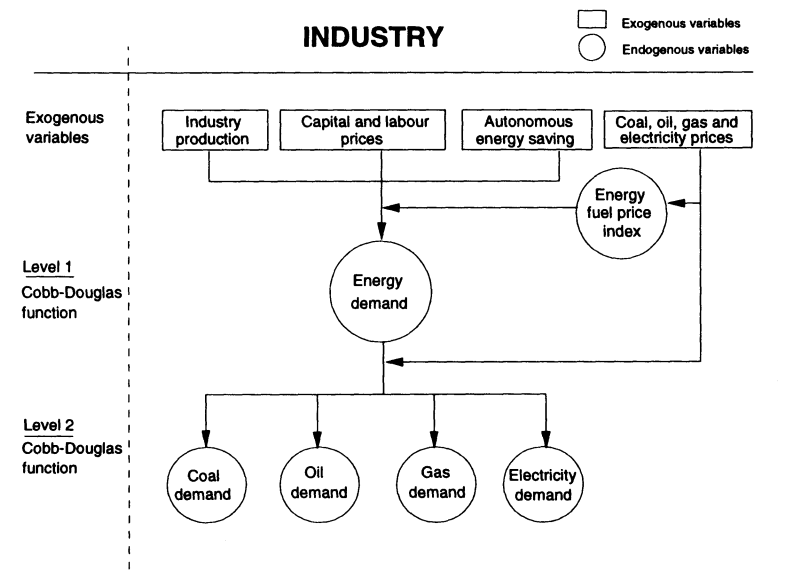
X_L = labour input

X_r = energy input (an aggregate consisting of coal, oil, gas and electricity)

A = constant

β_j, j = K,L,r, has the interpretation of being factor elasticities.

Figure 2.2



The optimal level of the aggregates are found by minimising factor expenditure given the production function. This corresponds to the first step in Ch. 2.2. We then obtain the following demand function for the energy aggregate.

(2.23) $$X_r = \beta\, P_K^{\frac{\beta_K}{\beta}} P_L^{\frac{\beta_L}{\beta}} P_r^{\frac{\beta-\beta_r}{\beta}} Z^{\frac{1}{\beta}}, \qquad \beta_K + \beta_L + \beta_r = \beta$$

where P_K, P_L and P_r are the price indices of capital, labour and energy respectively. As mentioned above, the energy aggregate is specified as a Cobb-Douglas function with coal, oil, gas and electricity as arguments. The optimal input of the different fuels will then take the form (2.11), and the price index for the energy aggregate will be given by (2.13). By substituting (2.23) into (2.11), we obtain the following *desired demand equations* for the different fuels

(2.24) $$x_j^* = \bar{B}\, P_K^{\frac{\beta_K}{\beta}} P_L^{\frac{\beta_L}{\beta}} P_r^{\frac{\beta-\beta_r}{\beta}}\, p_j^{-1} \prod_{i \in N_r} p_i^{\alpha_i}, \qquad j \in N_r$$

where x_j^* denotes *desired* demand for fuel j, and N_r is a set consisting of coal, oil, gas and electricity. As mentioned above, the p_j's represent the prices of the different fuels. *Desired* demand differs from *observed* or *actual* demand due to sluggishness in the adjustment process. Energy use is closely related to the choice of technology and thereby capital use. Since installation of new capital takes time, a static representation of energy demand will not be appropriate. Realising the dynamic nature of energy demand, actual energy use is specified as a partial adjustment process. This of course is a rather ad-hoc way of introducing dynamics, but it serves our overall intention of keeping things simple.

(2.25) $$x_{jt} = A_j (x_{jt}^*)^{\gamma} (x_{jt-1})^{1-\gamma}, \qquad j \in N_r$$

where x_{jt} is *actual* (or observed) use of fuel j in year t. γ represents the lag parameter and A_j is a calibration constant. This calibration constant serves two different purposes when simulating the model. First, A_j is calculated in such a way that simulated fuel use in the base year equals observed use in this year. Second, A_j is allowed to change over the simulation period to account for autonomous technological improvements.

The implemented industry model is given by (2.13), (2.24) and (2.25). These nine equations determine the nine variables x_j, x_j^*, $j \in N_r$, and P_r.

2.4 The household sector

2.4.1 Introduction

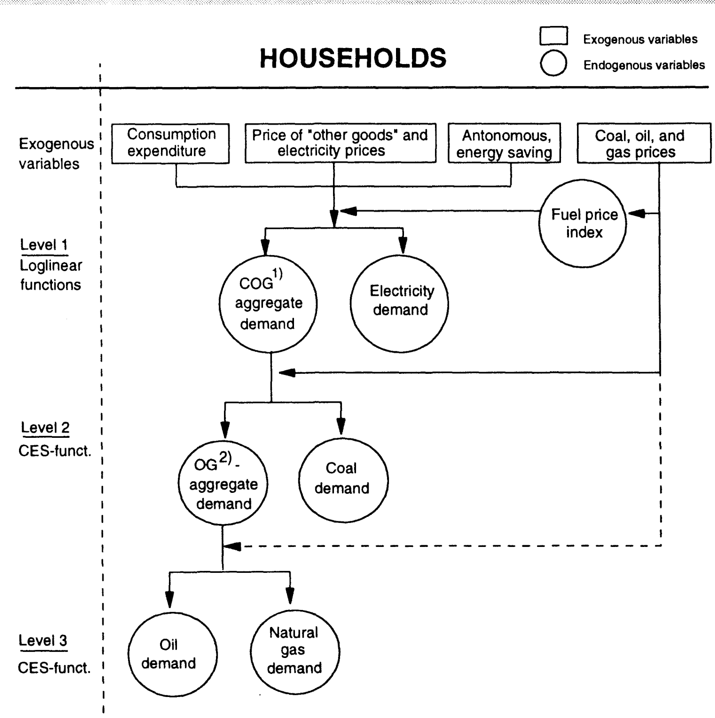
Energy is demanded by households for heating, lighting and appliances. The types of energy sources used for the different purposes depend on available technology and prices of capital and energy carriers. In the household sector of the SEEM model, we abstract from capital prices due to difficulties obtaining reliable data.

The households can in principle choose from different technologies implying different fuel use. But once a technology is installed, changing to a different fuel based technology is costly (dual fuel systems are not very common). This puts strong restrictions on the short-run substitution possibilities. A change in relative fuel prices can make it economically favourable to change technology, but it might take some time for households to respond. The model should therefore allow for different short and long run responses.

2.4.2 The household model

In figure 2.3 the structure of the household model is shown. On the upper level, demand for fossil fuels and electri-city is determined on basis of consumption expenditure, fossil fuel prices, electricity prices, prices on "other goods" and autonomous energy saving. On the intermediate level, the fossil fuel aggregate is distributed on the subaggregate and the remaining fuel (which in this example is coal) in proportions determined by the substitution possibilities and relative prices. Demand for the two fuels constituting the subaggregate is determined in the same way. This example corresponds to the case were all three fossil fuels are used. In

Figure 2.3



1) Coal + Oil + Gas
2) Oil + Gas

countries were only two types of fossil fuels are used, the third level is omitted. In the Netherlands only the first level applies, since the demand for oil and coal is not modelled.

To the degree that there exist significant substitution possibilities between energy carriers, it seems sensible to treat a household utility function as separable in an aggregate index of these carriers. As pointed out by Waverman (1992), potential substitutability between all fuels mainly exists for heating purposes. Considering lighting and most appliances, the only possible fuel choice is electricity. The fact that these purposes account for a significant share of total household energy use in most countries suggests treating electricity as a separate component in the objective function. Hence, the household utility function (objective function) is assumed to be separable in three arguments: Fossil fuels, electricity and "all other goods"

$$Y = F(X_C, X_E, X_r) \tag{2.26}$$

Y = household utility
X_C = aggregate index for "all other goods"
X_E = electricity use
X_r = aggregate index for fossil fuels

Assuming that households allocate their expenditure on goods in a utility maximising fashion, we can derive unconditional demand functions for the fossil fuel aggregate and electricity (the subset "all other goods" is not at the heart of interest here), corresponding to (2.6). We assume these demand functions to take the following form

$$X_i = A_i P_r^{\beta_1^i} P_E^{\beta_2^i} PC^{\beta_3^i} Z^{\beta_4^i}, \quad i = r,\ E \tag{2.27}$$

where P_r and P_E are the fossil fuel price index and electricity price, respectively, and PC is a price index for the subset "all other goods". Z denotes consumption expenditure. Imposing the homogeneity restriction, we have that $\sum_{j=1}^{4} \beta_j^i = 0$, thus one of the prices can be used as numeraire saving one degree of freedom when estimating. It should be noted that (2.27) can only be viewed as an approximation, since, assuming utility maximisation, there are no utility functions (i.e. no F function in (2.26)) consistent with log-linear demand functions.

Given the demand for the fossil fuel aggregate (2.27), demand for each of the fossil fuels are derived using the two-level CES procedure described in Ch. 2.2.2. Thus, a static version of the household model, in the case where all three fossil fuels are used, would be given by the equations (2.16)-(2.21) and (2.27). For countries where households only demand two different types of fossil fuels, the model is reduced by the equations (2.18), (2.19) and (2.21). The implemented dynamic model is mainly obtained by adding partial adjustment terms to the static equations. This will be described in more detail in chapter 4, together with the estimation results.

For the four Nordic countries the model is slightly different from the one outlined above (see appendix A1). The reason is that for these countries we implemented an already existing model estimated by Haug (1992). This model differs from the one outlined above in the sense that electricity is included in the aggregate index. As argued above, we do not find such an approach quite satisfactory and we might therefore modify the household model for the Nordic countries in an updated version of the SEEM model.

2.5 The services sector

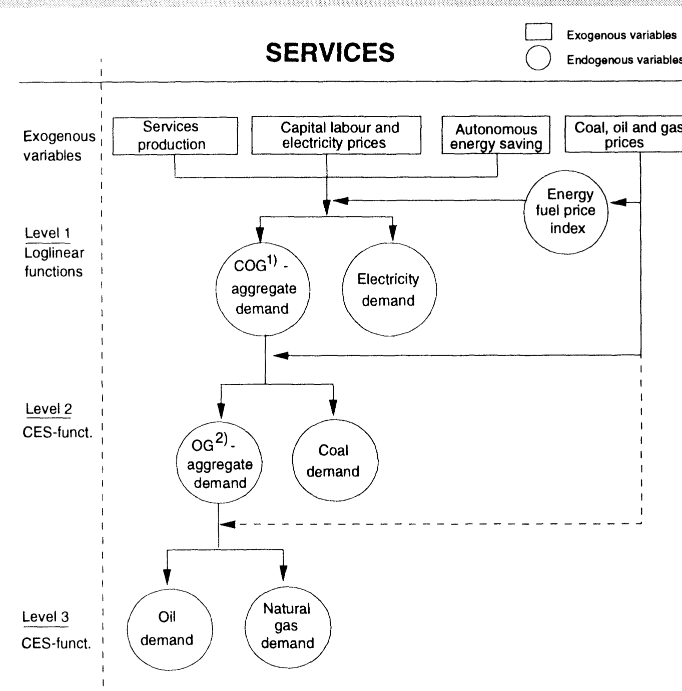
2.5.1 Introduction

Some studies, like e.g. Abodune et al. (1985), treat the household and the services sector as a single sector. In the SEEM model these sectors are modelled separately to open up for different income and price elasticities and implementation of specific policy measures for each sector. Also, the factors influencing energy use in the two sectors might differ. For example, in the services sector there is a potential effect of production factor costs such as wages and capital costs.

2.5.2 The services sector model

Figure 2.4 shows the structure of the model for the services sector. As can be seen, the structure is identical to that of the household sector. The only difference are some of the variables determining the demand on the upper level. Again, it should be noted that this example corresponds to the case were all three fuels are used.

Figure 2.4



1) Coal + Oil + Gas
2) Oil + Gas

The model framework of the services sector is identical to that of the household sector. The objective function is assumed to be an aggregate production function including capital, labour, electricity and a fossil fuel index as arguments, i.e. we separate electricity and fossil fuels as in the household sector.

(2.28) $$Z = F(X_K, X_L, X_E, X_r)$$

Z = production level in the services sector

X_K = capital input

X_L = labour input

X_E = electricity input

X_r = fossil fuel input

Minimising factor costs for a given level of output, we derive the demand functions for the fossil fuel aggregate and electricity, corresponding to (2.6), which we assume to be given by

$$X_i = A_i P_K^{\beta_1^i} P_L^{\beta_2^i} P_E^{\beta_3^i} P_r^{\beta_4^i} Z^{\beta_5^i}, \quad i = r, E \tag{2.29}$$

P_K, P_L, P_E and P_r denotes the price of capital, labour, electricity and fossil fuels, respectively, and Z is an index measuring services sector activity.

As mentioned in 2.2.2, a two level CES function (a one level function in the case of only two fossil fuels) is assumed to be the functional form representing the fossil fuel index. The conditional demand functions for the different fossil fuels will then be given by (2.16)- (2.19). A static version of the services sector model is given by the equations (2.16)-(2.21) and (2.29). As in the household model, the implemented dynamic equations are mainly obtained by including lag terms consistent with the partial adjustment hypothesis. This is further pursued in chapter 4.

2.6 The transport sector

2.6.1 Introduction

In SEEM, all demand for fuels used for transportation has been grouped into one sector, named the transport sector. Transportation can be divided into different modes. First, we can make a distinction between passenger transport and freight transport. For both of these subsectors there exists substitution possibilities between the different transport modes and fuels, and preferably the model should account for such possibilities. However, due to problems obtaining relevant data, some simplifications were necessary.

Figure 2.5

Transport modes

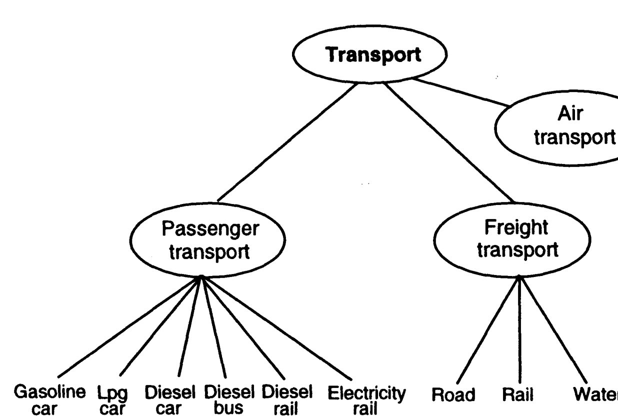


Figure 2.5 shows the transport modes in SEEM. Air transport is considered separately because most air transport is combined passenger and freight transport, and because of only small substitution possibilities with

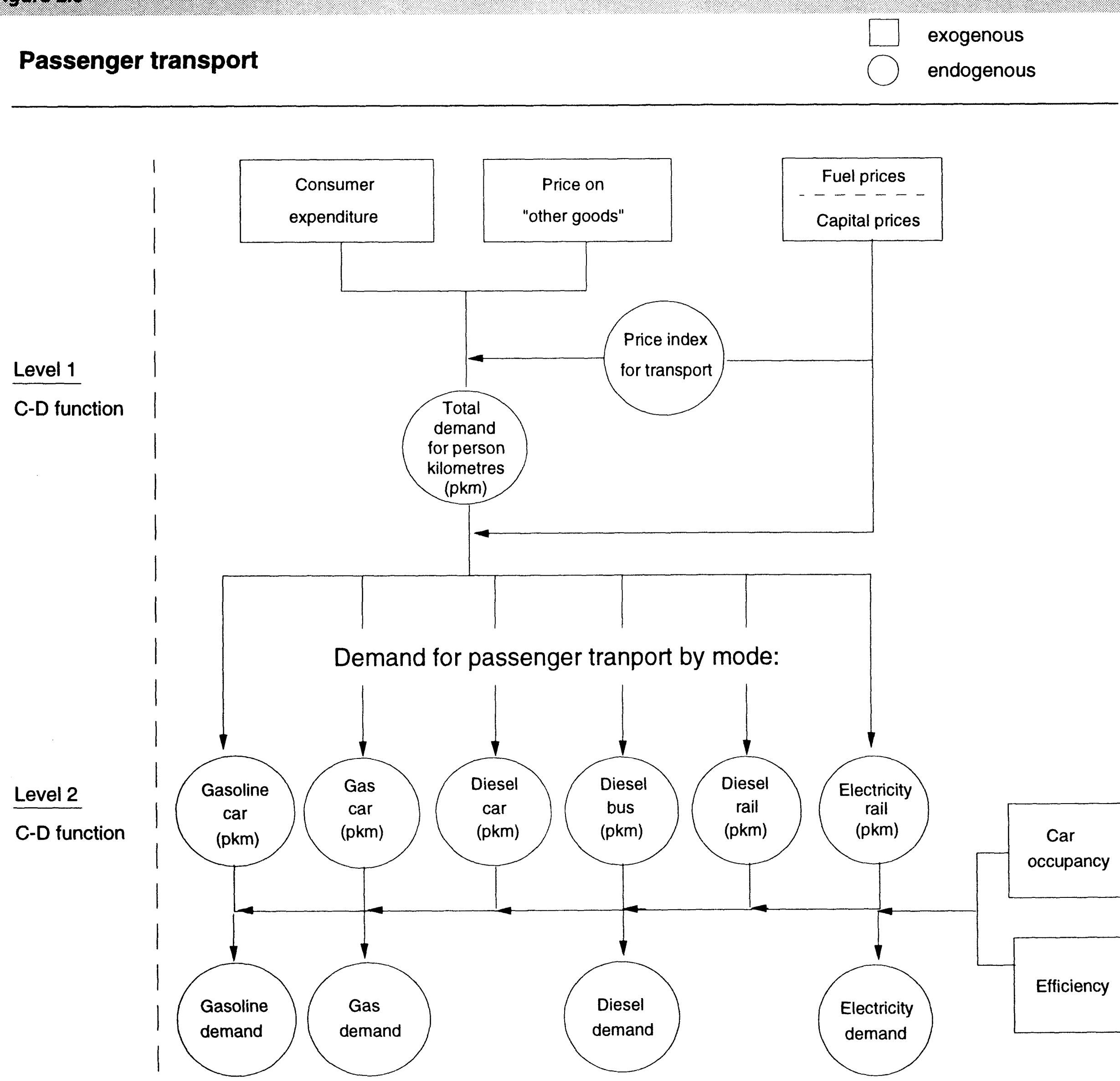
other modes. In passenger transport, a main distinction is made between private and public transport. Furthermore, private transport consists of cars on gasoline, lpg and gasoil, while in public transport rail (produced by diesel and electricity) and busses are distinguished. In most countries energy consumption in passenger water transport is a negligible part of total energy use and is therefore assumed to be exogenous in the SEEM model. In freight transport, we consider transport on road, rail and inland waterways.

2.6.2 The passenger transport model

Figure 2.6 shows the passenger transport submodel. Total demand for person kilometres is a function of consumer expenditure and a transport price index, both in real terms (the price of other goods is used as the deflator). Demand for transport is divided on the different transport modes in proportions depending on fuel prices and capital prices of the respective mode. This determines demand for person kilometres by mode. Given figures for car occupancy and efficiency, the corresponding fuel use can easily be computed.

Figure 2.6

Passenger transport



To simplify the modelling, demand for passenger transport, measured in passenger kilometres, is derived from the consumer side of the economy. The underlying objective function is a utility function with an index for passenger kilometres and for "other goods" as arguments. Passenger kilometres is assumed to be an aggregate consisting of passenger kilometres produced by gasoline cars, diesel cars, lpg cars, diesel buses, diesel trains and electricity trains (in the following we will refer to passenger kilometres produced by e.g. gasoline cars as "gasoline car" for convenience). This aggregate takes the Cobb-Douglas form corresponding to (2.10). Following the step-wise optimisation procedure outlined in 2.1, we start by maximising utility given consumer expenditure. In accordance with (2.6), we obtain a demand equation for passenger kilometres which we postulate to have the following simple form.

(2.30) $$X_r^P = A_P P_r^{\beta_1} Z^{\beta_2}$$

X_r^P = passenger kilometres (in per capita terms)

P_r = price per passenger kilometre (in fixed terms)

Z = consumption expenditure (in fixed per capita terms)

A_P = Constant

In (2.30) we have imposed the homogeneity restriction and used the consumer price index (a proxy for the price index of "other goods") as numeraire. This implies that the variables in (2.30) are measured in fixed terms. Corresponding to (2.13), the passenger transport price index P_r is given by

(2.31) $$P_r = B \prod_{j \in N_r^P} C_j^{\alpha_j}$$

where N_r^P={gasoline car, diesel car, natural gas car, diesel bus, electricity rail, diesel rail}, and C_j is the average price (or cost) per person kilometre of transport option j. The price of transport option j will depend on the variable costs, which for a large part consists of fuel costs, but also on variable capital costs, and some fixed term depending on capital costs. The fuel costs will of course be influenced by the efficiency of different fuels in producing passenger kilometres. The calculation of C_j is described in appendix A5. The chosen division of transportation modes in passenger transport implies a one to one correspondence between fuel type and transportation type, i.e. gasoline is the fuel used for gasoline cars, "bus diesel" is the fuel used to run diesel buses and so forth). For notational convenience, we therefore also relate the fuel subscript to the set of transport types, N_r^P, defined above.

Corresponding to the shares given in (2.12), the shares of the different means of transportation (gasoline car, diesel car a.s.f.) will be given by

(2.32) $$S_j^* = A_j \; C_j^{-1} \left(\prod_{i \in N_r^P} C_i^{\alpha_i} \right), \qquad j \in N_r^P$$

S_j^* denotes the share of transport mode j. As mentioned above, these shares will not add up to one. Because this was found to be an inconvenient property, the shares in (2.32) were normalised in the following way

(2.33) $$S_j = \frac{S_j^*}{\sum_{i \in N_r^P} S_i^*}, \qquad j \in N_r^P$$

Demand for the different types of fuels used in passenger transport can now be computed as

(2.34) $$D_j = B_j S_j X_r^P \frac{1}{E_j}, \quad j \in N_r^P$$

D_j = demand for fuel j

E_j = average efficiency of fuel j (person kilometres per unit of fuel j)[11]

B_j = calibration constant

The equations (2.30)-(2.34) summarises the passenger transport module of the transport sector.

2.6.3 The freight transport model

Figure 2.7 displays the freight transport module. The level of domestic production determines total demand for ton kilometres. Given the exogenous shares, distribution of total freight transport demand on the three transport modes can be found, which in turn determines the demand for the different fuels given some efficiency parameter.

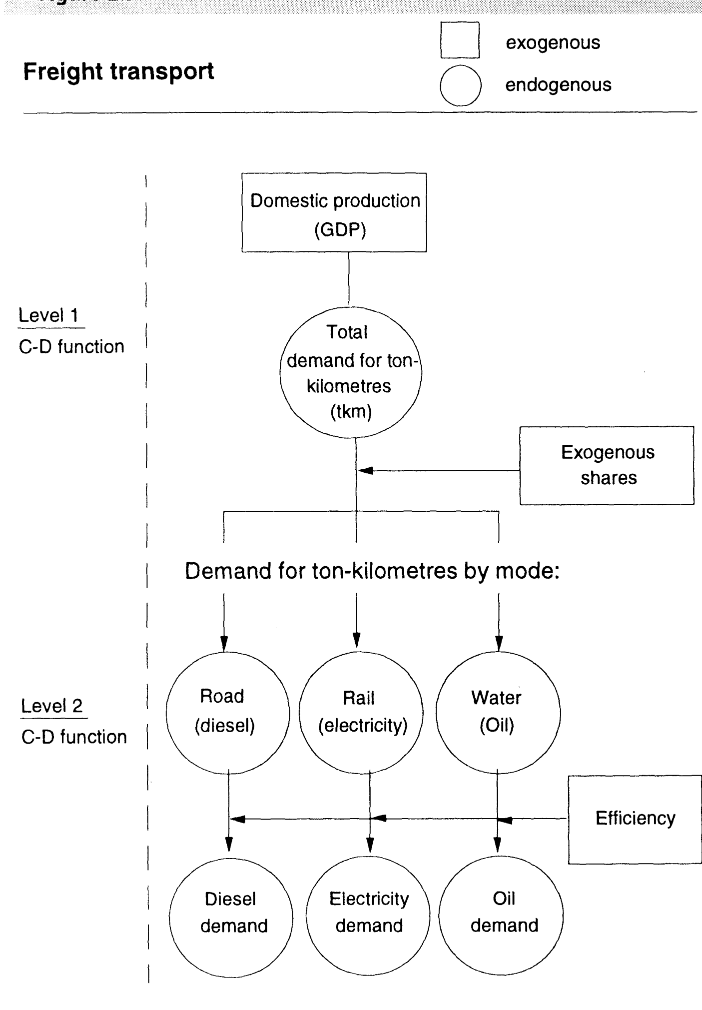
Freight transport is to some extent modelled similar to passenger transport. In freight transport we assume substitution possibilities between road, rail and water. Firms minimise expenditure on transport and other input factors given some production function. We assume this procedure to result in the following simple demand equation for freight transport (measured in tonkilometres)[12]

(2.35) $$X_r^F = A_F Z^\beta$$

X_r^F = demand for freight transport

Figure 2.7

Freight transport



[11]The computation of E_j is documented in appendix A5

[12]This specification implies that all factor price effects are set equal to zero. In principal, such an assumption could be tested, but this is not pursued further here.

Z = activity measure (GDP)

A_F = constant

The freight transport aggregate is assumed to be distributed on the three modes road, rail and water in accordance with some exogenously given shares S_j, $j \in N_f^F$={road,rail,water}. Thus we have that

(2.36) $$x_j = S_j X_r^F, \quad j \in N_r^F$$

x_j = demand for transport mode j (in tonkilometres)

It should be stressed that (2.36) differs somewhat from the general framework in the sense that the shares, S_j, is assumed to be exogenous, and hence, to be independent of costs. This is meant to reflect the empirical observation that the shares of the different freight transport modes are quite cost insensitive. Transport modes are not very price sensitive because the choice of transport mode is for a large part determined by the type of goods to be transported.

Again, we assume a one to one correspondence between transport modes and fuel. Road freight transport uses diesel, rail freight transport demands electricity and water freight transport uses oil. Demand for the different transport modes can then easily be expressed in fuel terms using a conversion factor (efficiency parameter)

(2.37) $$D_j = B_j x_j \frac{1}{E_j}, \quad j \in N_r^F$$

D_j = demand for fuel j

E_j = average efficiency of fuel j (used in transport mode j)[13]

B_j = calibration constant

The implemented model for the freight transport module is given by the equations (2.35)-(2.37)

2.6.4 Air transport

Air transport is modelled separately in the sense that we abstract from substitution possibilities between air and other transport modes. Further, we do not distinguish between passenger transport and freight transport. Instead of first specifying a demand equation for air transport and then use some appropriate conversion rule to derive the corresponding demand for air fuel (kerosene), we model fuel use for this mode directly as follows

(2.38) $$x_{ker} = A \ p_{ker}^{\beta_p} Z^{\beta_z}$$

x_{ker} = demand for air fuel (kerosene)

[13]See appendix A5

p_{ker} = price of kerosene

Z = activity measure (GDP)

A = calibration constant

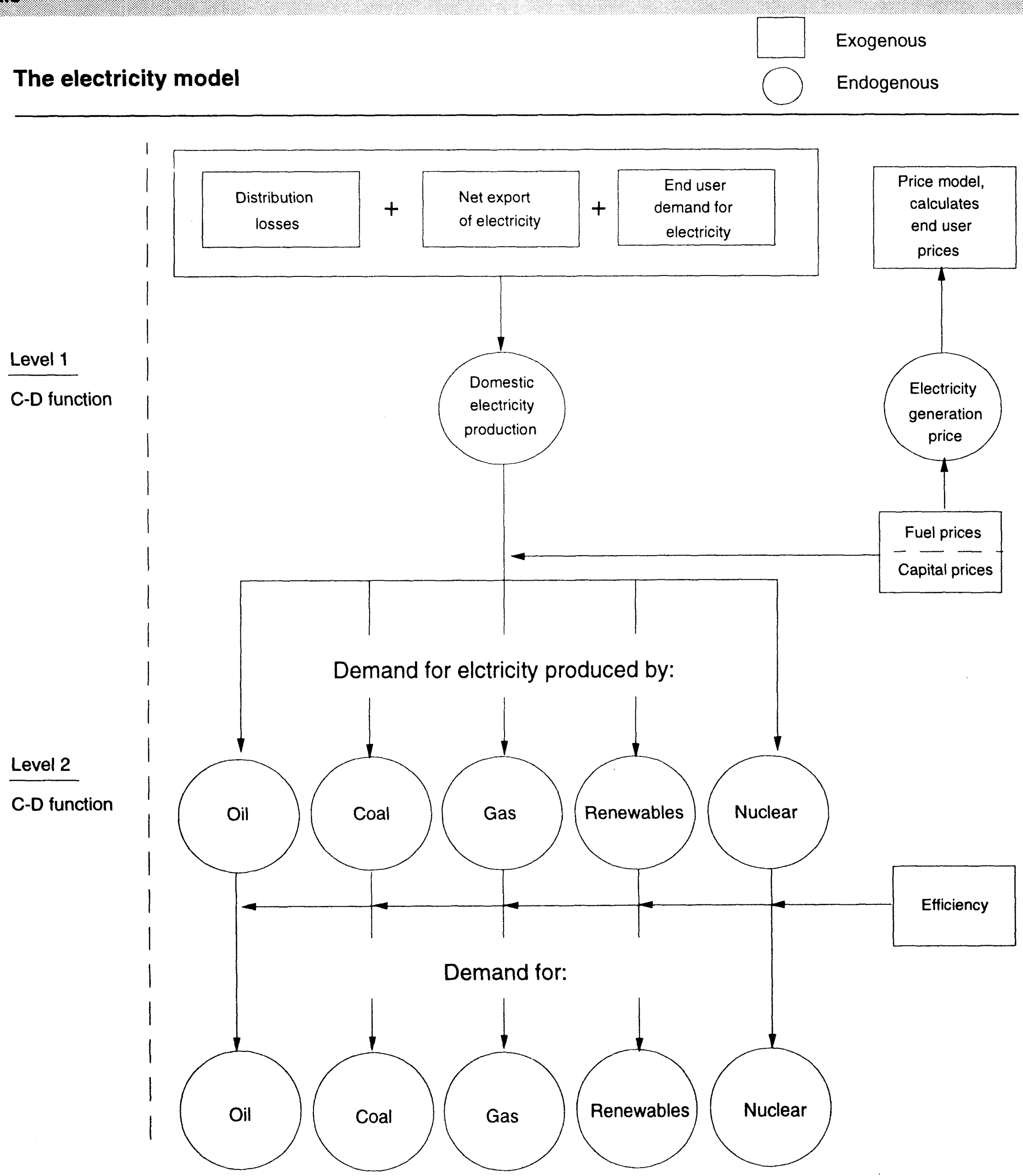
β_p and β_Z are the price elasticity and income elasticity, respectively.

2.7 The electricity generation sector

2.7.1 The electricity generation model

The electricity model is shown in figure 2.8. Adding end user demand for electricity from industry, households, services and transport, net exports and distribution losses (as a percentage of the two other parts), we obtain total domestic requirement for electricity. This requirement is assumed to be supplied by domestic producers. Electricity can be produced by different technologies relying on different energy sources.

Figure 2.8



The share of electricity produced by some specific fuel is determined by the relative costs of the different technologies, given by fuel and capital prices. This in turn determines the demand for the different fuels, given fuel efficiency.

Total domestic electricity production requirement, Q, is defined as follows

(2.39)
$$Q = \left(\sum_{i \in R} X_E^i + NX\right)(1 + DL)$$

X_E^i = electricity demand in sector i
NX = net electricity exports
DL = distribution loss
R = {industry, household, services, transport}

Electricity can be produced using different fuel based systems. The share of the total electricity requirement produced in plants using fuel j as input is assumed to be given by

(2.40)
$$S_j = A_j C_j^{-1} \prod_{i \in N_r} C_i^{\alpha_i}, \quad j \in N_r$$

S_j = share of electricity production capacity from plants using fuel j as input
C_j = average cost of producing one unit of electricity in plants using fuel j as input
A_j = constant
N_r = {coal, oil, gas, renewables, nuclear}

From (2.40), it is clear that the relative importance of the different types of plants in power production (i.e. coal plants, gas plants etc.) depends on the relative costs of producing electricity in these plants. Given the specification (2.40), the shares will not add up to one. In the implemented model, we have imposed such an adding up restriction by using a normalisation rule of the form (2.33). The cost variables C_j are computed in a similar way as in the passenger transport model, i.e. they depend on capital costs, fuel prices and the efficiency of the respective fuels (see appendix A5).

Demand for the different energy sources used in power production can be computed as follows

(2.41)
$$x_j = B_j S_j Q \frac{1}{E_j}, \quad j \in N_r$$

E_j = average efficiency of fuel j in power production (electricity per unit of fuel j)[14]
B_j = constant

[14]See appendix A5

An assumption underlying (2.41) is that total supply of electricity equals net demand for electricity, given by (2.39).

The electricity generation price is assumed to depend on the average costs in the different plants in the following way

$$P_{el} = \sum_{j \in N_r} C_j S_j \tag{2.42}$$

P_{el} = generation price of electricity

i.e. the electricity generation price is assumed to be a weighted sum of the costs in the different plants, where the weights equals the corresponding shares of the different plants in power generation. It should be stressed that P_{el} is not the end user price. End user prices for the different sectors are obtained adding taxes and margins to the generation price (shown below). The implemented electricity model is given by the equations (2.39)-(2.42).

2.7.2 The price model

The price model computes sectoral end user prices for the different fuels. The end user prices are divided into taxes, margins and import prices. For electricity, the "import price" corresponds to the electricity generation price. The gross margins include costs and profits in transformation, distribution, retailing etc. Taxes are divided into fuel specific taxes, carbon taxes and the value added tax. End user prices are calculated using the following identity

$$P_{ij} = (P_i^{CIF} + M_{ij} + T_{ij}^E + T_{ij}^C)\left(1 + T_{ij}^{VAT}\right) \tag{2.43}$$

P_{ij} = end user price of fuel i in sector j

P_i^{CIF} = import price (CIF) of fuel i

M_{ij} = margin for fuel i in sector j

T_{ij}^{E} = excise energy taxes

T_{ij}^{C} = carbon tax

T_{ij}^{VAT} = value added tax

3. The data

3.1 Energy consumption

The data has been taken from subscribable diskettes based on the publication "Energy Balances" (EB) from the International Energy Agency, IEA (IEA 1992) . The data series cover the period 1960-1991. The consumption for the different fuels are measured by ton oil equivalents, toe.

As SEEM calculates fuel demand for energy purposes, we have not included the post "Feedstocks in Petrochemical Industry" and "Non Energy Use" from EB in the model. However it seems like the EB figures for coal in some countries also includes some elements of coal used for reduction purposes in production processes in the iron, steel and aluminium industries. Such use of coal is strictly Non Energy Use. However, we have no data which allows us to identify the size of coal used in reduction processes, so we will have to live with this inaccuracy in the model.

In Energy Balances "Other Sectors" equals the sum of households, services, agriculture and other non specified sectors. For some countries the historical EB data is not distributed between these 4 sectors. In these cases we have done this split of data based on certain distribution keys.

3.2 Energy prices

All data for energy prices, taxes and margins have been taken from subscribable diskettes IEA's publication "Energy Prices and Taxes (EPT)". For Germany (West) and Sweden there are data for the period 1971-1992. For the other countries the data covers the years 1978 to 1992. We have used the Light Fuel Oil price as the oil price for the households, the Steam Coal price as the coal price in all sectors. In EPT the Steam Coal price is said to be the "best" average of prices on different coal qualities. As fuel price data for the services sector are lacking in EPT (and in other publications we have studied) we have used the household prices, adjusted for value added taxes when relevant.

3.3 Macroeconomic variables

The macroeconomic activity variables used for estimation purposes in the household, services and transport sector are all taken from the OECD statistics (OECD 1992, 1993). In the household model and in passenger transport, private consumption expenditure figures are used, In the services model, net product for the different services categories were added and in the freight transport sector GDP was used.

3.4 Other variables

The technology data used in the transport and electricity model were taken from the EFOM (Energy Flow Optimisation Model) database, except from the figures from the Nordic countries which were obtained from the Nordic Model database (Statistics Norway). Numbers on kilometres and seat occupancy used in the transport sector were obtained from different sources: International Road Federation (World Road Statistics), Statistisch Vademecum (Cuijpers (1992))and different statistical bureaus. Figures for electricity generation costs were taken from IEA.

4. Determination of parameters

4.1 Introduction

After choosing a suitable specification one must decide whether to calibrate or estimate the parameters. We hold the view that the parameters, to the extent permitted by the information set, should be estimated. For this reason, specifications allowing for simple estimation procedures, like the three level CES model, were chosen. In some sectors estimation was difficult due to data limitations. For these sectors a Cobb-Douglas specification was chosen to make calibration simple.[15] In some sectors (household and services), parameters could not easily be computed using base year observations as in the Cobb-Douglas case. For these sectors, we had to rely on qualified guesses and estimates reported in other studies. However, it turned out to be quite difficult obtaining corresponding estimates from other studies which could be easily implemented. A sectoral overview of methods and sources used to compute the parameters is given in table 4.1.1

Table 4.1.1 An overview

Sector	Method	Source
Industry	Calibration	Pindyck (1979) and IEA (International Energy Agency) data to compute cost shares
Household	Estimation/Calibration	OLS estimation on lower levels. Calibration on upper level based on Abodune et al. (1985) and Waverman (1992).
Service	Estimation/Calibration	OLS estimation on lower levels. Calibration on upper level.
Transport	Estimation/Calibration	OLS estimation on upper level. Country specific data used on lower level to compute cost shares (combined with IEA fuel prices).
Electricity	Calibration	Calibration Country specific data (combined with IEA fuel prices) to compute cost shares.

[15]As mentioned in chapter 2, the factor elasticities in a linear homogenous Cobb-Douglas function can be interpretated as cost shares.

4.2 The industry sector

4.2.1 Introduction

As can be seen from table 4.1.1, the parameters in the industry sector are calibrated. In an earlier stage of the model building process, some effort was made on estimating more flexible specifications like e.g. trans-log cost functions. However, rather disappointing estimation results combined with time restrictions lead to the Cobb-Douglas specification, which can be calibrated with rather limited information.

4.2.2 Computation of parameters on the lower level

Referring to the industry model outlined in chapter 2, α_j in (2.24) can be interpreted as the expenditure on fuel j relative to total energy expenditure. Taking the dynamics into account, these cost shares are given by

(4.1)
$$\alpha_{jt} = \frac{x_{jt-1}\left(\frac{x_{jt}}{x_{jt-1}}\right)^{\frac{1}{\gamma}} p_{jt}}{\sum_{i\in N_r} x_{it-1}\left(\frac{x_{it}}{x_{it-1}}\right)^{\frac{1}{\gamma}} p_{it}}, \quad j \in N_r$$

Given the lag parameter γ, the α's can be computed only knowing fuel prices at time t and fuel demand at time t and t-1. The implemented α's were taken to be the arithmetic mean of α_{jt}, α_{jt-1} and α_{jt-2} where t=1991 (the base year). However, γ is not known a priori and has to be calculated. Using the fact that $\gamma \, El_{p_i} x_i \big|_{LT} = El_{p_i} x_i \big|_{ST}$ ($i \in N_r$), where $El_{p_i} x_i$ is the elasticity of x_i with respect to the price of fuel i (the subscripts LT and ST denotes "long term" and "short term", respectively), γ will be determined given short and long term direct price elasticities. These elasticities were taken from Pindyck (1979).[16]

4.2.3 Computation of the parameters on the upper level

Referring to (2.23), the parameters on the upper level will be determined knowing the following price and activity elasticities

(4.2)
$$El_{p_i} X_r = \frac{\beta_i}{\beta}, \quad i = K, L$$
$$El_{p_r} X_r = \frac{\beta_r - \beta}{\beta}$$
$$El_Z X_r = \frac{1}{\beta}$$

These elasticities have the interpretation of being long-run elasticities. They are found in Pindyck (1979).

[16]It should be noted that Pindyck did not restrict the adjustment costs to be equal across fuels. The implemented lag parameter γ was therefore taken to be the mean of the fuel spesific lag parameters in Pindyck. For countries not included in the Pindyck study, γ was taken to be the same as in a "similar" or neighbour country, e.g. the adjustment cost in Belgium was assumed to be the same as in the Netherlands.

4.3 The household sector

4.3.1 Introduction

The parameters in the equations on the lower levels of the household sector, i.e. the parameters included in the equations (2.16)-(2.19), were estimated for all countries.[17] We also started out estimating the parameters on the upper level, but because of generally disappointing results we ended up with calibration.[18] Calibration on the upper level was partly based on elasticities reported in Abodune et al. (1985) and a survey by Waverman (1992), and partly on qualified guesses.[19]

4.3.2 Estimation on the lower levels

The household model outlined in 2.4 serves as a basis for the econometric specification. Dividing (2.16) by (2.17) and (2.18) by (2.19) and taking the logarithm on both sides, we obtain the following two equations

(4.3) $$\ln\left(\frac{X_k}{X_m}\right) = \kappa_r - \sigma_r \ln\left(\frac{P_k}{P_m}\right)$$

(4.4) $$ln\left(\frac{x_e}{x_f}\right) = \kappa_m - \sigma_m ln\left(\frac{p_e}{p_f}\right)$$

where

$$\kappa_i = \ln\frac{\delta_i}{1-\delta_i}, \qquad i = r, m$$

Taking the dynamic nature of energy demand into account, we include the lagged ratio on the left-hand side among the regressors. On log-linear form, we then obtain the following partial adjustment equations

(4.5) $$\ln\left(\frac{X_k}{X_m}\right)_t = \kappa_r^* - \sigma_r^* \ln\left(\frac{P_k}{P_m}\right)_t + \lambda_r \log\left(\frac{X_r}{X_m}\right)_{t-1}$$

(4.6) $$\ln\left(\frac{x_e}{x_f}\right)_t = \kappa_m^* - \sigma_m^* \ln\left(\frac{p_e}{p_f}\right)_t + \lambda_m \log\left(\frac{x_e}{x_r}\right)_{t-1}$$

where

$$\kappa_i^* = \ln\frac{\delta_i^*}{1-\delta_i^*}, \qquad i = r, m$$

λ_i, i=r,m, is the lag parameter. The * is indicating that the parameters are to be interpreted as short-run parameters. The corresponding long-run parameters are given by

[17]Except for the Nordic countries where we implemented the parameters estimated in Haug (1992).
[18]Although some of the estimated parameter values were retained.
[19]With "qualified guesses" we mean that the chosen parameter values were more or less based on the estimation results as far as justifiable.

(4.7) $$\kappa_i = \frac{\kappa_i^*}{1-\lambda_i}, \quad i = r, m$$

(4.8) $$\sigma_i = \frac{\sigma_i^*}{1-\lambda_i}, \quad i = r, m$$

σ_i is the long-run elasticity of substitution (corresponding to the static model given by (4.3) and (4.4)) and σ_i^* can be interpreted as the corresponding short-run elasticity. Introducing dynamics into the model in accordance with (4.5) and (4.6), implies somewhat more complex demand functions than the corresponding static functions given by (2.16)-(2.19). Using (2.14), (2.15) , (4.5) and (4.6), we can derive the implemented conditional demand functions

(4.9) $$X_{kt} = X_{rt}\,\delta_r\left[\delta_r + (1-\delta_r)\,\Psi_r^{1-\sigma_r}\right]^{\frac{\sigma_r}{1-\sigma_r}}$$

(4.10) $$X_{mt} = X_{rt}(1-\delta_r)\left[(1-\delta_r) + \delta_r\,\Psi_r^{-(1-\sigma_r)}\right]^{\frac{\sigma_r}{1-\sigma_r}}$$

(4.11) $$x_{et} = X_{mt}\,\delta_m\left[\delta_m + (1-\delta_m)\,\Psi_m^{1-\sigma_m}\right]^{\frac{\sigma_m}{1-\sigma_m}}$$

(4.12) $$x_{ft} = X_{mt}(1-\delta_m)\left[(1-\delta_m) + \delta_m\,\Psi_m^{-(1-\sigma_m)}\right]^{\frac{\sigma_m}{1-\sigma_m}}$$

where

$$\Psi_r = \left(\frac{P_k}{P_m}\right)_t^{(1-\lambda_r)}\left[\frac{\left(\frac{X_k}{X_m}\right)_{t-1}}{\left(\frac{1-\delta_r}{\delta_r}\right)}\right]^{-\frac{\lambda_r}{\sigma_r}}$$

$$\Psi_m = \left(\frac{p_e}{p_f}\right)_t^{(1-\lambda_m)}\left[\frac{\left(\frac{x_e}{x_f}\right)_{t-1}}{\left(\frac{1-\delta_m}{\delta_m}\right)}\right]^{-\frac{\lambda_m}{\sigma_m}}$$

The subaggregate X_m and the corresponding price aggregate P_m, given by (2.15) and (2.21) respectively, are unobservable and cannot be computed without information concerning the parameters δ_m and σ_m. This suggests a step-wise estimation procedure, starting by estimating (4.6) and then estimating (4.5).[20] This in turn determines X_r and P_r (from (2.14) and (2.20), respectively).

In the household sector, N_r is the set consisting of coal, natural gas and oil (for the countries where all fossil fuels are used) and N_m is the subset constituted by two of the three fossil fuels. Which fuels should be included in the subset, will depend on the country specific technology. In the absence of such information, this should be determined by data.

In table A 3.1 (in appendix A3) we report the estimation results of (4.5) and (4.6)[21] for seven of the thirteen countries.[22] The estimations were carried out using Ordinary Least Squares (OLS) based on annual observations from 1978 to 1991. As can be seen, a trend variable (time) and the lagged price ratio were included for some countries

4.4 Calibration on the upper level

The implemented specification on the upper level is obtained by including the lagged value of the endogenous variable in (2.27) as an explaining variable. On log-linear form it will be given by

$$(4.13) \qquad \ln X_{it} = \beta_0^i + \beta_1^i \ln P_{rt} + \beta_2^i \ln P_{Et} + \beta_3^i \ln PC_t + \beta_4^i \ln Z_t + \lambda_i \ln X_{it-1}, \quad i = r,\ E$$

λ_i is a lag parameter measuring the sluggishness in the adjustment-process. We started out estimating (4.13) for some of the countries, but the results were in general not very promising. Because of time restrictions, we therefore turned to calibration.

For the countries Austria, Belgium, Germany, Spain and Switzerland the chosen parameters were partly based on the survey by Waverman and partly on the estimation results, as far as justifiable. For the remaining countries (France, Great Britain, Italy and The Netherlands), the parameters were computed on basis of the parameter estimates reported in Abodune et al (1985).

[20]Having determined δ_m and σ_m from estimating (4.6), time series for X_m and P_m can be computed (from (2.14) and (2.20), respectively) and (4.5) can then be estimated. We have that $\delta_m = \frac{\exp(\kappa_m)}{1+\exp(\kappa_m)}$.

[21]For some of the countries were the estimation results are reported, coal use is neglectable and assumed exogenous in the model. This implies that the fossil fuel aggregate only is a function of gas and oil, leaving out the third level, i.e. (4.5) and (4.6) is reduced to (4.5) where e.g X_k and X_m can be interpreted as gas and oil demand respectively.

[22]For the remaining six countries the following applies: The second and third level of the household model for Spain was calibrated due to estimation problems. In the household model for The Netherlands only demand for electricity and gas was modeled. This implies that the household model for The Netherlands is given by the equations (2.20). The estimation results for the household model in the Nordic countries are reported in Haug (1992), as mentioned in chapter 2.

4.5 The services sector

4.5.1 Introduction

The CES specification was initially chosen for the services sector to obtain econometric relations that could be easily estimated. On the lower levels, the estimation results were quite satisfactory. However, this was in general not the case on the upper level. Thus, the parameters in the demand equations for the fossil fuel aggregate and electricity were in general calibrated.

4.5.2 Estimation on the lower levels

The dynamic specification in the services sector is identical to the one in the household sector, both on the lower levels and the upper level. This means that the implemented model includes conditional demand functions on the lower levels of the form (4.9)-(4.12). To determine the parameters on the lower level, partial adjustment equations corresponding to (4.5) and (4.6) were estimated using OLS. The estimations were based on annual observations from 1978 to 1991, and the results are displayed in table A 3.2 (appendix A3). In some countries, only one fossil fuel is (significantly) used in the service sector. For these countries, there will of course be no lower levels in the model. Hence, table A 3.2 only reports estimation results for countries with significant use of two or more fossil fuels in the services sector. For the services sector in Austria, only use of electricity is reported in the IEA statistics. Thus, the services model for Austria is simply given by a demand function for electricity.

4.5.3 Calibration on the upper level

The implemented equations on the upper level in the services sector are partial adjustment specifications of (2.29). On log-linear form we thus obtain the following specification

$$(4.14)\quad \ln X_{it} = \beta_0^i + \beta_1^i \ln P_{Kt} + \beta_2^i \ln P_{Lt} + \beta_3^i \ln P_{rt} + \beta_4^i \ln P_{Et} + \beta_5^i \ln Z_t + \lambda_i \ln(X_i)_{t-1}, \qquad i = r, E$$

As in the household sector, some attempt was made to estimate the parameters on the upper level, but rather disappointing results led to calibration.[23]

4.6 The transport sector

4.6.1 Introduction

The parameters on the upper level of the transport sector were estimated. Due to a rather limited information set concerning price and volume figures (very short time series) for the different transport modes, the parameters on the lower level were calibrated. The equation for air fuel (kerosene) was initially estimated for all countries. However, in the implemented model, the estimated parameter values for Germany are used for all countries.

[23]Although not without exceptions. In the few cases where fairly sensible estimation results were obtained, the estimated parameter values were implemented.

4.6.2 The parameters on the lower level

Passenger transport

The passenger transport aggregate is modelled as a linear homogenous Cobb-Douglas function, thus implying that the α's in (2.32(and of course (2.31)) can be interpreted as cost-shares. In accordance with the notation in 2.6.2, the cost-shares can be computed as follows

$$(4.15)\ \alpha_{jt} = \frac{C_{jt}\, x_{jt}}{P_{rt}\, X_{rt}}$$

where x_j denotes passenger kilometres by mode j $\left(i.e.\ x_j = S_j X_r^P\right)$. Knowing e.g. the base year values, these shares can easily be calculated.

Freight transport

As mentioned in chapter 2.6.3 , the shares on the lower level in freight transport was assumed to be exogenous and calibrated in the base year to reflect the relative importance of the different modes in freight transport.

4.6.3 Estimation on the upper level

Passenger transport

On the upper level of the passenger transport model, the parameters in (2.29) was estimated for all countries except for Austria where no reliable time series were available. In the empirical specification, we used the log-linear version of (2.30)

$$(4.16) \qquad ln\, X_{rt}^P = \beta_0 + \beta_1 ln\, P_{rt} + \beta_2 ln\, Z_t$$

The estimation was carried out using OLS based on annual observations from 1978 to 1991. The estimation results are displayed in table A 3.3 (see appendix A3).

Freight transport

In freight transport, the only explanation variable is GDP. Taking the logarithm of (2.35), we obtain the following relation

$$(4.17) \qquad \ln X_{rt}^F = \beta_0 + \beta_1 \ln Z_t$$

This specification was estimated using OLS based on annual observations from 1978 to 1991. The results can be found in table A 3.4 (appendix A3).

4.7 The electricity sector

4.7.1 Introduction

As in the transport model, it turned out difficult to obtain sufficiently long series for the cost variables. Hence, the parameters in the electricity sector were calibrated using base year observations.

4.7.2 Parameter determination in the electricity model

The determination of the parameters on the lower level model is identical to determination of the parameters on the lower level of the transport model. The α's in (2.40) can be interpreted as cost shares and will therefore, corresponding to (4.15), be given by

$$\alpha_{jt} = \frac{C_{jt}\, x_{jt}^{el}}{P_{el,t}\, Q_t}, \quad j \in N_r \tag{4.18}$$

where x_{jt}^{el} denotes the quantity of electricity produced by fuel j (at time t). The remaining notation is in correspondence with the notation in 2.7. In the implemented model, the base year values were used to calculate (4.18), which corresponds to setting t=1991.

5. Final remarks

This report has documented the model structure of the SEEM model and how the parameters in the model are determined. Although the version 2.0 should be a quite powerful tool to analyse energy demand in Western Europe, the SEEM model could be improved in a number of ways. Below we list some possible extensions.

1. Number of countries

There are still some West European countries not included in the model: Ireland, Portugal, Greece, Luxembourg and Iceland are among these. Furthermore, an inclusion of East European countries would be interesting. Eastern Europe might face a development towards closer integration with rest of Europe. This would have great impact on future energy production and consumption, and pollution. In fact Eastearn Europe now contributes to a large part of pollution in Europe.

2. Endogenous electricity trade

There is a discussion in the European Union to deregulate the energy markets in EU before 1996. To include endogenous electricity trade in SEEM would make the model a better tool for analysing problems related to such deregulations.

3. Deeper/closer studies of some of the sectors.

Such studies could improve the quality of the model. Most of the behaviour relations in this version of the SEEM model are calibrated and not estimated. Those sectors which are econometrically based are moreover based on short time series of various quality. Therefore, a closer look at the most important sectors, like transportation and power generation will be interesting. Time should then be allowed for extensive data collection and literature studies of these sectors.

4. Endogenous macroeconomic links

The link between the energy markets and the macro economy could be modelled to study the interaction between different developments in the energy markets and the rest of the economy.

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Appendix

A1. The household model for the Nordic countries

For the Nordic countries, coal and gas demand in the household sector is negligible and is assumed to be exogenous. Hence, only demand for electricity and oil is modelled. The household model of the Nordic countries is essentially similar to the model outlined in Ch.. 2.3, and only differs to the extent that oil and electricity use is not separated in the utility (or objective) function. Both fuels are included in what could be viewed as an energy aggregate. The energy aggregate X_U, is assumed to be represented by a CES function, i.e.

$$X_U = \left[\delta_U\left(\frac{X_O}{\delta_U}\right)^{-\frac{1-\sigma_U}{\sigma_U}} + (1-\delta_U)\left(\frac{X_E}{1-\delta_U}\right)^{-\frac{1-\sigma_U}{\sigma_U}}\right]^{-\frac{\sigma_U}{1-\sigma_U}} \tag{A1.1}$$

where X_O is oil use and the parameters has the same interpretation as in (2.14) and (2.15). As in the general model, the optimal level of fuel use is derived using step-wise optimisation. In the first stage, the optimal level of the energy aggregate is found by maximising utility subject to a given level of expenditure. In Haug (1992) it is assumed that the utility function is of the Stone-Geary type, which gives the following demand function for the energy aggregate

$$X_U = \beta_0 + \beta_1\frac{Z}{P_U} + \beta_2\frac{PC}{P_U} \tag{A1.2}$$

where P_U is the price per unit of energy, Z denotes consumption expenditure and PC is the price index for the aggregate "other goods". Independently of this first step, the conditional demand functions for oil and electricity can be obtained by minimising the expenditure on energy, i.e. on oil and electricity, subject to (A1.1). This exercise results in demand functions of the form (2.16)-(2.17) (or equivalently (2.18)-(2.19)), i.e.

$$X_O = \delta_U X_U P_U^{\sigma_U} P_O^{-\sigma_U} \tag{A1.3}$$

$$X_E = (1-\delta_U) X_U P_U^{\sigma_U} P_E^{-\sigma_U} \tag{A1.4}$$

In the implemented versions of (A1.3) and (A1.4), dynamics is introduced as in the general household model, which is described in 4.3. Hence, the implemented conditional demand functions for oil and electricity in the household sector of the Nordic countries are of the form (4.11)-(4.12). Not surprisingly, the price index for energy is given by an expression of the form (2.20). Thus the implemented model is given by (A1.2), conditional demand functions of the form (4.11)-(4.12) and an energy price index of the form (2.20).

A2. The model - an overview

Below we list a general model which - with a few minor exceptions - encompasses all the different country models. After having presented the general model, we turn to country specific differences

A 2.1 A general model that encompasses the different country models

The industry model			
Price index for energy	$P_r = \prod_{j \in N_r} p_j^{\alpha_j}$	$i \in N_r^I = \{electricity, coal, oil, gas\}$	A2.1
Desired demand for fuel j	$x_i^* = P_K^{\frac{\beta_K}{\beta}} P_L^{\frac{\beta_L}{\beta}} P_r^{\frac{\beta_r - \beta}{\beta}} Z^{\frac{1}{\beta}} p_i^{-1} \prod_{j \in N_r^I} p_j^{\alpha_j}$	$i \in N_r^I$	A2.2
Actual demand for fuel j	$x_{it} = A_i (x_{it}^*)^{\gamma} (x_{it-1})^{1-\gamma}$	$i \in N_r^I$	A2.3
The household model			
Price indices for the fossil fuel aggregate and the subaggregate	$P_r = \left[\delta_r P_k^{1-\sigma_r} + (1-\delta_r) P_m^{1-\sigma_r}\right]^{\frac{1}{1-\sigma_r}}$ $P_m = \left[\delta_m p_e^{1-\sigma_m} + (1-\delta_m) p_f^{1-\sigma_m}\right]^{\frac{1}{1-\sigma_m}}$		A2.4
Demand functions for electricity and the fossil fuel aggregate (1. level)	$X_i = A_i P_r^{\beta_1^i} P_E^{\beta_2^i} Z^{\beta_3^i} X_{it-1}^{\gamma_i}$	$i = r, E$ E = subscript for electricity r = subscript for the fossil fuel aggregate	A2.5

Demand functions for the subaggregate and the different fossil fuels (2. and 3. level)	$X_{kt} = X_{rt}\delta_r\left[\delta_r + (1-\delta_r)\Psi_r^{1-\sigma_r}\right]^{\frac{\sigma_r}{1-\sigma_r}}$ $X_{mt} = X_{rt}(1-\delta_r)\left[(1-\delta_r) + \delta_r\Psi_r^{-(1-\sigma_r)}\right]^{\frac{\sigma_r}{1-\sigma_r}}$ $x_{et} = X_{mt}\delta_m\left[\delta_m + (1-\delta_m)\Psi_m^{1-\sigma_m}\right]^{\frac{\sigma_m}{1-\sigma_m}}$ $x_{ft} = X_{mt}(1-\delta_m)\left[(1-\delta_m) + \delta_m\Psi_m^{-(1-\sigma_m)}\right]^{\frac{\sigma_m}{1-\sigma_m}}$ *where* $\Psi_r = \left(\frac{P_m}{P_k}\right)_t^{1-\lambda_r}\left[\frac{\left(\frac{X_m}{X_k}\right)_{t-1}}{\left(\frac{1-\delta_r}{\delta_r}\right)}\right]^{-\frac{\lambda_r}{\sigma_r}}$ $\Psi_m = \left(\frac{p_f}{p_e}\right)_t^{1-\lambda_m}\left[\frac{\left(\frac{x_f}{x_e}\right)_{t-1}}{\left(\frac{1-\delta_m}{\delta_m}\right)}\right]^{-\frac{\lambda_m}{\sigma_m}}$	**r** = subscript for fossil fuels **m** = subscript for the subaggregate of two fossil fuels **k** = subscript for the third fossil fuel not included in the sub-aggregate **e** = subscript for one of the fossil fuels included in the subaggregate **f** = subscript for the other fossil fuel included in the subaggregate An example could be: **k** = subscript for gas **m** = subscript for oil/coal **e** = subscript for oil **f** = subscript for coal	A2.6
The commercial sector			
Price indices for the fossil fuel aggregate and the subaggregate	$P_r = \left[\delta_r P_k^{1-\sigma_r} + (1-\delta_r)P_m^{1-\sigma_r}\right]^{\frac{1}{1-\sigma_r}}$ $P_m = \left[\delta_m p_e^{1-\sigma_m} + (1-\delta_m)p_f^{1-\sigma_m}\right]^{\frac{1}{1-\sigma_m}}$		A2.7
Demand functions for electricity and the fossil fuel aggregate (1. level)	$X_i = A_i P_K^{\beta_1^i} P_L^{\beta_2^i} P_r^{\beta_3^i} P_E^{\beta_4^i} Z^{\beta_5^i} X_{it-1}^{\gamma_i}$	i=E, r **E** = subscript for electricity **r** = subscript for the fossil fuel aggregate	A2.8

Demand functions for the subaggregate and the different fossil fuels (2. and 3. level)	$X_{kt} = X_{rt}\delta_r\left[\delta_r + (1-\delta_r)\Psi_r^{1-\sigma_r}\right]^{\frac{\sigma_r}{1-\sigma_r}}$ $X_{mt} = X_{rt}(1-\delta_r)\left[(1-\delta_r) + \delta_r\Psi_r^{-(1-\sigma_r)}\right]^{\frac{\sigma_r}{1-\sigma_r}}$ $x_{et} = X_{mt}\delta_m\left[\delta_m + (1-\delta_m)\Psi_m^{1-\sigma_m}\right]^{\frac{\sigma_m}{1-\sigma_m}}$ $x_{ft} = X_{mt}(1-\delta_m)\left[(1-\delta_m) + \delta_m\Psi_m^{-(1-\sigma_m)}\right]^{\frac{\sigma_m}{1-\sigma_m}}$ where $\Psi_r = \left(\frac{P_m}{P_k}\right)_t^{1-\lambda_r}\left[\frac{\left(\frac{X_m}{X_k}\right)_{t-1}}{\left(\frac{1-\delta_r}{\delta_r}\right)}\right]^{-\frac{\lambda_r}{\sigma_r}}$ $\Psi_m = \left(\frac{p_f}{p_e}\right)_t^{1-\lambda_m}$	r = subscript for fossil fuels m = subscript for the subaggregate of two fossil fuels k = subscript for the third fossil fuel not included in the subaggregate e = subscript for one of the fossil fuels included in the subaggregate f = subscript for the other fossil fuel included in the subaggregate An example could be: k = subscript for gas m = subscript for oil/coal e = subscript for oil f = subscript for coal	A2.9
The transport model			
Passenger transport			
Price index for passenger transport	$P_r = \prod_{j \in N_r} C_j^{\alpha_j}$	$j \in N_r^P = \{$gasoline car, energy car, diesel car, diesel bus, diesel train, electricity train	A2.10
Demand for passenger transport	$X_r^P = A P_r^{\beta_1} Z^{\beta_2}$		A2.11
The optimal share of transport mode j	$s_j^* = A_j C_j^{-1} \prod_{i \in N_r} C_i^{\alpha_i}$	$j \in N_r^P$	A2.12
Normalised shares	$S_j = \frac{S_j^*}{\sum_{i \in N_r^P} S_i^*}$	$j \in N_r^P$	A2.13

Demand for fuel j in passenger transport	$x_j = A_j S_j X_r^P \frac{1}{E_j}$	$j \in N_r^P$	A2.14
Freight transport			
Total demand for tonkilometres	$X_r^F = AZ^\beta$		A2.15
Demand for transport mode j	$x_j = S_j X_r^F$	$j \in N_r^F = \{road, rail, water\}$	A2.16
Demand for fuel j	$D_j = A_j \frac{x_j}{E_j} e^{\mu_j t}$	$J \in N_r^F$	A2.17
Air transport			
Demand for air fuel (kerosene)	$x_k = A p_k^{\beta_p} Z^{\beta_z}$	$k = kerosene$	A2.18
The electricity model			
Total domestic electricity production requirement	$Y = \left(\sum_{i \in R} X_E^i + NX\right)(1 + DL)$	$R = \{industry, household, commercial, transport\}$	A2.19
"Share" of electricity produced using fuel j	$s_j^* = A_j C_j^{-1} \prod_{i \in N_r} C_i^{\alpha_i}$	$J \in N_r^E = \{coal, oil, gas, rnawables, nuclear\}$	A2.20
Normalized shares	$S_j = \frac{S_j^*}{\sum_{i \in N_r} S_i^*}$	$j \in N_r^E$	A2.21
Demand for fuel j	$x_j = A_j S_j X_r^E \frac{1}{E_j}$	$j \in N_r^E$	A2.22

The electricity generation price	$P_{el} = \sum_{j \in N_r^E} C_j S_j$	$j \epsilon N^E$	

A 2.2 Exceptions from the general model

As mentioned above, the model described in A 2.1 encompasses the different country models (with a few minor exceptions) and all the country models are special cases of this general specification. Concerning the industry sector, the only exception is Norway which has no reported natural gas use for this sector. The transport model in some countries also differs from the above model in the sense that not all fuels are used. For example, no gas use is reported in Norway simply because gas cars are not used in Norway. The obvious implication of this is that there will be no equation for gas demand in the transport model for Norway, and furthermore, gas prices will not effect the use of other fuels in the transport model for Norway. Correspondingly in the electricity model, very few countries use all five energy sources (coal, oil, gas, renewables and nuclear) in power production. For example, In Norway only demand for renawables is modelled, because this is the only energy source used in power production. Departures from the model A 2.1 due to the fact that not necessarily all fuels are used in all sectors in a specific country, will not be pursued further here. However, in the household and services models some additional exceptions occur. We will now turn to the country specific exceptions for these two sectors

Austria

Household

In the household model for Austria, cross-price elasticities in the equations on the 1. level are set equal to zero, i.e there is no effect of the fossil fuel price index on electricity demand and conversely, no effect of electricity price on fossil fuel demand.

Services

Only demand for electricity is modelled because according to Energy Balances (IAE) no other fuel is used in the services sector in Austria. This implies that the services model in Austria reduces to a single demand equation for electricity. Since there is no fossil fuel use, the cross-price effect is set equal to zero, i.e. electricity demand is a function of income and the electricity price only. An additional departure from the model A 2.1, is that the electricity price is lagged one period (one year), i.e. the electricity demand in year t depends on the price in year t-1 (and of course on income in year t).

Belgium

Household

The household model for Belgium is similar to that of Austria. This means that the cross-price effects in the demand equations on the 1. level are set equal to zero. In addition, no dynamics are assumed in these equations, i.e. the effect of demand in year t-1 is set equal to zero in both the equation for the fossil fuel aggregate and for electricity.

Services

The equation for electricity demand is obtained by setting the effects of the fossil fuel price and capital price equal to zero and including the lagged values of the electricity price, wage and activity, i.e. electricity demand not only depends on the electricity price, wage and activity in year t, but also on the values of these variables in year t-1.

Germany

The household and services model in Germany are identical to the general model A 2.1. In other words, there are no exceptions.

Switzerland

Household

The household model is identical to A 2.1, except from the fact that coal demand is modelled exogenously.

Services

The electricity demand function is similar to that in Belgium. Electricity demand is a function of electricity price, wage and activity, both current and lagged (one year). As in the electricity demand function in the services sector in Belgium, there is no effect of fossil fuel prices in the electricity demand function. However, a lagged effect of the capital price is included.

Denmark

The household model in Denmark is as described in appendix A1

France

Household

The equations on the 1. level are identical to eq. A2.5. However, in the equations on the 2. level(eq. A2.6), which for France is the demand functions for gas and the subaggregate consisting of oil and coal, the lagged price ratio is used instead of the current price ratios

Great Britain

Households

In the equations on the 2. level we have included both the ratio of current and lagged prices, i.e. the conditional demand equations for gas and the subaggregate consisting of oil and coal, depend both on the current relative prices and also the lagged relative prices.

Italy

Both the household and services model for Italy is identical to A 2.1, except from the fact that coal use is modelled as exogenous in both sector models.

The Netherlands

In the Netherlands, coal and oil use is exogenous in the household model and in the services sector, coal is taken to be exogenous. Apart from this, the household and services models are in line with A 2.1.

Norway

The household model for Norway is described in A1. The services model corresponds to A 2.1, except from that the equations on the 2. and 3. level are omitted (no coal and gas use is reported in the services sector for Norway).

Finland

The household model for Finland is described in A1. The services model corresponds to A 2.1, except from the fact that the equations on the 2. and 3. level are omitted (no significant coal and gas use is reported in the services sector for Finland).

Sweden

The household model for Sweden is described in A1. The services model corresponds to A 2.1, except from the fact that the equations on the 2. and 3. level are omitted (no significant coal and gas use is reported in the services sector for Sweden).

Spain

The equation for coal in the household and services model is omitted. Except from this, the model is identical to A 2.1.

A3. Estimation results

Table A 3.1 Estimation results for the household sector - lower levels

	Austria	Belgium	Germany	Great Britain	France	Italy	Switzer-land
Second level	k = oil	k = gas	k = gas	k = gas	k = gas	k = gas	k = gas
	m = gas/	m = coal/	m = oil/	m = coal/		m = coal/m = oilm =	
oil							
	coal	oil	coal	oil	oil		
Const.	- 0.03	- 0.01	- 0.08	1.42	0.76	0.26	- 9.00
	(- 0.90)	(- 0.08)	(- 1.96)	(18.95)	(42.48)	(2.61)	(- 4.05)
$(\frac{P_k}{P_m})_t$	- 0.34	- 0.33	-0.21	- 0.27	-	- 0.14	- 0.10
	(-1.38)	(-1.81)	(-2.07)	(-1.52)	-	(-1.53)	(-1.62)
$(\frac{P_k}{P_m})_{t-1}$	-	-	-	- 0.27	- 0.29	-	
				(-1.52)	(- 2.11)		
$(\frac{X_k}{X_m})_{t-1}$	0.72	0.57	0.69	-	-	0.65	0.30
	(4.91)	(3.06)	(25.34)	-	-	(2.57)	(1.78)
Time	-	0.03	0.03[1)]	0.08	0.06	0.04	0.07
	-	(2.14)	-	(6.28)	(18.25)	(1.63)	(3.56)
R^2_{adj}	0.65	0.83	0.97	0.92	0.99	0.99	0.99
DW	2.70	1.73	2.37	1.83	1.87	2.27	2.02
Third level	e = gas f = coal	e = coal f = oil	e = oil f = coal	e = coal f = oil	e = coal f = oil		
const.	0.58	- 0.56	0.42	0.31	0.00		
	(9.99)	(- 2.76)	(2.38)	(1.59)	(0.00)		
$(\frac{p_e}{p_f})_t$	- 0.35	- 0.28	- 0.17	- 0.26	- 0.10		
	(- 1.79)	(- 4.29)	(2.00)	(- 2.17)	(-2.00)		
$(\frac{x_e}{x_f})_{t-1}$	-	0.67	0.74	0.55	0.89		
	-	(5.60)	(7.67)	(2.26)	(13.01)		
time	0.06						
	(6.45)						
R^2_{adj}	0.92	0.87	0.80	0.57	0.95		
DW	1.67	1.93	1.91	2.19	1.54		

1) Restricted

Table A 3.2 Estimation results for the services sector - lower levels

	Germany	Great Britain	Belgium	France	The Netherlands	Switzerland
Second level	k = coal m = Oil/ gas	k = oil m = coal/ gas	k = oil m = gas	k = oil m = gas	k = oil m = gas	k = gas m = oil
Const.	0.38	0.15	- 0.12	- 0.05	- 0.24	- 0.64
	(1.84)	-	(- 1.56)	(-0.77)	(- 1.36)	(-1.77)
$(\frac{P_k}{P_m})_t$	- 0.48	- 0.05	- 0.32	- 0.31	- 0.05	-
	(-3.69)	-	(-2.13	(- 2.67)	-	-
$(\frac{P_k}{P_m})_{t-1}$	-	-	-	-	-	- 0.38
	-	-	-	-	-	(- 1.11)
$(\frac{X_k}{X_m})_{t-1}$	0.72	0.90	0.89	0.93	0.86	0.48
	(12.52)	-	(2.57)	(22.15)	(5.57)	(2.05)
Time	-	-	-	-	-	0.04
	-	-	-	-	-	(1.02)
R^2_{adj}	0.91	-	0.83	0.98	-	0.61
DW	2.34	-	1.46	2.44	-	1.86

Third level	e = oil f = gas	e = coal f = gas
const.	0.10	- 0.17
	(1.51)	(- 3.32)
$(\frac{P_e}{P_f})_t$	- 0.27	- 0.21
	(- 2.36)	(- 0.73)
$(\frac{X_e}{X_f})_{t-1}$	0.84	0.91
	(21.83)	(12.34)
R^2_{ad}	0.97	0.94
D	2.40	1.63

A 3.3 Estimation results for the transport sector - upper level

A 3.3.1 Passenger transport

	Austria[1)]	Belgium	Germany	Great Britain	France	Italy	Switzer-land
Price	-	- 0.21	-	- 0.67 (1.00)	- 0.11 (-1.3)	- 0.61 (-2.1)	- 0.44 (-2.6)
Income	-	0.47	1.05 (25.5)	0.55 (3.3)	1.22 (20.9)	1.06 (17.6)	1.10 (13.2)
R^2	-		0.98	0.77	0.98	0.96	0.98
D	-		0.96	0.98	1.24	1.52	1.03

	Denmark	Finland	Netherlands	Norway	Spain [2)]	Sweden
Price	- 0.53 (- 1.3)	- 0.34 (- 1.4)	- 0.79 (- 2.3)	- 1.20 (- 1.6)	1.33 (3.5)	-
Income	1.11 (4.2)	0.60 (8.1)	0.50 (2.4)	1.16 (8.5)	1.24 (5.5)	1.06 (20.8)
R^2	0.79	0.98	0.95	0.85	0.74	0.97
D	0.37	1.33	1.55	0.35	2.24	1.72

1) For Austria no reliable time series were available, therefor the results for Switzerland were also used for Austria.
2) The results for Spain were not very convenient (positive price elasticity), therefor the results for Italy will also be used for Spain.

A 3.3.2 Freight transport

	Austria	Belgium	Germany	Great Britain	France	Italy	Switzer-land
Income	0.45 (2.3)	1.48 (12.6)	0.97 (21.0)	0.66 (5.3)	0.52 (3.3)	2.24 (13.6)	1.94 (16.4)
R2	0.27	0.94	0.97	0.67	0.48	0.93	0.95

	Denmark	Finland	Netherlands	Norway	Spain	Sweden
Freight transport						
Income	1.05 (3.8)	0.82 (7.5)	0.97 10.5	0.38 (3.0)	1.65 (14.5)	0.64 (5.3)
R2	0.51	0.84	0.89	0.40	0.94	0.67

A4. Simulated elasticities in the industry, services and household sectors

Elasticities in Austria

Elasticity of fuel use to	Coal price ST	Coal price LT	Oil price ST	Oil price LT	N.gas price ST	N.gas price LT	Electr. price ST	Electr. price LT	Activity ST	Activity LT
Industry										
Coal	- 0.20	- 0.98	0.00	0.01	0.00	0.02	0.02	0.10	0.15	0.76
Oil	0.00	0.01	- 0.20	- 0.98	0.00	0.02	0.02	0.10	0.15	0.76
N. gas	0.00	0.01	0.00	0.01	- 0.19	- 0.97	0.02	0.10	0.15	0.76
Electricity ..	0.00	0.01	0.00	0.01	0.00	0.02	- 0.18	- 0.89	0.15	0.76
Services										
Coal	.	.	.	.	.	.	.	.	.	.
Oil	.	.	.	.	.	.	.	.	.	.
N. gas	.	.	.	.	.	.	.	.	.	.
Electricity ..	.	.	.	.	.	.	0.00	- 0.17	0.00	1.26
Households										
Coal	- 0.34	- 0.51	0.07	0.38	0.08	- 0.27	0.00	0.00	0.45	0.90
Oil	0.00	0.16	- 0.27	- 0.82	0.07	- 0.26	0.00	0.00	0.45	0.90
N. gas	0.00	- 0.17	0.07	0.38	- 0.27	- 0.62	0.00	0.00	0.45	0.90
Electricity ..	0.00	0.00	0.00	0.00	0.00	0.00	- 0.30	- 0.60	0.65	1.30

ST = Short term, LT = Long term
. Not applicable

Elasticities in Belgium

Elasticity of fuel use to	Coal price ST	Coal price LT	Oil price ST	Oil price LT	N.gas price ST	N.gas price LT	Electr. price ST	Electr. price LT	Activity ST	Activity LT
Industry										
Coal	- 0.24	- 0.97	0.00	0.02	0.01	0.02	0.03	0.10	0.20	0.82
Oil	0.01	0.02	- 0.24	- 0.97	0.01	0.02	0.03	0.10	0.20	0.82
N. gas	0.01	0.02	0.00	0.02	- 0.24	- 0.97	0.03	0.10	0.20	0.82
Electricity ..	0.01	0.02	0.00	0.02	0.01	0.02	- 0.22	- 0.89	0.20	0.82
Services										
Coal	.	.	.	.	.	.	.	.	.	.
Oil	.	.	- 0.13	- 1.28	- 0.02	1.05	0.05	0.08	0.40	0.61
N. gas	.	.	- 0.13	1.58	- 0.02	- 1.79	0.05	0.08	0.40	0.61
Electricity ..	.	.	0.00	0.00	0.00	0.00	- 0.05	- 0.13	0.63	1.52
Households										
Coal	- 0.29	- 0.83	0.01	0.28	0.07	0.32	0.00	0.00	0.20	0.20
Oil	- 0.01	0.05	- 0.27	- 0.57	0.07	0.32	0.00	0.00	0.20	0.20
N. gas	0.00	0.05	0.00	0.24	- 0.26	- 0.49	0.00	0.00	0.20	0.20
Electricity ..	0.00	0.00	0.06	0.00	0.00	0.00	- 0.12	- 0.12	0.12	0.12

ST = Short term, LT = Long term
. Not applicable

Elasticities in Denmark

Elasticity of	Coal price		Oil price		N.gas price		Electr. price		Activity	
fuel use to	ST	LT	ST	LT	ST	LT	ST	LT	ST	LT
Industry										
Coal	- 0.25	- 0.98	0.01	0.04	0.01	0.02	0.02	0.09	0.21	0.85
Oil	0.00	0.01	- 0.24	- 0.95	0.01	0.02	0.02	0.09	0.21	0.85
N. gas	0.00	0.01	0.01	0.04	- 0.24	- 0.97	0.02	0.09	0.21	0.85
Electricity ..	0.00	0.01	0.01	0.04	0.01	0.02	- 0.23	- 0.90	0.21	0.85
Services										
Coal	.	.	.	.	.	.	.	.	.	.
Oil	.	.	- 0.25	- 0.38	.	.	0.10	0.15	0.50	0.77
N. gas	.	.	.	.	.	.	.	.	.	.
Electricity ..	.	.	0.05	0.11	.	.	- 0.20	- 0.44	0.60	1.34
Households										
Coal	.	.	.	.	.	.	.	.	.	.
Oil	.	.	- 0.43	- 2.00	.	.	- 0.17	1.42	0.60	0.60
N. gas	.	.	.	.	.	.	.	.	.	.
Electricity ..	.	.	- 0.12	1.03	.	.	- 0.48	-1.62	0.60	0.60

ST = Short term, LT= Long term
. Not applicable

Elasticities in Finland

Elasticity of	Coal price		Oil price		N.gas price		Electr. price		Activity	
fuel use to	ST	LT	ST	LT	ST	LT	ST	LT	ST	LT
Industry										
Coal	- 0.24	- 0.97	0.01	0.03	0.00	0.01	0.02	0.13	0.21	0.85
Oil	0.01	0.02	- 0.24	- 0.96	0.00	0.01	0.02	0.13	0.21	0.85
N. gas	0.01	0.02	0.01	0.03	- 0.25	- 0.98	0.02	0.13	0.21	0.85
Electricity ..	0.01	0.02	0.01	0.03	0.00	0.01	- 0.22	- 0.89	0.21	0.85
Services										
Coal	.	.	.	.	.	.	.	.	.	.
Oil	.	.	- 0.15	- 0.30	.	.	0.10	0.20	0.60	1.20
N. gas	.	.	.	.	.	.	.	.	.	.
Electricity ..	.	.	0.10	0.20	.	.	- 0.15	- 0.30	0.60	1.20
Households										
Coal	.	.	.	.	.	.	.	.	.	.
Oil	.	.	- 0.20	- 3.24	.	.	0.10	3.03	0.10	0.28
N. gas	.	.	.	.	.	.	.	.	.	.
Electricity ..	.	.	0.06	1.36	.	.	- 0.16	- 1.65	0.10	0.28

ST = Short term, LT = Long term
. Not applicable

Elasticities in France

Elasticity of	Coal price		Oil price		N.gas price		Electr. price		Activity	
fuel use to	ST	LT	ST	LT	ST	LT	ST	LT	ST	LT
Industry										
Coal	- 0.21	- 0.97	0.00	0.02	0.01	0.03	0.02	0.10	0.16	0.78
Oil	0.00	0.02	- 0.20	- 0.97	0.01	0.03	0.02	0.10	0.16	0.78
N. gas	0.00	0.02	0.00	0.02	- 0.20	- 0.96	0.02	0.10	0.16	0.78
Electricity ..	0.00	0.02	0.00	0.02	0.01	0.03	- 0.19	- 0.89	0.16	0.78
Services										
Coal	.	.	.	.	.	.	.	.	.	.
Oil	.	.	- 0.19	- 1,79	0.00	1.49	0.05	0.08	0.60	0.92
N. gas	.	.	0.11	2.33	- 0.31	- 2.61	0.05	0.08	0.60	0.92
Electricity ..	.	.	0.03	0.05	0.07	0.09	- 0.35	- 0.50	0.50	0.71
Households										
Coal	- 0.10	- 0.59	0.00	0.30	- 0.23	- 0.09	0.03	0.03	1.09	1.25
Oil	0.00	0.31	- 0.10	- 0.60	- 0.23	- 0.09	0.03	0.03	1.09	1.25
N. gas	-0.05	0.00	- 0.05	0.00	- 0.23	- 0.37	0.03	0.03	1.09	1.25
Electricity ..	0.00	0.00	0.00	0.00	0.02	0.03	- 0.58	- 0.66	1.30	1.50

ST = Short term, LT= Long term
. Not applicable

Elasticities in Germany

Elasticity of	Coal price		Oil price		N.gas price		Electr. price		Activity	
fuel use to	ST	LT	ST	LT	ST	LT	ST	LT	ST	LT
Industry										
Coal	- 0.19	- 0.97	0.00	0.01	0.00	0.02	0.02	0.10	0.15	0.76
Oil	0.00	0.02	- 0.20	- 0.98	0.00	0.02	0.02	0.10	0.15	0.76
N. gas	0.00	0.02	0.00	0.01	- 0.20	- 0.97	0.02	0.10	0.15	0.76
Electricity ..	0.00	0.02	0.00	0.01	0.00	0.02	- 0.18	- 0.89	0.15	0.76
Services										
Coal	- 0.35	- 2.65	0.11	1.63	0.05	0.74	0.05	0.08	0.50	0.83
Oil	0.02	0.17	- 0.24	- 0.88	0.02	0.38	0.05	0.08	0.50	0.83
N. gas	0.02	0.17	0.03	0.73	- 0.25	-1.23	0.05	0.08	0.50	0.83
Electricity ..	0.00	0.00	0.03	0.05	0.02	0.02	- 0.10	- 0.15	0.80	1.23
Households										
Coal	- 0.16	- 0.63	0.07	0.22	0.10	0.25	0.00	0.16	0.00	0.00
Oil	0.01	0.02	- 0.10	- 0.42	0.10	0.25	0.00	0.16	0.00	0.00
N. gas	0.02	0.06	0.09	0.24	- 0.11	- 0.45	0.00	0.16	0.00	0.00
Electricity ..	0.01	0.00	0.04	0.04	0.04	0.04	- 0.53	- 0.53	0.46	0.46

ST = Short term, LT= Long term
. Not applicable

Elasticities in Germany

Elasticity of	Coal price		Oil price		N.gas price		Electr. price		Activity	
fuel use to	ST	LT	ST	LT	ST	LT	ST	LT	ST	LT
Industry										
Coal	- 0.19	- 0.97	0.00	0.01	0.00	0.02	0.02	0.10	0.15	0.76
Oil	0.00	0.02	- 0.20	- 0.98	0.00	0.02	0.02	0.10	0.15	0.76
N. gas	0.00	0.02	0.00	0.01	- 0.20	- 0.97	0.02	0.10	0.15	0.76
Electricity ..	0.00	0.02	0.00	0.01	0.00	0.02	- 0.18	- 0.89	0.15	0.76
Services										
Coal	- 0.35	- 2.65	0.11	1.63	0.05	0.74	0.05	0.08	0.50	0.83
Oil	0.02	0.17	- 0.24	- 0.88	0.02	0.38	0.05	0.08	0.50	0.83
N. gas	0.02	0.17	0.03	0.73	- 0.25	-1.23	0.05	0.08	0.50	0.83
Electricity ..	0.00	0.00	0.03	0.05	0.02	0.02	- 0.10	- 0.15	0.80	1.23
Households										
Coal	- 0.16	- 0.63	0.07	0.22	0.10	0.25	0.00	0.16	0.00	0.00
Oil	0.01	0.02	- 0.10	- 0.42	0.10	0.25	0.00	0.16	0.00	0.00
N. gas	0.02	0.06	0.09	0.24	- 0.11	- 0.45	0.00	0.16	0.00	0.00
Electricity ..	0.01	0.00	0.04	0.04	0.04	0.04	- 0.53	- 0.53	0.46	0.46

ST = Short term, LT= Long term
. Not applicable

Elasticities in Italy

Elasticity of	Coal price		Oil price		N.gas price		Electr. price		Activity	
fuel use to	ST	LT	ST	LT	ST	LT	ST	LT	ST	LT
Industry										
Coal	- 0.20	- 0.98	0.00	0.02	0.00	0.02	0.02	0.11	0.18	0.88
Oil	0.00	0.01	- 0.20	- 0.97	0.00	0.02	0.02	0.11	0.18	0.88
N. gas	0.00	0.01	0.00	0.02	- 0.19	- 0.97	0.02	0.11	0.18	0.88
Electricity ..	0.00	0.01	0.00	0.02	0.00	0.02	- 0.18	- 0.88	0.18	0.88
Services										
Coal	.	.	.	.	.	.	.	.	.	.
Oil	.	.	- 0.06	- 0.13	- 0.04	- 0.07	0.05	0.10	0.35	0.70
N. gas	.	.	- 0.01	0.20	- 0.09	- 0.40	0.05	0.10	0.35	0.70
Electricity ..	.	.	0.03	0.06	0.02	0.04	- 0.10	- 0.20	0.55	1.10
Households										
Coal	.	.	.	.	.	.	.	.	.	.
Oil	.	.	- 0.16	- 0.54	- 0.02	- 0.21	0.03	0.12	0.34	1.42
N. gas	.	.	- 0.02	- 0.14	- 0.16	- 0.60	0.03	0.12	0.34	1.42
Electricity ..	.	.	0.01	0.04	0.02	0.08	- 0.45	- 1.85	0.37	1.55

ST = Short term, LT= Long term
. Not applicable

Elasticities in The Netherlands

Elasticity of	Coal price		Oil price		N.gas price		Electr. price		Activity	
fuel use to	ST	LT	ST	LT	ST	LT	ST	LT	ST	LT
Industry										
Coal	- 0.25	- 0.98	0.01	0.05	0.01	0.04	0.02	0.06	0.20	0.82
Oil	0.00	0.01	- 0.24	- 0.94	0.01	0.04	0.02	0.06	0.20	0.82
N. gas	0.00	0.01	0.01	0.05	- 0.24	- 0.95	0.02	0.06	0.20	0.82
Electricity ..	0.00	0.01	0.01	0.05	0.01	0.04	- 0.23	- 0.93	0.20	0.82
Services										
Coal	.	.	.	.	.	.	.	.	.	.
Oil	.	.	- 0.06	- 0.30	- 0.09	0.07	0.05	0.08	0.40	0.61
N. gas	.	.	- 0.01	0.05	- 0.14	- 0.28	0.05	0.08	0.40	0.61
Electricity ..	.	.	0.01	0.02	0.04	0.08	- 0.10	- 0.20	0.60	1.20
Households										
Coal	.	.	.	.	.	.	.	.	.	.
Oil	.	.	.	.	.	.	.	.	.	.
N. gas	.	.	.	.	- 0.08	- 0.16	0.03	0.06	0.61	1.22
Electricity ..	.	.	.	.	0.03	0.06	- 0.37	- 0.73	0.68	1.36

ST = Short term, LT = Long term
. Not applicable

Elasticities in Norway

Elasticity of	Coal price		Oil price		N.gas price		Electr. price		Activity	
fuel use to	ST	LT	ST	LT	ST	LT	ST	LT	ST	LT
Industry										
Coal	- 0.25	- 0.99	0.01	0.04	.	.	0.03	0.12	0.22	0.88
Oil	0.00	0.00	- 0.24	- 0.95	.	.	0.03	0.12	0.22	0.88
N. gas	.	.	.	.	.	.	.	.	.	.
Electricity ..	0.00	0.00	0.01	0.04	.	.	- 0.22	- 0.87	0.22	0.88
Services										
Coal	.	.	.	.	.	.	.	.	.	.
Oil	.	.	- 0.25	- 0.45	.	.	0.05	0.09	0.50	0.91
N. gas	.	.	.	.	.	.	.	.	.	.
Electricity ..	.	.	0.05	0.08	.	.	- 0.35	- 0.53	0.80	1.23
Households										
Coal	.	.	.	.	.	.	.	.	.	.
Oil	.	.	- 0.40	- 1.09	.	.	- 0.07	0.64	0.47	0.47
N. gas	.	.	.	.	.	.	.	.	.	.
Electricity ..	.	.	0.00	0.01	.	.	- 0.46	- 0.47	0.47	0.47

ST = Short term, LT = Long term
. Not applicable

Elasticities in Spain

Elasticity of	Coal price		Oil price		N.gas price		Electr. price		Activity	
fuel use to	ST	LT	ST	LT	ST	LT	ST	LT	ST	LT
Industry										
Coal	- 0.21	- 0.97	0.01	0.04	0.00	0.02	0.02	0.10	0.16	0.78
Oil	0.00	0.02	- 0.20	- 0.95	0.00	0.02	0.02	0.10	0.16	0.78
N. gas	0.00	0.02	0.01	0.04	- 0.21	- 0.97	0.02	0.10	0.16	0.78
Electricity	0.00	0.02	0.01	0.04	0.00	0.02	- 0.19	- 0.89	0.16	0.78
Services										
Coal	.	.	.	.	.	.	.	.	.	.
Oil	.	.	- 0.24	- 1.43	0.14	1.28	0.05	0.08	0.35	0.54
N. gas	.	.	0.26	1.89	- 0.35	- 2.02	0.05	0.08	0.35	0.54
Electricity	.	.	0.02	0.03	0.03	0.06	- 0.10	- 0.20	0.55	1.10
Households										
Coal	.	.	.	.	.	.	.	.	.	.
Oil	.	.	- 0.21	- 0.43	0.03	0.15	0.12	0.30	0.18	0.45
N. gas	.	.	- 0.01	0.23	- 0.17	- 0.50	0.12	0.30	0.18	0.45
Electricity	.	.	0.04	0.05	0.05	0.05	- 0.69	- 0.82	0.95	1.12

ST = Short term, LT = Long term
. Not applicable

Elasticities in Sweden

Elasticity of	Coal price		Oil price		N.gas price		Electr. price		Activity	
fuel use to	ST	LT	ST	LT	ST	LT	ST	LT	ST	LT
Industry										
Coal	- 0.25	- 0.98	0.01	0.03	0.00	0.00	0.03	0.12	0.22	0.86
Oil	0.00	0.01	- 0.24	- 0.96	0.00	0.00	0.03	0.12	0.22	0.86
N. gas	0.00	0.01	0.01	0.03	- 0.25	- 0.99	0.03	0.12	0.22	0.86
Electricity	0.00	0.01	0.01	0.03	0.00	0.00	- 0.22	- 0.87	0.22	0.86
Services										
Coal	.	.	.	.	.	.	.	.	.	.
Oil	.	.	- 0.30	- 0.46	.	.	0.10	0.15	0.50	0.77
N. gas	.	.	.	.	.	.	.	.	.	.
Electricity	.	.	0.05	0.08	.	.	- 0.20	- 0.33	0.80	1.34
Households										
Coal	.	.	.	.	.	.	.	.	.	.
Oil	.	.	- 0.13	- 3.44	.	.	- 0.11	3.31	0.24	0.24
N. gas	.	.	.	.	.	.	.	.	.	.
Electricity	.	.	0.01	0.30	.	.	- 0.25	- 0.54	0.24	0.24

ST = Short term, LT = Long term
. Not applicable

Elasticities in Switzerland

Elasticity of	Coal price		Oil price		N.gas price		Electr. price		Activity	
fuel use to	ST	LT	ST	LT	ST	LT	ST	LT	ST	LT
Industry										
Coal	- 0.20	- 0.99	0.00	0.01	0.00	0.02	0.02	0.12	0.15	0.76
Oil	0.00	0.00	- 0.20	- 0.98	0.00	0.02	0.02	0.12	0.15	0.76
N. gas	0.00	0.00	0.00	0.01	- 0.19	- 0.97	0.02	0.12	0.15	0.76
Electricity ..	0.00	0.00	0.00	0.01	0.00	0.02	- 0.18	- 0.87	0.15	0.76
Services										
Coal	.	.	.	.	.	.	.	.	.	.
Oil	.	.	- 0.14	- 0.34	- 0.05	0.14	0.00	0.00	1.25	1.25
N. gas	.	.	- 0.14	0.39	- 0.05	- 0.59	0.00	0.00	1.25	1.25
Electricity ..	.	.	0.00	0.00	0.00	0.00	- 0.05	- 0.46	0.60	1.00
Households										
Coal	.	.	.	.	.	.	.	.	.	.
Oil	.	.	- 0.23	- 0.53	- 0.04	- 0.14	0.12	0.30	0.18	0.45
N. gas	.	.	- 0.12	- 0.37	- 0.15	- 0.30	0.12	0.30	0.18	0.45
Electricity ..	.	.	0.02	0.02	0.01	0.01	- 0.25	- 0.29	0.95	1.12

ST = Short term, LT = Long term
. Not applicable

Elasticities in United Kingdom

Elasticity of	Coal price		Oil price		N.gas price		Electr. price		Activity	
fuel use to	ST	LT	ST	LT	ST	LT	ST	LT	ST	LT
Industry										
Coal	- 0.26	- 0.98	0.00	0.02	0.01	0.03	0.03	0.10	0.20	0.78
Oil	0.00	0.01	- 0.25	- 0.97	0.01	0.03	0.03	0.10	0.20	0.78
N. gas	0.00	0.01	0.00	0.02	- 0.25	- 0.96	0.03	0.10	0.20	0.78
Electricity ..	0.00	0.01	0.00	0.02	0.01	0.03	- 0.23	- 0.89	0.20	0.78
Services										
Coal	- 0.19	- 1.83	- 0.02	- 0.02	0.09	1.57	0.05	0.10	0.35	0.70
Oil	- 0.01	0.03	- 0.07	- 0.51	- 0.07	0.18	0.05	0.10	0.35	0.70
N. gas	0.02	0.33	- 0.02	- 0.02	- 0.12	- 0.62	0.05	0.10	0.35	0.70
Electricity ..	0.01	0.01	0.01	0.01	0.04	0.06	- 0.10	- 0.17	0.60	1.00
Households										
Coal	- 0.31	- 0.65	0.05	0.12	0.05	0.13	0.03	0.06	0.47	0.90
Oil	0.10	0.25	- 0.36	- 0.78	0.05	0.13	0.03	0.06	0.47	0.90
N. gas	0.01	0.00	0.00	0.00	-0.22	- 0.40	0.03	0.06	0.47	0.90
Electricity ..	0.00	0.00	0.00	0.00	0.03	0.06	- 0.53	- 1.01	0.53	1.02

ST = Short term, LT= Long term
. Not applicable

A5 - Technology characterization and cost computation in transport and electricity production

On basis of EFOM (Energy Flow Optimization Model) data bases for the EU countries and country data from national Bureaus of Statistics for the other countries, technologies are characterized for the transport and electricity sector.

A 5.1 Transport

As mentioned in 2.6.2, the passenger transport model considers six different transport types: gasoline car, diesel car, lpg car, diesel bus, diesel train and electricity train. For all alternatives there will be different technologies. We have assumed that there exists an "old" (or present) and a "new" (or future) technology, characterized with different efficiency parameters and costs. A penetration path for new technologies must be defined to calculate the development in costs and efficiencies of introduction of new technology. It is assumed that in the base-year all technologies are "old" technologies, while in the end-year the car fleet is completely replaced by "new" technologies. Thus the average efficiency of transport option j at time t is given by

$$E_j(t) = \frac{t}{T}E_{j,n}(t) + \frac{(T-t)}{T}E_{j,o}(t) \qquad \text{(A5.1)}$$

where

E_j = average fuel efficiency of option j (vkm/MJ)

$E_{j,n}$ = fuel efficiency of the "new" technology

$E_{j,o}$ = fuel efficiency of the "old" technology

T = time span

where (A5.1) simply states that the average fuel efficiency is a weighted sum of the efficiencies of the two technologies. Correspondingly, the cost of option j at time t is a weighted sum of the costs of the two different technologies.

$$C_j(t) = \frac{t}{T}C_{j,n}(t) + \frac{T-t}{T}C_{j,o}(t) \qquad \text{(A5.2)}$$

C_j = average costs of option j (\$/pkm)

$C_{j,n}$ = average costs for new technology, option j

$C_{j,o}$ = average costs for old technology, option j

The average costs per pkm consists of technology related costs and fuel costs. In the SEEM model, the average costs of option j using technology i, i=n,o, is calculated as follows

$$C_{j,i} = \frac{P^F_{j,i}}{M_{j,i}SO_j} + P^V_{j,i} + \frac{P^f_j}{E_{j,i}SO_j}, \qquad i=n,o \qquad \text{(A5.3)}$$

where

P_j^F = fixed costs ($/vehicle)

P_j^V = variable technology costs ($/pkm)

P_j^f = fuel price of option j

E_j = fuel efficiency (vkm/MJ)

M_j = average mileage (vkm/year)

SO_j = seat occupancy (persons/veh)

A 5.2 Electricity production sector

In the electricity sector, technologies are characterized for the following types of plants: coal plants, oil plants, natural gas plants, nuclear plants and renewables plants. Again we consider two possible technologies, viz. an "old" and a "new" technology. The technology penetration path in the electricity sector is comparable to the one used in the transport sector, although we here allow for new technology also in the base year. A linear penetration path is considered from a certain starting point to an exogenous determined end point (based on expert opinion on costs, capacity, etc.). However, the average efficiency parameter for plant j is calculated in a similar way as in the transport sector (see (A5.1)). Total average costs of producing electricity in plant j with technology i consists of technology related costs (investment and operation/maintenance costs) and fuel costs, and are calculated as follows

$$C_{j,i} = P^F_{j,i} + P^V_{j,i} + \frac{P^f_j}{E_{j,i}}, \qquad i=n,o \qquad \text{(A5.4)}$$

where

P_j^F = fixed costs ($/unit output)

P_j^V = variable technology costs ($/unit output)

P_j = fuel price

E_j = fuel efficiency

Total average costs in plant j is given as a weighted sum of the average costs of the two different technologies and can be computed as in (A5.2).

For coal plants three plants are characterized, viz. a conventional coal plant, a new coal plant with improved efficiency and higher investment costs, and a coal-gasification plant. Renewable electricity production consists of hydro power and wind power plants (on-shore and off-shore), depending on the country specific situation.

An option to the "new " technology, which is assumed to be country specific, is what we have labelled the Best Available Technologies (BATs), which can be introduced to simulate a free technology transfer in the electricity production sector (an option for the model user). These plants are not always the cheapest plants available in Europe, but they are chosen on basis of cost, efficiency, and environmental considerations.

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