Environmental satellite models for ADAM.

CO_2, SO_2 and NO_x emissions

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Frits Møller Andersen
Peter Trier
Department of Policy Analysis

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Authors: Frits Møller Andersen, Peter Trier

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Abstract: The report gives a technical documentation of forecast models for the energy consumption and related emissions of CO_2, SO_2 and NO_x developed as satellite models for the Danish macro-economic model ADAM.

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Department of Policy Analysis
Frederiksborgvej 399
P.O. Box 358
DK-4000 Roskilde
Tel. +45 46 30 12 00
Fax. +45 46 30 11 14

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Preface

Concern about climate changes and the acidification of forests and lakes has initiated the setting-up of international conventions aimed at limiting emissions of CO_2, SO_2 and NO_x. For Denmark the national policy targets for these emissions are:

- A 20 percent reduction of the energy related CO_2 emissions in year 2005 relative to the level in 1988. In addition according to the climate convention we are committed to stabilize CO_2 emissions in year 2000 at the 1990 level.
- An 80 percent reduction of SO_2 emissions in year 2000 relative to the level in 1980.
- A 30 percent reduction of NO_x emissions in year 1998 relative to the level in 1986.

In order to evaluate whether these targets are obtained within present policies, or additional policy actions should be taken, emission projections are needed. As emissions of CO_2, SO_2 and NO_x come mainly from the use of energy, projections for these emissions require projections for the energy consumption. Taking the macro-economic model ADAM as a starting point, this report presents energy- and emission models, that may be used for national projections of CO_2, SO_2 and NO_x emissions. The report is a technical documentation that presents emission models and additional energy relations estimated and tested on historical data. The report will form the basis for a formal implementation of emission models as satellite models to ADAM.

The research presented is part of the research programme of the AMOR-centre and is financed by the Strategic Environmental Research Program. The AMOR-centre is a collaboration between:
The Danish Statistical Office
The National Environmental Research Institute
Research Centre Risø
The University of Roskilde, Institute of Economics and Planning
and
The University of Copenhagen, Institute of Economics.

The research within AMOR is organised in three projects:
A The linking of emission coefficients to the national accounting statistics and the development of a branch nomenclature that is suitable for environmental problems.
B The development of models for the projection of emissions.
C The development of a methodology for the description of how depletion of natural resources and environmental changes affect economic development and welfare.

This report is part of project B and draws heavily on data generated by project A.

The individual chapters of the report may be read independently of each other but form a whole in describing the total energy consumption and energy related emissions.

Frits Møller Andersen are responsible for the chapters I.1, I.2 and part II, while Peter Trier is responsible for the chapters I.3 and I.4.

We thank Thomas Thomsen, the modelling group of The Danish Statistical Office for stimulating discussions and valuable comments to an earlier draft.

Finally we thank Peter Stephensen, Research Centre Risø for compilation of data used for estimations in chapter I.4.

I. Environmental satellite models for ADAM

I.1. Introduction

In general economic activities use and affect the environment, and the state of the environment sets conditions for economic activities. The environment contributes to economic activities as factors of production and as consumer goods and is a recipient of emissions in a broad sense. At an aggregate level macroeconomic-environmental models aim at describing these interactions between the economy and the environment. The models presented in this report may be seen as a first step towards this integrated economic-environmental modelling, but have the more limited scope of determining emissions generated by economic activities, that is, which emissions are generated by which activities, and what are the level and development of different emissions? For a fully integrated economic-environmental modelling the environmental- and economic consequences of the emissions should be included, however this is outside the models presented here. That is, the emission models presented are submodels to the economic model.

The main purpose of the models is to generate emission projections at a national level, and using the models the type of questions that may be analyzed are: Given the economic development, which emissions will be generated? Given targets for emissions or emission reductions, will these be obtained given the projected economic development and present policies? Are the targets obtainable assuming an alternative economic development or with additional policy actions?

The starting point for modelling emissions is the definition:

emission = activity level * emission coefficient

and for each pollutant total emissions are the sum of emissions from different sources.

In general the activity level is defined as variables in an economic model, and accordingly emission coefficients are defined in relation to these. Therefore, in order to be useful, the economic model has to include variables, that are proper indicators for the emissions.

Emission coefficients are technical variables that in general are assumed to be exogenous to the economic model. This is a simplification as technical changes and thereby emission coefficients do depend on economic conditions and development, however the specific relation between economic changes and emission coefficients is seldom known. How serious this assumption is depend of the pollutant in question and the level of aggregation. For the models presented in this report, emission coefficients are calculated from a fairly detailed level of aggregation, and aggregated emission coefficients may be calculated assuming alternative technical conditions.

For some pollutants economic changes are the main cause of changes in the emissions, for others technical changes are equally or even more important. Whether technical changes are important or not, linking to the economic development is important. Assuming unchanged technology emissions follow the economic development. If technical changes are important, this has to be taken into account in the projection of the emission coefficients. Linking to a national macro-economic model may not always be very helpful. For pollutants where the emissions are caused by a few very specific productions or where the spatial distribution is of paramount importance, linking to a national macro-economic model may not be very informative. Pollutants that most successfully may be modelled in a national macro-economic context are characterized by:

1: The emissions follow the national economic development
2: Problems caused by the emissions are of a national or international character.
3: The agents causing the emissions are numerous.

Emissions of CO_2, SO_2 and NO_x, for which models linked to the macro-economic model ADAM are presented in this report, comply with these characteristics. Emissions of CO_2, SO_2 and NO_x come mainly from the use of fossil fuels, which to a large extent follows the national economic development and are used by numerous agents. The problems caused by the emissions are global warming and acidification, which are of international concern.

To describe the Danish economy the macro-economic model ADAM is chosen. ADAM is a short- to medium-term econometric model, that distinguishes 19 production branches and 12 categories of consumer goods, and is the model used for the official planning in Denmark. In order to be useful for linking CO_2, SO_2 and NO_x emission models the description of the energy demand in ADAM has to be extended. Therefore part one of this report gives proposals for extensions of the energy description in ADAM, and part two documents models for the calculation of emission coefficients and -projections for CO_2, SO_2 and NO_x emissions.

Concerning the demand for energy by branches, ADAM determines the total energy demanded by each branch. In order to be useful for emission projections this has to be extended in two ways. The ADAM branch "other transport" has to be disaggregated, and for all branches the total energy demand has to be divided between fuels. Chapter I.2 presents a model for the energy demand of the branch "other transport" disaggregated into 9 sub-branches, and chapter I.3 presents a disaggregation of the total energy demand into demand for 6 fuels of which substitution between three groups are estimated. Chapter I.4 presents extended models for the energy demand by households.

Part two of the report contains three chapters; one for each of the three pollutants CO_2, SO_2 and NO_x. These chapters document the calculation of emission coefficients and the emission models developed. The models may be linked to the extended ADAM model described in part one, and thereby be used for emission projections.

I.2. A simple model for the production and energy consumption of the transport branches

I.2.1 Introduction

About 1/4 of the total energy consumption in Denmark is used for transport purposes, and this share has increased over the past. Since 1966 the transport energy consumption has increased with about 70 percent, and the environmental problems related to transport has become increasingly important. Looking at CO_2 and NO_x-emissions, about 20 percent of the total CO_2-emissions and close to 50 percent of the total NO_x-emissions come from the use of transport energy.

The transport energy consumption and related emissions change due to the economic development, structural changes and the different needs for different kinds of transport services of the individual branches, the energy efficiency of the different kinds of transport services, changes in the energy efficiency and the mix of fuels used. At an aggregate level, the model presented in this chapter aims at a simple description of these interactions between the economy and the transport related energy consumption. The emissions are described in part two of the report. The model presented in this chapter takes the macroeconomic model ADAM as a starting point and may be seen as a disaggregated satellite model to ADAM.

The consumption of transport energy is determined in different parts of ADAM.

The direct transport energy consumption by branches is part of the total energy consumption by branches, which in ADAM is determined by an energy-relation per branch. The interfuel substitution model described in chapter I.3, separates transport fuels as one of the fuels.

The demand for transport services by branches is part of the input of materials, and is determined by fixed input/output coefficients for deliveries from the branches 'sea transport' and 'other transport services'.

The demand for transport energy and -services by households is described by the consumer demand system in ADAM and the energy model presented in chapter I.4.

The model presented in this chapter consists of a simple input/output model disaggregating the branch 'other transport services' into 9 transport branches and ad-hoc energy-relations for these 9 transport branches and the sea transport. The main reason for the disaggregation is, that the different transport branches have different energy-efficiencies and therefore different emissions and, that economic and structural changes affect the demand for the different transport services differently. Therefore, the aim of the model is to analyze, how alternative economic developments affect the demand for services from the different transport branches and the energy consumption and emissions related to this.

To keep the model simple and easily adaptable to ADAM, a number of simplifying assumptions are made. Describing the demand for the different transport services by fixed input/output coefficients implies a limitational production function, where the price-elasticities for the demand for transport services and the substitution elasticities between the different kinds of transport services are zero. This implies, that the model is not able to analyze, how changes in the prices of the different transport services affect the demand for and substitution between these services. A study of the price- and substitution elasticities of the transport services has been performed by the Local Governments' Research Institute (AKF), and is reported in Jensen,T. and Bjørner, T.B. (1995). The result from this study is, that effects of price changes are not negligible. However in the present modelling we stick to the assumption of fixed input/output coefficients. At a later stage this description may be changed by including price-effects.

Another simplifying assumption is the separability between the transport energy consumption by branches (included in the energy consumption) and the demand for transport services (included in input of materials). From a theoretical point of view, in the long run own-transport (produced by a firm itself) and purchases of transport services should be perfect substitutes, however the model assumes a zero substitution. With the present structure of ADAM and the data available, this limitation is not easily overcome. For a more correct modelling, in the individual branches the transport energy consumption and related capital and labour use should be separated form other activities and modelled together with the purchase of transport services. For ADAM this would imply changes in the relations for investments, labour demand and energy consumption, and the data for separating the use of capital and labour for transport purposes are not easily available. A number of methods for generating the data have been proposed, however they each include somewhat dubious assumptions. From an environmental point of view, who performs the transport is not very important. The problem is whether the transport divided between the different means of transport is modelled reasonably. If the relative size of own- and purchased transport has been constant or trend wise changing, and the trends are modelled correctly in the energy and transport models, assuming the trends to continue, for forecasting purposes and from an environmental point of view, a separate modelling of own- and purchased transport may not be very harmful. By looking at the direct transport energy consumption by branches and the indirect deliveries of transport energy form the transport branches the size of the problem will be illustrated in section I.2.2.3 of this chapter.

I.2.2 The composition and development of the transport energy consumption

I.2.2.1 The aggregate consumption structure and development.

In 1990 the total transport energy consumption was about 192 PJ, of which 73 PJ were used by the transport branches, 62 PJ were used by the other branches and 57 PJ were used by the households. Considering the 73 PJ used by the transport branches as indirect deliveries to the other uses, about 40 percent were delivered to the other branches, 25 percent to the households, 25 percent to exports and the remaining 10 percent were deliveries between the transport branches.

The development of the total transport energy consumption and the three uses is shown in figure 2.1. Over the period 1966 to 1990 the total transport energy consumption has increased about 67 percent or on average 2.2 percent per year. As is seen from the figure, the development has not been trendwise and somewhat different for the three uses.

For the transport branches the energy consumption more than doubled over the period 1966 to 1987. The energy price increases in 1973 and 1979/80 implied minimal and temporary decreases, however from 1987 to 1990 the energy consumption decreased with about 20 percent. The development mirrors both a drastic increase of the air transport and changes in the energy coefficients of the individual transport branches. In general the energy coefficients have been increasing from 1966 to 1987 and decreasing after 1987. The transport energy consumption of the 'other branches' has fluctuated between 50 PJ and 60 PJ without any clear trend. In general the development mirrors structural changes with a decreasing production in some of the transport intensive branches like construction, an increase in the service sector and considerable changes in the primary branches.

For households the transport energy consumption almost doubled from 1966 to 1979. Due to the energy price increase in 1979/80 the transport energy consumption dropped about 20 percent from 1980 to 1984. Since the transport energy consumption has increased, however the annual increase is about half the increases in the 1960s and 1970s.

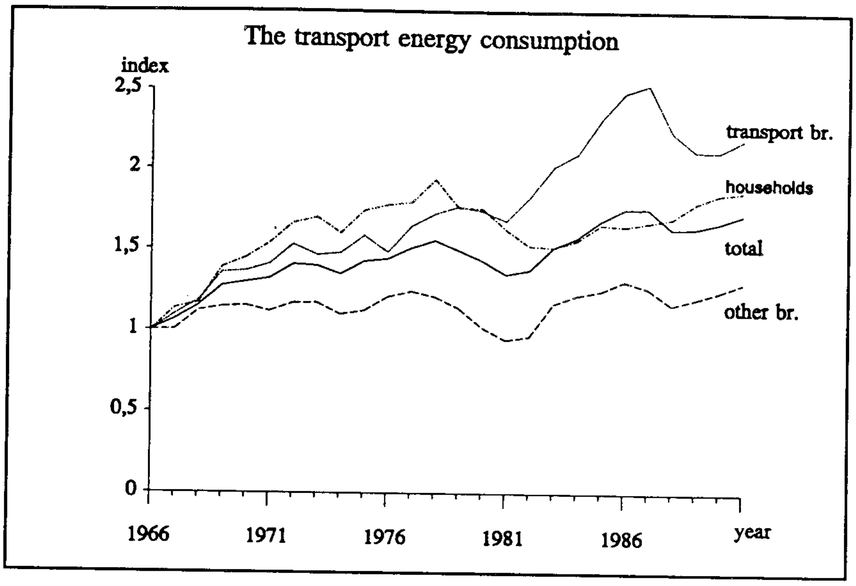

Figure 2.1 The development of the transport energy consumption by different users in PJ, index 1966=1.0

I.2.2.2 The transport branches

For a start it has to be noticed, that in this chapter the transport branches include Danish transport companies only, and the activities of these companies are included, whether the transport is performed in Denmark or abroad. The activities of foreign transport companies in Denmark are not separated in the input-output tables and the national accounting system. Imports are calculated in c.i.f. prices, that is the price of imported goods include transport costs to the importer, and imports from foreign transport companies are by definition zero.

As mentioned in the previous section in 1990 the transport branches consumed about 73 PJ of transport energy. The distribution of this between the individual transport branches, the production of these branches, the transport energy coefficients and the implicit deliveries of transport energy to the different uses are shown in table 2.2.1. In this table the implicit deliveries of transport energy are calculated assuming a uniform energy coefficient for all deliveries from a given transport branch. As will be seen later, this is a somewhat heroic assumption, and the figures in table 2.2.1 express only the deliveries from the transport branches weighted by the average transport energy coefficient of the branch, and not the actual energy used for individual deliveries. A further disaggregation of the transport branches shows, that for the individual branches given in the table, the energy coefficient for deliveries to different uses vary quite substantially.

Keeping these limitations in mind table 2.2.1 shows, that the transport branches include both energy intensive and less energy intensive branches. The energy intensive branches rail, road freight and air transport use about 90 percent of the transport energy consumption and produce only 1/3 of the production in the transport branches. The less energy intensive transport branches mail and telecommunication, services related to the transport branches and sea transport include the major part of the production in the transport branches, but use only about 10 percent of the transport energy consumption. The transport energy coefficient therefore vary between the different transport branches, and for analyses and forecasts of the transport energy consumption it is important to know, whether changes in the production of the transport branches are caused by changes in the production of rail and bus transport or in the branch mail and telecommunication. This point is further illustrated in figure 2.2.1 showing the development of the production and transport energy consumption of the different transport branches. From figure 2.2.1 it is noticed, that the production has increased mainly in the less energy-intensive transport branches, while the energy consumption has increased mainly in the energy-intensive branches. In relation to the ADAM-model it is therefore important, that the branch "other transport" is disaggregated.

Looking at the implicit deliveries of transport energy it is seen, that there are important differences as to which uses the different transport branches deliver. The branch rail and bus transport delivers to households and other branches mainly. Of the other branches it is mainly the branches "manufactures of food and beverages", "trade" and "public services" that draw on rail and bus transport. As will be seen later the transport energy implicitly delivered to households is somewhat under-estimated, and the energy used for deliveries to other branches is somewhat over-estimated. The energy coefficient for deliveries to households is higher than for deliveries to other branches. The branch freight and taxi etc. delivers mainly to other branches and export. The

Branches	Production	Transport-energy consumption	Energy-coefficient	Implicit deliveries of transport energy to uses PJ			
	bill 1980-prices	PJ	PJ/bill 1980-prices	House-holds	Transp. branches	Other branches	Exports
Rail, bus	3.7	13.4	3.57	6.5	2.2	4.4	0.2
Freight, taxi	13.5	29.4	2.17	3.5	0.8	17.8	7.3
Air transp.	6.1	25.5	4.20	6.7	5.8	5.1	7.9
Mail, tele	10.7	1.5	0.14	0.5	0.1	0.9	0.0
Sea transp.	24.1	2.0	0.08	0.1	0.1	0.1	1.7
Services	12.0	1.2	0.10	0.1	0.6	0.4	0.1
Total	70.2	73.0	1.04	17.4	9.6	28.8	17.2

Table 2.2.1 The production, transport energy consumption of the transport branches and the implicit deliveries of transport energy to the different uses in 1990.

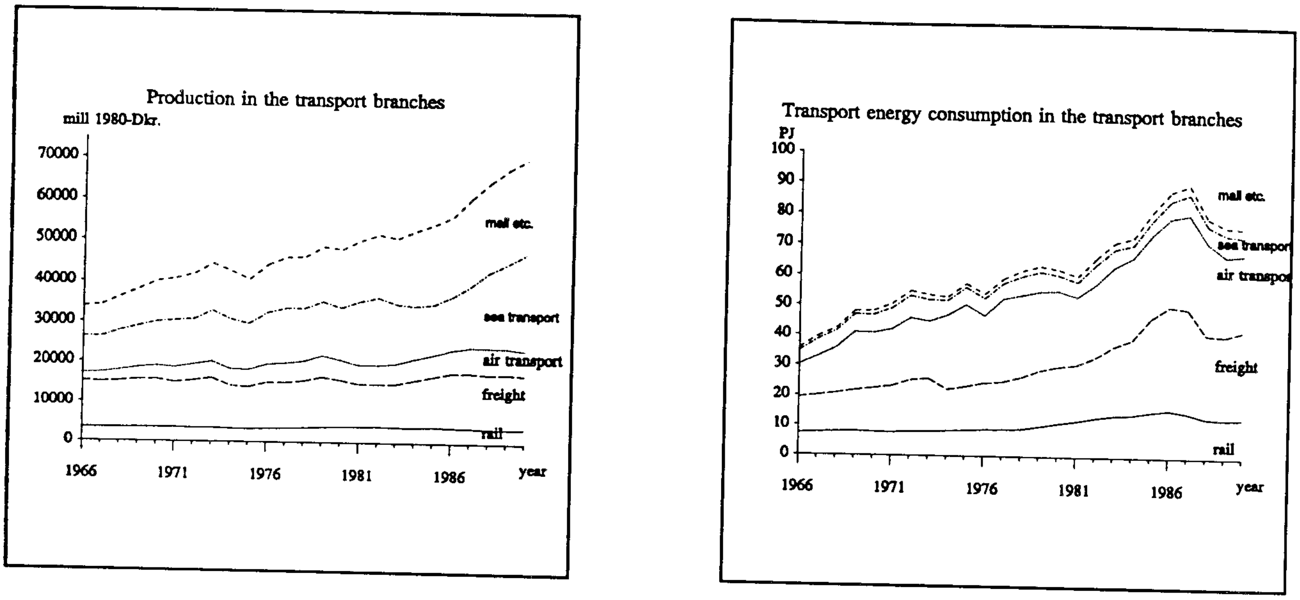

Figure 2.2.1 Production and transport energy consumption in the transport branches

deliveries to the other branches go mainly to the branches construction and trade.

Air transport is delivered to all the uses. As will be seen later air transport is mainly transport of persons, while freight transport is of minor importance. Mail and telecommunication delivers to households and other branches. Deliveries to the other branches are relatively evenly distributed between the individual branches. Sea transport is mainly used for exports, and services related to the transport branches are mainly delivered to the transport branches.

Rail and bus transport

Rail and bus transport includes private and public owned rail roads, busses in regular service and ferries owned by the Danish rail roads. Tourist coaches are not included in this branch. As is seen from table 2.2.2 the transport energy consumption of the branch (incl. the fuel oil used for transport) is about 16 PJ and has doubled since 1966. Production has been almost constant, that is the transport energy coefficient has doubled over the period. Looking at the sub-branches about 4 PJ of transport energy are used by the rail roads of which the main part is used for transport of persons. Rail freight is of minor importance. Beside the transport energy consumption as defined here the rail roads use about 2 PJ of electricity (net) for electrified trains. The electricity used for transport has increased gradually from about 1 PJ in 1966. Including the electricity used for transport the energy coefficient for the rail transport has increased slightly. The ferries use about 5 PJ and have experienced a slight increase in the energy coefficient. The rest about 7 PJ is used by the busses in regular service, and as seen from figure 2.2.2 this energy consumption has increased explosively since the mid 1970s. With

	Production in bill. 1980-Dkr.		Transport energy consumption in PJ		Energy coefficient	
	1966	1990	1966	1990	1966	1990
Rail transport freight	1.0	0.9	1.0	0.6	0.99	0.67
Rail transport persons	1.5	1.3	3.7	3.4	2.46	2.57
Bus transport	0.7	1.0	0.4	7.2	0.53	7.47
Ferries	0.3	0.5	2.4	2.2*	7.27	4.40
Total	3.5	3.7	7.5	13.4	2.12	3.62

Table 2.2.2 Production and transport energy consumption of the branch rail and bus transport

*In addition 2.4 PJ fuel oil is used for transport. In 1966 this was classified as autodiesel oil and therefore correctly included in the transport energy consumption.

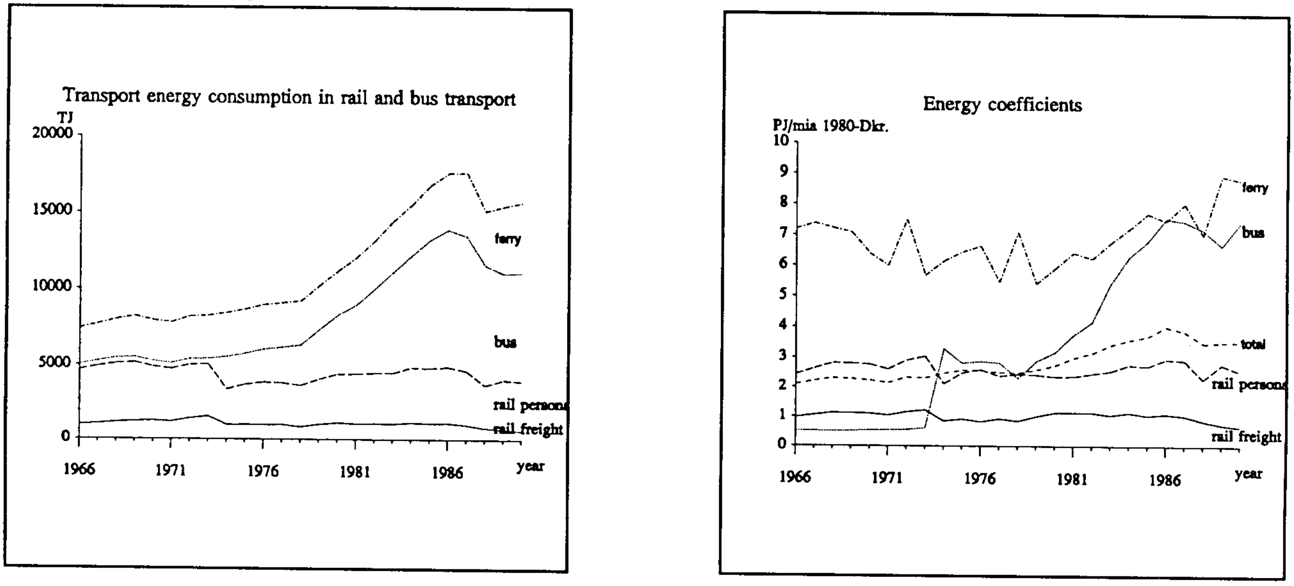

Figure 2.2.2 The transport energy consumption and -coefficient for the rail and bus transport

only a slight increase in the production this implies, that is the energy coefficient has increased more than tenfold. (The shift in 1974 is due to a change in the calculation of the data, however the increases in the late 1970s and 1980s are real changes).

Concluding on the development shown in table 2.2.2 and figure 2.2.2, for rail and ferries the energy coefficient is relatively constant. For busses in regular service the energy coefficient increased drastically in the 1980s, however, as the production by busses in regular service is heavily subsidized, production in 1980-prices is a poor indicator for the activity. In the 1980s subsidies increased considerably implying an increase in the activity level but a decrease in the production in 1980-prices. Looking at other indicators for an explanation of the increase in the energy consumed by busses, in the period 1980 to 1989 the energy consumption increased with 32 percent, kilometres driven increased with 16 percent and the person-kilometres increased with 27 percent. That is, the kilometres driven and the person-kilometres do not fully explain the increase in the energy consumption, and the decreases in 1988 and 1989 are not explained by similar changes in the physical transport. An explanation which is difficult to measure by the current data is, that the busses have become larger and more energy consuming per kilometre driven and that the capacity has increased faster than the person-kilometres.

Road freight, taxi etc.

This branch includes tourist coaches, taxies and road freight performed by Danish road haulage contractors. Road freight performed by other companies and the freight by foreign contractors in Denmark is not included. The production value therefore includes the freight of Danish contractors in foreign countries and not the freight of foreign contractors in Denmark. The energy consumption is calculated as fuels sold in Denmark, that is, implicit it is assumed that the refuelling of Danish contractors in foreign countries equals the refuelling of foreign contractors in Denmark.

Looking at table 2.2.3 road freight accounts for the major part (about 80 percent) of the production and energy consumption of the aggregated branch. Of the total transport energy consumption 29 PJ in 1990 about 3 PJ is used by tourist coaches, 2 PJ is used by taxies and about 24 PJ is used by road freight. In the period 1966 to 1990 the production of the branch (in 1980-prices) varied between 10 and 14 bill. Dkr.. This variation mirrors the development within the branches construction and trade and a considerable increase in deliveries to exports. (In the period 1966 to 1990 deliveries to exports increased more than sixfold and accounts for about 1/4 of the production in 1990). In this connection it should be noticed, that exports are deliveries of transport services to foreign companies. Export of Danish goods on Danish lorries is deliveries from the transport branches to the branch that exports the goods.

	Production in bill. 1980-Dkr.		Transport energy consumption in PJ		Energy coefficient	
	1966	1990	1966	1990	1966	1990
Tourist coaches	0.5	0.9	1.2	3.4	2.33	3.62
Taxi	1.5	1.2	2.6	2.2	1.69	1.87
Road freight	9.7	11.4	8.3	23.8	0.86	2.09
Total	11.7	13.5	12.0	29.4	1.03	2.17

Table 2.2.3 Production and transport energy consumption of the branch road freight, taxi etc.

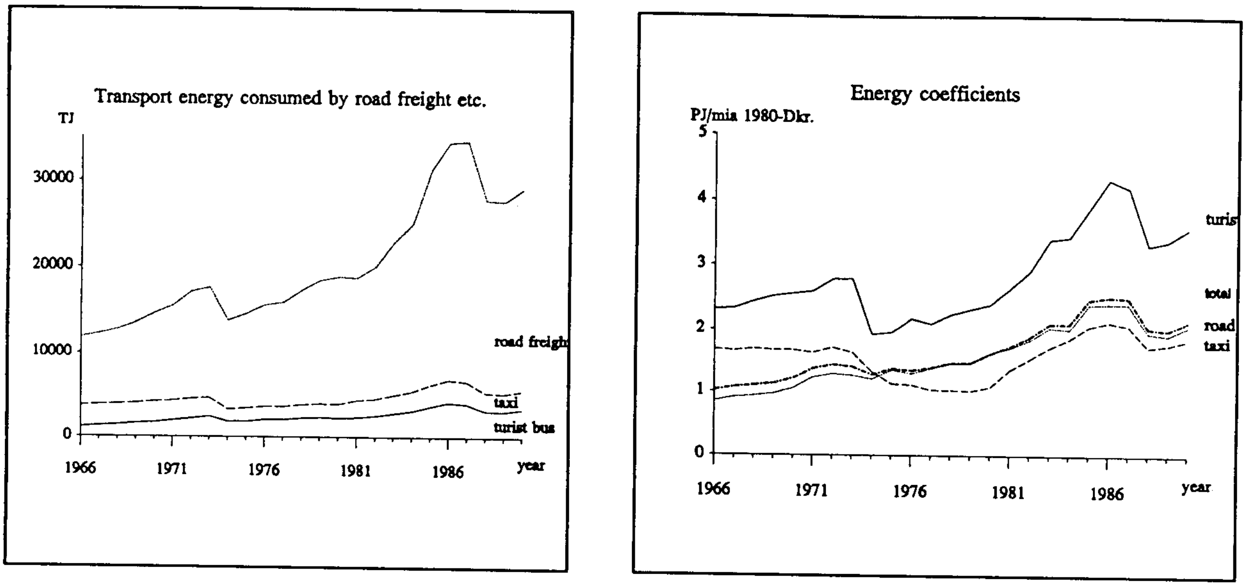

Figure 2.2.3 The transport energy consumption and -coefficient for road freight, taxi and tourist coaches

Looking at figure 2.2.3 it is noticed, that the transport energy consumption and -coefficient is more than doubled in the period, especially the consumption increased in the period 1975 to 1987. (The drop in the energy coefficient in 1974 is a break in the series.) The energy consumption and -coefficients have increased especially for tourist coaches and road freight. This mirrors some increase in the production, but mainly a substitution to larger and heavier coaches and lorries and a reduction of the capacity utilization rate of the lorries. Since 1980 the ton-kilometres have increased about 30 percent, the transport capacity has increased about 50 percent, and the capacity utilization rate has decreased from about 75 percent to about 60 percent. The substitution to larger and heavier coaches and lorries is mainly driven by labour savings and increases in tourism and long distance export freight.

Air transport

This branch includes Danish airlines and airports only. Transport performed by foreign airlines in Denmark are not included. Exports from the branch include foreigners purchase of trips with Danish airlines and the purchase of services by foreign airlines from Danish airports. This export has doubled since 1966 and accounts for about 1/3 of the production of the branch. The purchase of trips abroad by Danes is deliveries to households or other branches.

The energy consumption is calculated as fuels sold in Denmark, whether it is sold to Danish or foreign airlines, that is, implicitly it is assumed, that the refuelling of Danish airlines abroad equals the refuelling of foreign airlines in Denmark. Looking at the figures in table 2.2.4 it is noticed, that the transport of passengers is the dominating activity, and of this trips abroad are the main activity. The energy consumption for domestic flights is about 1 PJ and as such negligible in relation to the total energy consumption of the branch.

The energy consumption modelled in this chapter is the total amount of fuels sold in Denmark, however according to international environmental conventions only part of the emissions coming from this energy consumption is the responsibility of Denmark. According to ECE Denmark is responsible for emissions coming from landing and take-off of flights whether these are domestic or international. For reporting to IPCC emissions have to be calculated for domestic and international flights respectively. Specific guidelines on how to calculate the relevant emissions are presently being developed. The models described in part II of this report calculate emissions from fuels sold in Denmark. At a later stage when the guidelines are approved the models will be extended with categories required for reporting to the different international organisations.

Looking at the development it is seen, that production has tripled, the energy consumption has increased less than threefold, and the

	Production in bill. 1980-Dkr.		Transport energy consumption in PJ		Energy coefficient	
	1966	1990	1966	1990	1966	1990
Air transport freight	0.2	0.3	2.3	2.9	10.26	11.71
Air transport passengers	1.5	5.2	8.5	22.5	5.52	4.30
Airports	0.2	0.6	0.01	0.07	0.08	0.11
Total	1.9	6.1	10.9	25.5	5.65	4.20

Table 2.2.4 Production and transport energy consumption of the air transport.

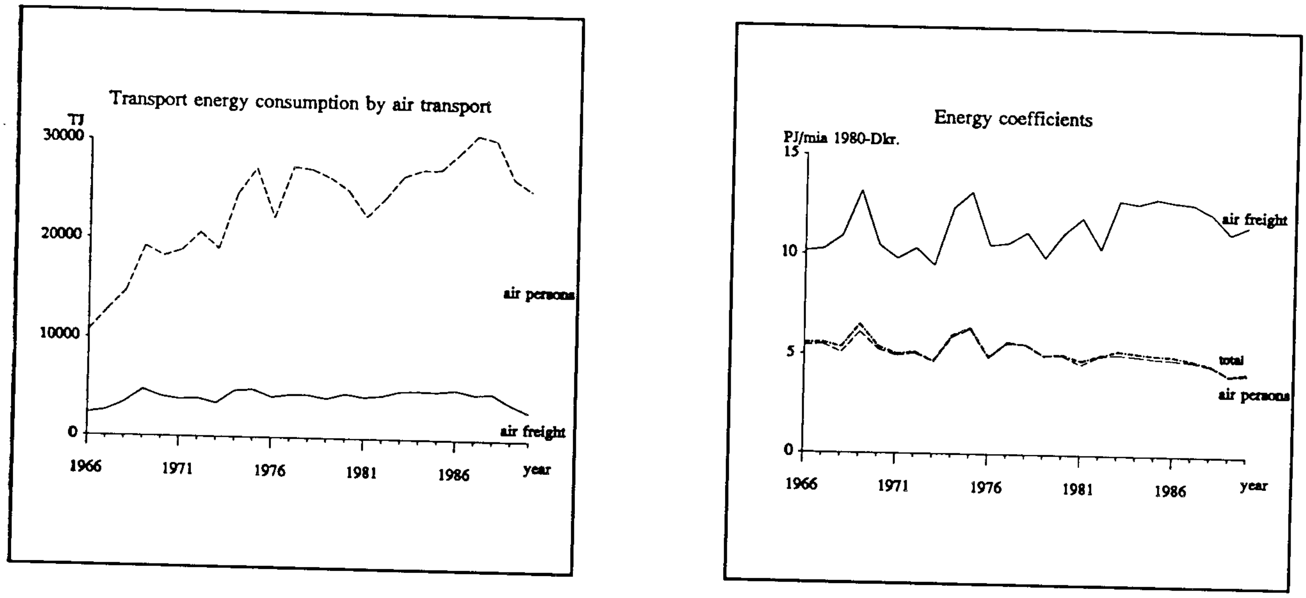

Figure 2.2.4 The transport energy consumption and -coefficient for air transport

energy coefficient has decreased about 25 percent over the period. These changes have taken place mainly within the passenger transport. The production within passenger traffic has increased more than threefold, while the freight have been more or less constant. Looking at the development in deliveries to different uses, over the period 1966 to 1980 deliveries to the other branches increased more than fivefold and have since varied around a level of 120 mill. Dkr. in 1980-prices. Deliveries to households have, except for a few years around the energy crises, shown a continuous increase and have increased about fivefold since 1966. On average this equals an annual increase of 7 percent. Deliveries to exports account for about 30 percent of production and have increased only twofold.

Mail and tele-communication

As is seen from the table 2.2.5 the transport energy consumption and -coefficient is quite small. Since 1966 the production and transport energy consumption has increased threefold with an almost constant energy coefficient. The branch delivers mainly to households and other branches, and the increase is evenly distributed among the different deliveries. Over the period considerable changes have occurred within telecommunication, however concerning the structure of deliveries and the transport energy coefficient the changes have been of minor importance.

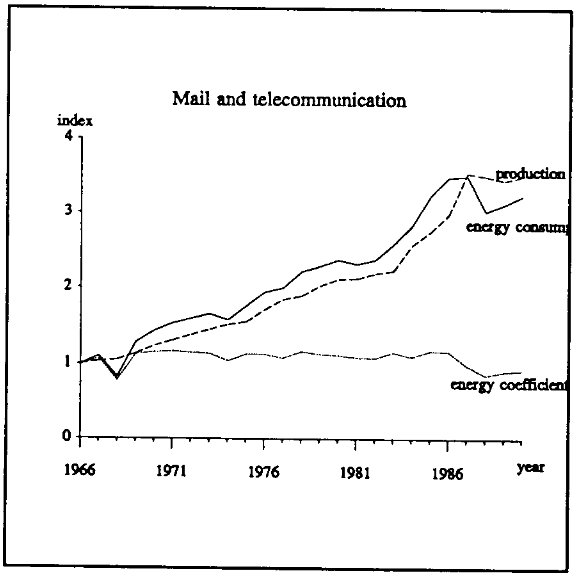

Table 2.2.5 Production and transport energy consumption of the branch mail and telecommunication.

Year	Production in bill. 1980-Dkr.	Transport energy PJ	Energy coeff.
1966	3.1	0,5	0,15
1990	10.7	1,5	0,14

Sea transport

In economic terms this branch includes the economic activities of Danish shipping companies whether the activity is in Denmark or abroad. A substantial part of the activity is shipping at foreign destinations, which rarely bunker in Denmark. (About 90 percent of the production in this branch is delivered to exports.) The energy consumption is calculated as domestic bunkering plus a part of the international bunkering in Denmark that is estimated to be bunkered by Danish ships in international trade. The bunkering of Danish ships in foreign harbours is not included. That is, the energy consumption given in table 2.2.6 does not express the energy consumed by the economic activity included in the production given. Excluding the deliveries to exports and setting the energy consumption in relation to the deliveries for domestic uses the energy coefficient is 4.3 in 1966 and 2.1 in 1990. These coefficients are somewhat too high, as they include part of the international bunkering on Danish ships but not the corresponding export income, however they appear more reasonable than the coefficients given in table 2.2.6.

Looking at the development, whether one looks at the energy coefficient in relation to the total production or in relation to the domestic deliveries only, the coefficient has been about halved in the period. The major part of this decline took place just after the second energy price increase, where in general the speed of the vessels were decreased. The size of this effect is difficult to reveal as the decrease was accompanied by a considerable increase in the production/domestic deliveries from the branch. In general the energy data fluctuates without a corresponding fluctuation in the production or domestic deliveries of the branch, that is the energy coefficient fluctuates more or less random.

Concerning the calculations of implicit deliveries of transport energy given in table 2.2.1 it should be noticed, that the deliveries are somewhat fictive. The figures are a distribution of the transport energy consumption bunkered by Danish ships in Denmark using the energy coefficient related to the total production. The bunkering of Danish ships abroad is not included, that is the figures under-estimate the energy consumption.

	Production in bill. 1980-Dkr.		Transport energy consumption in PJ*		Energy coefficient	
	1966	1990	1966	1990	1966	1990
Sea transport freight	8.1	21.7	2.0	1.2	0.25	0.06
Sea transport persons	1.0	2.4	1.2	0.8	1.20	0.33
Total	9.1	24.1	3.2	2.0	0.35	0.08

Table 2.2.6 Production and transport energy consumption for sea transport.

* In addition fuel oil is used for transport purposes: 1.4 PJ in 1966 and 3.9 PJ in 1990.

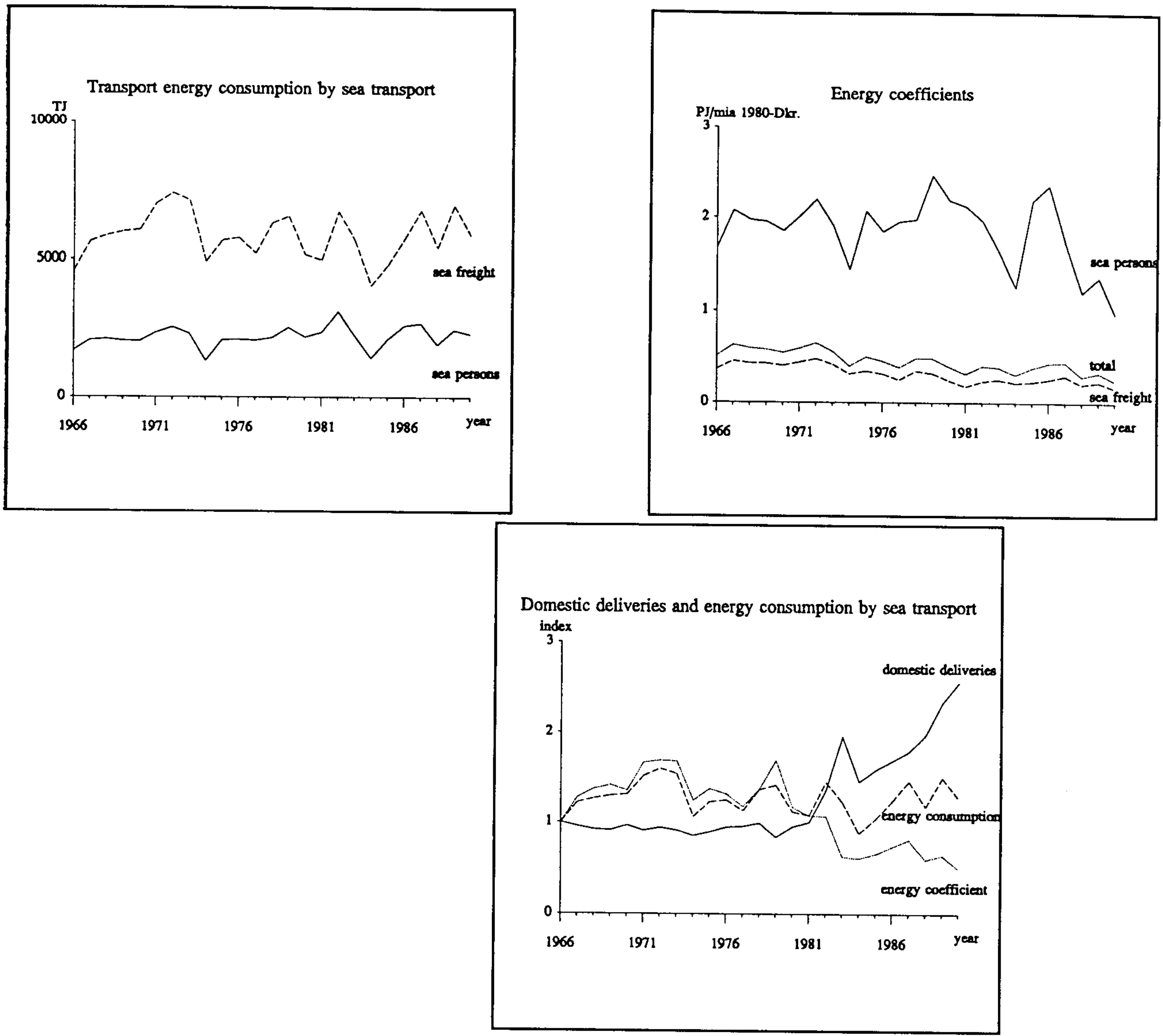

Figure 2.2.6 The transport energy consumption (incl. fuel oil) and -coefficient for sea transport

Services related to the transport branches

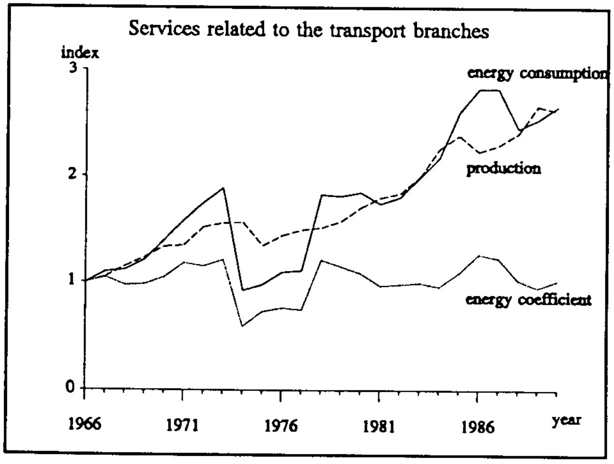

Table 2.2.7 Production and transport energy consumption by services related to the transport branches

Year	Production in bill. 1980-Dkr.	Transport energy PJ	Energy coeff.
1966	4.6	0.5	0.10
1990	12.0	1.2	0.10

In ADAM this branch is included in the transport branch, however it is a services branch that delivers mainly to the transport branches. In economic respect the branch is a considerable part of the transport branch in ADAM, however with respect to the energy consumption the branch is negligible with an energy coefficient of about 0.1.

I.2.2.3 The transport energy consumption of the ADAM branches

Of the 73 PJ transport energy consumed by the transport branches (given in table 2.2.1), about 29 PJ or 40 percent is implicitly delivered to the other branches. (The rest is deliveries to households and exports.) Seen in relation to the total transport energy consumption of the branches (the direct + implicit deliveries) the implicit deliveries are about 30 percent (excluding the agriculture about 40 percent), however as is seen from table 2.2.8, this share varies considerably between the branches.

The most transport consuming branches are agriculture, manufacturing of food, construction, trade, other services and public services. Except for agriculture the transport intensive branches are also the branches that receive the largest deliveries from the transport branches. The large direct transport energy consumption in agriculture is mainly for off-roaders and fishing vessels (agriculture includes fishery). While the transport intensive branches have both a considerable own transport and are major purchasers of transport services, for the less transport intensive branches transport delivered from the transport branches is in general larger than the own transport. That is, the transport intensive branches have a considerable transport capacity of road freight within the branch and supplement this with purchases from the transport branches. The less transport intensive branches mainly purchase transport from the transport branches.

Looking at the different transport branches, rail transport is mainly delivered to the public sector, trade and other services. Road freight is mainly delivered to trade and construction, while air transport is more evenly distributed although the largest part is delivered to the services branches. The large deliveries of air transport to the energy producing branch is mainly transport to the oil fields in the North Sea.

In order to indicate whether the separate modelling of the own transport (part of the energy consumption of the branches) and the purchase of transport services (part of the material input) is a serious practical problem, the development of the share of transport energy delivered by the transport branches is shown in table 2.2.9. The development of the shares gives only an indication of problems and is not a conclusive test, however if the share is constant or trendwise changing the separate modelling is a limited problem in practical modelling, assuming that the trends are modelled correctly in the modelling of the energy consumption and the demand for transport services. Significantly fluctuating shares indicate, that a separate modelling is a serious practical problem, and that ideally the transport should be modelled jointly.

ADAM branches	Direct transport energy consumption TJ	Implicit deliveries of transport energy in TJ from						
		Total	Rail	Freight	Air	Mail	Sea transp	Service
Agriculture	23833.4	449.1	6.7	323.3	74.2	19.1	0.3	25.4
Energy production	1.0	195.7	0.5	3.3	164.5	1.5	25.5	0.4
Petroleum refineries	4.0	19.3	6.5	9.8	2.1	0.5	0.4	0.0
Energy suppliers	148.4	150.2	5.1	73.7	56.2	14.5	0.2	0.5
Manuf. of food	3638.4	1621.5	484.0	923.1	147.9	26.7	9.2	30.6
Bev. and tobacco	218.5	824.2	289.2	488.8	34.2	8.7	1.6	1.7
Building materials	593.3	743.2	83.5	591.7	46.7	11.8	2.2	7.2
Iron and steel	1025.1	1481.1	212.9	723.4	443.9	57.9	6.6	36.4
Transp. equipment	40.2	117.1	11.0	53.6	35.5	8.3	0.5	8.2
Chemical industry	413.0	1081.6	240.2	504.1	271.4	31.7	7.6	26.6
Other industries	669.8	2045.4	127.0	1429.8	413.0	43.6	2.2	29.7
Construction	9594.6	3823.2	134.5	3155.4	429.2	62.6	22.5	19.1
Trade	14897.0	8645.5	730.3	6827.4	817.2	79.9	6.3	184.4
Financial service	70.0	750.4	33.9	215.8	376.4	119.3	1.6	3.5
Other services	4148.9	2220.4	579.6	617.2	800.4	205.3	3.5	14.3
Dwellings	0.0	48.4	2.3	14.3	25.0	6.4	0.1	0.2
Public service	2538.2	4538.1	1490.3	1807.2	925.7	248.8	11.2	55.0
Total	61833.9	28754.5	4437.5	17762.0	5063.6	946.6	101.7	443.1

Table 2.2.8 The transport energy consumption of the ADAM branches and the implicit deliveries from the transport branches in 1990.

Looking at the total in table 2.2.9, there is a general increase in the share of the transport energy delivered by the transport branches. For the separate modelling the trend is not a serious problem, however, at least at this very aggregated level, the data indicate, that there might be problems with generating data for a joint modelling. The increased share of transport energy delivered from the transport branches implies either

a) that the transport energy coefficient of the transport branches has increased more than the transport energy coefficient for own transport, or
b) that the share of own transport has decreased.

ADAM branches	The share of transport energy delivered from the transport branches[A]					
	1966	1970	1975	1980	1985	1990
Agriculture	0.02	0.01	0.01	0.02	0.02	0.02
Energy production	1.00	1.00	1.00	1.00	1.00	1.00
Petroleum refineries	0.97	0.87	0.65	0.86	0.87	0.83
Energy suppliers	0.48	0.48	0.61	0.58	0.55	0.50
Manuf. of food	0.47	0.38	0.35	0.36	0.34	0.31
Bev. and tobacco	0.40	0.36	0.79	0.75	0.76	0.79
Building materials	0.52	0.47	0.67	0.65	0.66	0.56
Iron and steel	0.36	0.39	0.57	0.60	0.65	0.59
Transp. equipment	0.31	0.31	0.70	0.75	0.76	0.74
Chemical industry	0.46	0.45	0.65	0.68	0.70	0.72
Other industries	0.44	0.46	0.74	0.76	0.80	0.75
Construction	0.30	0.25	0.22	0.20	0.33	0.28
Trade	0.28	0.39	0.35	0.35	0.39	0.38
Financial service	0.65	0.78	0.91	0.90	0.93	0.91
Other services	0.20	0.24	0.28	0.29	0.36	0.35
Dwellings	1.00	1.00	1.00	1.00	1.00	1.00
Public service	0.25	0.27	0.42	0.63	0.40	0.64
Total	0.21	0.23	0.26	0.31	0.34	0.32

Table 2.2.9 The share of transport energy delivered by the transport branches.
[A] Calculated as: (implicit deliveries)/(direct + implicit deliveries) in PJ.

For the construction of data for a joint modelling it is normally assumed, that the transport energy coefficient for purchased - and own transport develop equally, which at this aggregated level conflicts with point a). Combining a decrease in the share of own transport with a decrease in the input/output coefficients for deliveries from the transport branches implies, that total transport should have been a decreasing share of production. This conflicts with the impression, that transport has increased more than economic activity in general.

Looking at the individual branches, due to a change in the calculation of the transport energy consumption in 1974, for some of the branches there are a shift in the share from 1970 to 1975, that is, analyzing the development the shift is a data problem and not a behavioral change. Looking at the shares before and after 1974 for most of the branches the share is relatively constant or trendwise changing. However for the branches construction and public services there are significant changes in the share. Concluding, the analyses indicate, that for most branches the separate modelling is more a theoretical than a practical problem, however at least for the branch construction a separate modelling is a problem. It should however be kept in mind, that this analysis gives only an indication and is not a conclusive test. Due to data problems and the present construction of ADAM, the present modelling will continue assuming separability between the own transport and the purchase of transport from the transport branches, although this is problematic.

I.2.2.4 The transport energy consumption of the households and the deliveries from the transport branches to households and export.

For completeness this section gives a short description of the purchase of transport energy and transport services by households and the export of transport services. For households the purchase of transport energy and collective transport is modelled in section I.4.

Looking at table 2.2.10 it should be kept in mind, that the implicit deliveries of transport energy is calculated assuming a uniform energy coefficient for all deliveries from the transport branches and, that the electricity used by electrified trains is not included. This mainly implies, that deliveries from rail to households are somewhat underestimated. Looking at the figures it is noticed, that the implicit deliveries are only about 1/3 for the direct transport energy consumption of the households, and looking at the delivering branches deliveries to households come mainly from rail (incl. busses in regular service) and air transport. Freight is of minor importance. Looking at the development figure 2.2.8 shows, that the direct transport energy consumption of households nearly doubled in the period 1966 to 1978. Following the energy price increase consumption decreased about 25 percent till 1983 and has been increasing since. The deliveries in 1980-prices

		transport energy PJ	implicit deliveries of transport energy in PJ from						
			total	rail	freight	air	mail	sea transp.	service
Households	1970	44.8	10.0	3.9	2.2	3.5	0.2	0.2	0.0
	1980	54.3	14.5	5.6	3.1	5.3	0.4	0.1	0.1
	1990	57.2	17.4	6.5	3.5	6.7	0.5	0.1	0.1
Export	1970		13.7	0.0	1.3	8.1	0.0	4.1	0.1
	1980		13.4	0.1	3.7	7.5	0.0	2.2	0.1
	1990		17.2	0.2	7.3	7.9	0.0	1.7	0.1

Table 2.2.10 The transport energy consumption of households and the implicit deliveries from the transport branches to households and export

have increased gradually over the entire period, however the decreasing direct energy consumption from 1978 to 1983 was not accompanied by a similar increase in the demand for collective transport, that is the decrease was mainly a decrease in the private transport and only a minor substitution to collective transport. The increase in the implicit deliveries of transport energy is mainly an increase in the transport energy coefficient. Looking at deliveries from the individual transport branches figure 2.2.9 shows, that in constant prises the deliveries have increased mainly from air transport. For the branches rail and freight the implicit deliveries of transport energy have increased mainly due to increases in the energy coefficients.

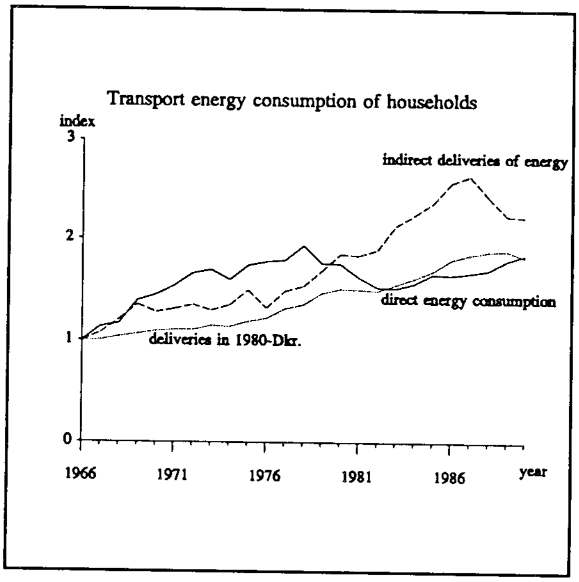

Figure 2.2.8 The transport energy consumption of households

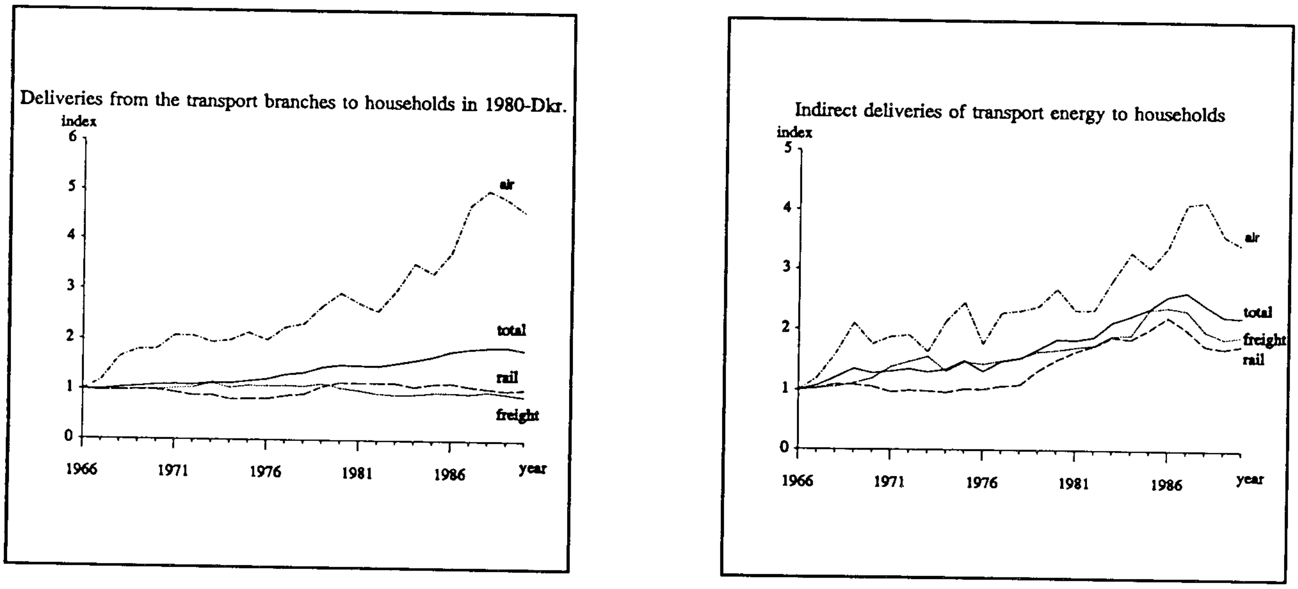

Figure 2.2.9 Deliveries from the transport branches to households

Looking at exports deliveries come mainly from freight, air- and sea transport. In 1980-prices deliveries from sea transport are by far the largest part of the deliveries from the transport branches.

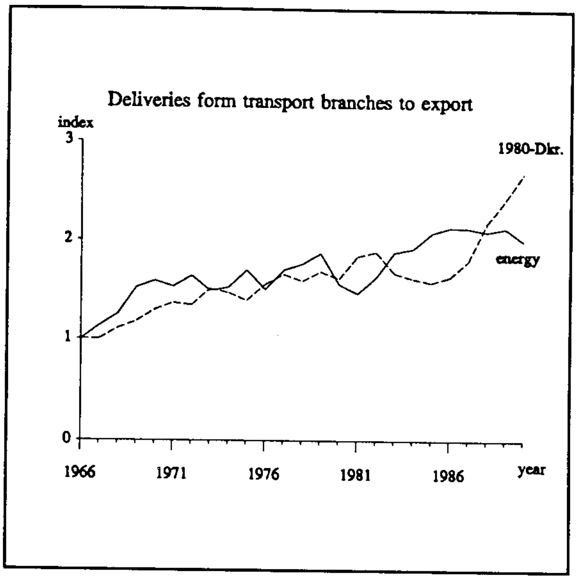

Figure 2.2.10 The implicit deliveries of transport energy to exports

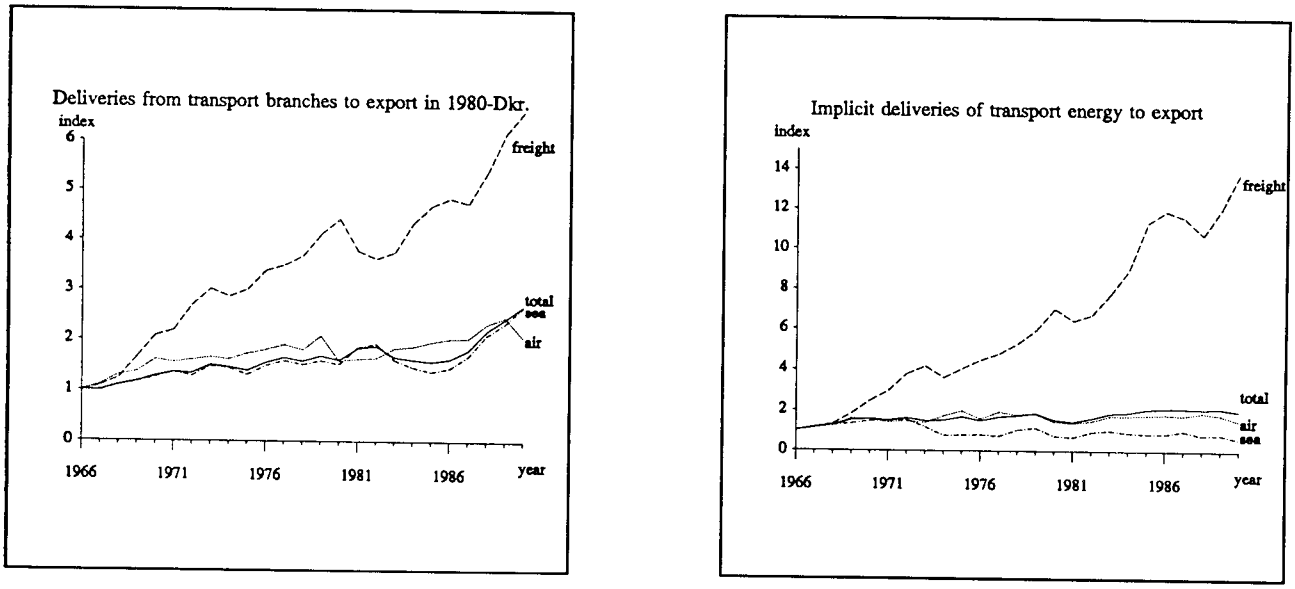

Figure 2.2.11 Deliveries from the transport branches to exports

Concerning energy consumption for sea transport it should be noticed, that the major part "bunkering of Danish ships abroad" is not included, that is, the development in deliveries and energy consumption of figure 2.2.10 are not directly comparable. Looking at deliveries from the individual transport branches it is noticed, that in 1980-prices the total follows the development of the sea transport, and that deliveries from the branch freight have increased more than sixfold. However in 1990 freight is only about 10 percent of total deliveries from the transport branches. Looking at the implicit deliveries of transport energy, keeping in mind that only part of the energy consumption for sea transport is included, in 1990 freight and air transport delivers almost equal amounts of transport energy, however, while deliveries from freight have increased more that tenfold, since 1970 deliveries from air transport have fluctuated between 7 PJ and 10 PJ.

I.2.3 An input/output model for deliveries from the transport branches

Production in the disaggregated transport branches is determined assuming constant input-output coefficients, that is deliveries from a given transport branch to other branches or categories of final demand are a constant share of the output of the receiving branch or category of final demand. Adding deliveries to the different uses production in a given transport branches is determined by:

eq. 2.3.1
$$Q_i = \sum_j a_{i,j} \cdot Q_j + \sum_k a_{i,k} \cdot C_k$$

where	Q_i	is production in the transport branch i
	Q_j	is production in branch j
	C_k	is final demand for category k
	$a_{i,j}$	is input-output coefficients for deliveries from branch i to branch j
and	$a_{i,k}$	is i-o coefficients for deliveries from branch i to final demand for category k

The input-output coefficients in eq. 2.3.1 are a disaggregation of the input-output coefficients for the aggregated transport branch in ADAM. This implies that the sum of the productions determined by eq. 2.3.1 add up to the production in the ADAM branch 'other transport'. That is this satellite model may be run separately from but conditioned on an ADAM calculation. It should however be noticed, that $\Sigma_j a_{i,j} Q_j$ include the transport branches and therefore that eq. 2.3.1 describes a simultaneous block of equations.

The input-output coefficients are fixed to the 1990 coefficients and are shown in table 2.3.1.

Deliveries to ADAM branches and final consumption	from transport branches												
	Rail transport	Bus transport	Ferries	Rail and bus total	Tourist coaches	Taxi	Road freight	Road transp. total	Air transport	Mail and telecomm.	Services rel. transport	Total, other transport	Sea transport
Agriculture	0.0010	-	0.0029	0.0039	0.0052	0.0095	0.2926	0.3072	0.0364	0.2807	0.5178	1.1460	0.0081
Energy production	0.0011	-	0.0000	0.0011	0.0013	0.0025	0.0078	0.0116	0.2983	0.0806	0.0276	0.4193	2.3965
Petroleum refin.	0.0144	-	0.0000	0.0144	0.0006	0.0010	0.0341	0.0357	0.0040	0.0306	0.0015	0.0862	0.0399
Energy suppliers	0.0058	-	0.0037	0.0095	0.0121	0.0222	0.1923	0.2265	0.0893	0.6875	0.0339	1.0466	0.0199
Manuf. of food	0.1781	-	0.0201	0.1982	0.0051	0.0094	0.6060	0.6206	0.0514	0.2779	0.4404	1.5885	0.1658
Brew. and tobacco	1.4717	-	0.0602	1.5319	0.0218	0.0400	4.1908	4.2526	0.1538	1.1711	0.3143	7.4237	0.3787
Building material	0.1475	-	0.0284	0.1759	0.0117	0.0216	2.0133	2.0466	0.0836	0.6309	0.5310	3.4680	0.2071
Iron and steel	0.0827	-	0.0206	0.1033	0.0130	0.0240	0.5394	0.5764	0.1829	0.7138	0.6214	2.1978	0.1407
Transp. equipment	0.0232	-	0.0098	0.0330	0.0113	0.0207	0.2319	0.2639	0.0903	0.6306	0.8688	1.8866	0.0600
Chemical industry	0.2407	-	0.0150	0.2557	0.0157	0.0289	0.8366	0.8812	0.2453	0.8568	0.9969	3.2359	0.3547
Other industries	0.0844	-	0.0152	0.0996	0.0157	0.0290	1.7976	1.8423	0.2751	0.8683	0.8211	3.9064	0.0756
Construction	0.0066	-	0.0646	0.0712	-	-	2.7442	2.7442	0.1930	0.8418	0.3557	4.2059	0.5226
Trade	0.1379	-	0.1417	0.2796	0.0144	0.0265	4.2517	4.2927	0.2656	0.7768	2.4851	8.0999	0.1065
Rail transport	12.1632	-	-	12.1632	0.0009	0.0022	0.0235	0.0265	0.0810	0.6481	0.0294	12.9482	0.0290
Bus transport	-	7.6280	-	7.6280	0.0158	-	0.0011	0.0169	0.1204	0.9633	0.0437	8.7723	0.0431
Ferries	-	-	0.0031	0.0031	0.0011	-	0.8212	0.8223	0.2482	1.9854	0.0901	3.1491	0.0888
Rail and bus, total	7.6270	2.0560	0.0004	9.6834	0.0046	0.0013	0.1234	0.1292	0.1165	0.8976	0.0443	10.8710	0.0260
Tourist coaches	0.7564	0.2911	0.1862	1.2337	0.0392	-	-	0.0392	0.0360	0.2884	0.0235	1.6208	3.6025
Taxi	0.5897	0.2516	0.6764	1.5177	-	0.0561	-	0.0561	0.0165	0.1322	0.0061	1.7286	0.0079
Road freight	0.0342	0.0962	0.0788	0.2092	-	-	0.0185	0.0185	0.0193	0.1546	0.0145	0.4161	2.2735
Road transp., total	0.1724	0.1597	0.1801	0.5122	0.0026	0.0049	0.0153	0.0228	0.0206	0.1586	0.0128	0.7270	1.9139
Air transport	0.0090	-	0.0114	0.0204	0.0248	0.0455	0.1432	0.2135	17.6468	1.4827	1.9141	21.2774	0.0429
Mail and telecomm.	0.5235	0.0822	0.0719	0.6777	0.0165	0.0303	0.0954	0.1422	0.8039	0.9880	0.2721	2.8839	0.0290
Services rel transp.	0.5996	-	0.2684	0.8680	0.0123	0.0917	2.6550	2.7591	1.0583	0.6787	42.6947	48.0587	0.3829
Sea transport	0.0005	-	0.0007	0.0012	0.0015	0.0028	0.0766	0.0810	0.4610	0.0842	0.5153	1.1427	2.4996
Financial service	0.0189	-	0.0264	0.0453	0.0550	0.1011	0.3177	0.4738	0.4273	4.0527	0.1624	5.1615	0.0952
Other services	0.1453	-	0.0537	0.1990	0.0303	0.0558	0.2620	0.3481	0.2333	1.7907	0.1727	2.7438	0.0535
Dwellings	0.0002	-	0.0013	0.0015	0.0018	0.0032	0.0102	0.0152	0.0137	0.1057	0.0052	0.1414	0.0031
Public service	0.1453	0.1458	0.0501	0.3412	0.1601	0.2534	0.2660	0.6795	0.1799	1.4468	0.4428	3.0902	0.1122
Purchased transport	16.1636	10.7713	2.3237	29.2586	10.4403	11.6009	4.0646	26.1058	25.5644	-	3.7264	84.6552	9.5490
Communication	-	-	-	-	-	-	-	-	-	84.9026	-	84.9026	-
Consump. of service	-	-		-		-	-	-	-	0.2829	2.0589	2.3418	-
Export	-	-	0.0311	0.0311	-	-	1.7211	1.7211	0.9591		0.6442	3.3556	10.9534

*Table 2.3.1 Input-output coefficients for deliveries from the transport branches to uses in ADAM branches and final consumption in 1990 (1980-prices*100)*

I.2.4 Equations for the energy consumption of the transport branches

I.2.4.1 The model

In line with the energy relations for the other branches of ADAM the relations for the disaggregated transport branches are specified as a logarithmic error-correction-model. The long run equilibrium relation is specified by the log-linear form

$$\textit{eq. } 2.4.1 \qquad \log\left(\frac{E}{Q}\right) = a + b \log\left(\frac{P^E}{P^N}\right) + \gamma T$$

where E is the direct energy consumption in TJ
Q is production in 1980-prices
P^E is the energy price index
P^N is the price index for non-energy inputs
and T is time

that is, the equation is homogenous of degree zero in prices, the long run output elasticity is one, the price-elasticity (b) is constant and there is an exponential trend in the energy coefficient.

Assuming constant returns to scale the functional form given in eq. 2.4.1 is equivalent to an energy demand function derived from a Cobb-Douglas production function in two factors: energy- and non-energy inputs. An implication of the Cobb-Douglas production function is, that the substitution elasticity between energy- and non-energy inputs is one and, that numerically the price-elasticity for energy inputs ($|b|$) equals the cost share for non-energy inputs. Equivalently the price-elasticity for non-energy inputs equals the cost share for energy inputs, that is ($1-|b|$). This implies a restriction on the price coefficient in the demand equation for non-energy inputs. Therefore, in order to interpret eq. 2.4.1 as coming from a Cobb-Douglas production function eq. 2.4.1 should be estimated simultaneously with the demand equation for non-energy inputs imposing the cross-equational restriction on the price-elasticities. In this paper we concentrate on the energy demand and estimate eq. 2.4.1 as a single equation. As will be seen from the estimation results, the price-elasticity for energy is relatively small and if interpreted as a Cobb-Douglas function this should imply a relatively large equilibrium cost share for energy inputs. Historically, even in the transport branches the cost shares for energy have been fairly moderate. In addition preliminary simultaneous estimations of energy- and non-energy demand equations show a significant different estimate of the price-coefficient b, and a significant larger standard error of regression. Therefore in this paper eq. 2.4.1 is to be interpreted as an ad hoc relation.

Changing the dependent variable of eq. 2.4.1 from the logarithm of the energy coefficient to the logarithm of the factor input ratio eq. 2.4.1 would represent a CES-production technology. Preliminary estimations of such a relation show, that statistically this specification is slightly inferior to the specification given in eq. 2.4.1, however the differences are minor, and the estimated price-elasticities are of the same order of magnitude as the ones estimated from eq. 2.4.1. Therefore in this paper the preferred specification for the long run equilibrium relation is eq. 2.4.1 interpreted as an ad hoc relation.

The adjustment to the long run equilibrium is specified by the error-correction-model, which describe the adjustment as a proportion of the change in the equilibrium value plus a proportion of the one year lagged difference between the equilibrium and the actual value, that is:

$$\textit{eq. 2.4.2} \qquad x_t - x_{t-1} = k_1 (x_t^* - x_{t-1}^*) + k_2 (x_{t-1}^* - x_{t-1})$$

$$\Updownarrow$$

$$\Delta x_t = k_1 \Delta x_t^* - k_2 (x_{t-1} - x_{t-1}^*)$$

where Δ is a difference operator
x_t is the observed value
x^*_t is the equilibrium value of x_t
and k_1, k_2 are adjustment parameters

Defining $x_t = \log(E_t/Q_t)$ and inserting eq. 2.4.1 in eq. 2.4.2 gives:

$$\textit{eq. 2.4.3} \quad \Delta \log\left(\frac{E_t}{Q_t}\right) = k_1 b \Delta \log\left(\frac{P_t^E}{P_t^N}\right) + k_1 \gamma - k_2 (\log\left(\frac{E_{t-1}}{Q_{t-1}}\right) - a - b \log\left(\frac{P_{t-1}^E}{P_{t-1}^N}\right) - \gamma T_{t-1})$$

Redefining the parameters the observable equation becomes:

$$\textit{eq. 2.4.4} \quad \Delta \log\left(\frac{E_t}{Q_t}\right) = a_0 + a_1 \Delta \log\left(\frac{P_t^E}{P_t^N}\right) - k (\log\left(\frac{E_{t-1}}{Q_{t-1}}\right) - b \log\left(\frac{P_{t-1}^E}{P_{t-1}^N}\right) - \gamma T_{t-1})$$

Allowing the output elasticity to differ from one in the short run and adding a dummy-variable to take account of data breaks the final equation becomes:

$$\textit{eq. 2.4.5} \quad \Delta \log\left(\frac{E_t}{Q_t}\right) = a_0 + a_1 \Delta \log\left(\frac{P_t^E}{P_t^N}\right) + a_2 \Delta \log Q_t + d \Delta \mathit{Dummy}$$

$$- k (\log\left(\frac{E_{t-1}}{Q_{t-1}}\right) - b \log\left(\frac{P_{t-1}^E}{P_{t-1}^N}\right) - \gamma T_{t-1} - d \mathit{Dummy}_{t-1})$$

In order to obtain a smooth adjustment the parameters should satisfy the restrictions: $0<k<1$, $-1<a_2<0$ and $|a_1|<|b|$. If $k = 0$ the equation reduces to a first difference equation and if $k = 1$ the equation is a level equation. If $a_2>0$ there is a first year overreaction in the adjustment to output changes, that is in the short run the energy consumption changes more than the level of output. In a number of cases this is quite plausible, for instance when an increase in the output level requires, that old less energy-efficient equipment is re-employed in the short run but replaced in the long run. Another example is increasing the speed in the short run and adjusting the capacity in the long run. If $|a_1|>|b|$ the first year reaction to changes in the energy price is larger than the long run reaction. This may be the case for instance if the energy budget is relatively fixed in the short run while adjustable in the long run, or the first year reaction is a change, that does not last in the long run.

I.2.4.2 Estimations

Equation 2.4.5 may be estimated in one step or by the Engle-Granger two-step procedure, where the first step is estimating the static long run eq. 2.4.1, and the second step is estimating the short run and adjustment parameters conditioned on the first step estimates. Asymptotic the two procedures give identical estimates, however in small sample it is not quite evident which procedure should be preferred. In small sample multicollinearity may cause serious problems in the one step procedure. In the two-step procedure, disregarding dynamics in the first step estimation may seriously bias the estimation of the long run parameters. For the estimations reported in this section both procedures have been tried.

The preferred estimations for the individual transport branches are given in table 2.4.1. Looking briefly at the results the coefficients vary significantly between the branches. The long run price elasticity varies between -0.06 and -0.50 and is on average -0.15, the first year price elasticity varies between -0.00 and -0.41 and is on average -0.10, the first year output elasticity is on average 0.79 and the trend is on average 0.02. In general the statistical properties of the equations are not very convincing and some of the estimates are dubious, however, given the quality of the data, the results are the best, we have been able to achieve. The rest of this section comments on the estimations and the problems encountered branch by branch and tries to evaluate, to what extent the estimated trends should be continued or modified in forecasts.

Rail transport: For this branch it is noticed, that the first year price elasticity is larger than the long run price elasticity. This is a fairly general result independent of the specification and whether the equation is estimated in one or two steps. The long run price elasticity is not significant when estimated in one step, however when estimated in two steps the coefficient is significant and of about the same size. The price elasticities mainly reflect the effects of the first oil price increase in 1974. Estimating on a moving 15 years sample period, the equation breaks down when the period before 1975 is excluded from the estimation (k becomes larger than one and b becomes zero). Including $\Delta\log Q_t$ in the equation, a_2 becomes significantly larger than zero, and this is independent of the specification. This indicates that adjustments to output changes will imply a first year overreaction.

Bus transport: For this branch the equation is estimated in two steps. When estimated in one step, the adjustment parameter k approaches zero, and b becomes very large. The coefficients of the first step estimation of the two step procedure are all significant and stable, when estimated on a moving 15 years sample period after 1969, that is the long term relation appears relatively stable. The short term coefficients are not stable, but reflect mainly the effects in the last part of the sample period. The very large trend reflects excluded explaining variables or equivalently, that the output value is a poor indicator for the activity of the branch. In Denmark bus transport is heavily subsidised. Over the period 1980 to 1990 subsidies increased from about 20 percent to over 50 percent of the output value of the branch, that is the output in constant prices decreased, but the activity increased. Including a variable like the person kilometres per output value as an explaining variable and estimating on a reduced sample gives a significant coefficient and reduces the trend to 0.5 percent p.a. (Data for person kilometres are available only for the period after 1970). Concluding, for forecasts the trend is expected to be significantly lower than 7 percent unless one expects a continued increase in the rate of subsidies to bus transport.

Ferries: For this branch the adjustment is very slow, the adjustment parameter k is little, the first year price elasticity is zero and the coefficient to $\Delta\log Q$ is close to -1.0 implying, that the first year reaction to output changes is little. The coefficients to the long term equation is not significant when estimated by the one step procedure, however estimating the coefficients by the two step procedure the first step estimates are significant. The price coefficient is stable when estimated on a moving 15 years sample and not significantly different from the estimate given by the one step procedure. The trend varies dependent on the sample and is about 0.5 percent p.a. when estimated by the two step procedure.

Tourist coaches: The estimations for this branch cause a number of problems. As is seen from figure 2.2.3, there is a considerable shift in the energy coefficient in 1974, and this shift partly represent a data break and partly a response to the first oil price hike. Introducing a freely estimated dummy for 1966-1973, what happens is, that the coefficient adjusts to the level after the price hike including lagged adjustments, and the coefficient becomes larger than the actual shift in 1973/74. At the same time the long term price coefficient is downward biased and becomes positive.

Without the dummy, the shift (including the data break) is explained by the price hike solely, and the long term price coefficient is upward biased and estimated to -0.25. Therefore, for the estimation reported in table 2.4.1, the coefficient to the dummy D6673 is a priori fixed to the actual shift in 1973/74. This implies, that the complete shift in 1974 is explained by the dummy, and therefor that the price coefficient is downward biased, however the bias is smaller than with a free estimation of the coefficient to the dummy. Dependent of the share of the shift that is ascribed to the data break, the long term price elasticity should lie between -0.08 and -0.25.

Looking at the estimates given in table 2.4.1, it is noticed, that the short term price coefficient (a_1) is larger than the long term price coefficient. Perhaps this may be ascribed to the coefficients being downward biased, however it can not be ruled out, that this describes a reality, where in the short term driving behaviour is changed, but the change does not last in the long term. In addition it is noticed, that the trend is fairly large. This partly reflects, that there has been an increase in the person kilometres per unit of production in 1980-prices. Including this ratio as an explaining variable reduces the coefficient to the trend to about half the size.

Taxi: The estimations for this branch are rather poor. As for "Tourist coaches" the dummy D6673 creates problems, and a free estimation of the coefficient to this dummy implies a coefficient, that is larger than the actual change in 1974. Therefore, in the estimation reported the coefficient to the dummy is a priori fixed to the actual change in 1974. Without the dummy included, the long term price coefficient is estimated to -0.25, that is, the long term price coefficient should lay between the coefficient reported in table 2.4.1 (-0.12) and -0.25. The short term price elasticity is estimated to be larger than the long term elasticity. As for "Tourist coaches" perhaps this is a reasonable description of driving behaviour, however the coefficients are biased, and statistically it can not be rejected that the two price coefficients are equal. In general the estimated coefficients are not stable when estimated on a 15 years moving sample. That is, the development of the energy consumption of this branch is difficult to explain, and the equation should be taken with some reservations, however, as the branch is little (accounts for less than 3 percent of the energy consumption of the transport branches) and the cars not very polluting, for the aggregated transport branch this is not very important.

Road freight: This branch is very important and accounts for about 25 percent of the total energy consumption of the transport branches. Looking at the estimation results it is noticed, that the first year price elasticity is larger than the long term elasticity, however the long term elasticity estimated in the first step of the two step procedure is neither significant nor stable. Estimating the equation in one step but setting b to different values between

$$\Delta \log\left(\frac{E_t}{Q_t}\right) = a_0 + a_1 \Delta \log\left(\frac{P_t^E}{P_t^N}\right) + a_2 \Delta \log Q_t + d \Delta Dummy - k \left(\log\left(\frac{E_{t-1}}{Q_{t-1}}\right) - b \log\left(\frac{P_{t-1}^E}{P_{t-1}^N}\right) - \gamma T_{t-1} - d\, Dummy_{t-1}\right)$$

Branch	a_0	a_1	a_2	k	b	γ	D6673	D8890	R^2_{adj}	s	DW	Procedure
Rail transport	-6.041 (9.035)	-0.1835 (0.076)	-	0.4798 (0.1985)	-0.1238 (0.1197)	+0.0102 (0.0091)	-	-0.1508 (0.085)	0.40	0.065	1.96	1 step
Bus transport	-55.153 (22.137)	-0.1002 (0.089)	-0.7324 (0.216)	0.3765 (0.151)	-0.2676 -	0.0782 -	-1.2568 -	-0.3410 -	0.93	0.083	1.75	2 step
Ferries	-3.238 (4.013)	-	-0.8994 (0.151)	0.1551 (0.200)	-0.1904 (0.209)	0.0150 (0.018)	-	-	0.75	0.068	2.84	1 step
Tourist coaches, d$_1^{6673}$ fixed a priori	-20.5265 (14.219)	-0.1356 (0.059)	-0.2086 (0.190)	0.2105 (0.145)	-0.0842 -	0.0534 -	0.3410 -	-0.3230 -	0.83	0.044	2.27	2 step
Taxi, d$_1^{6673}$ fixed a priori	-11.617 (5.247)	-0.2125 (0.133)	-0.8578 (0.269)	0.2511 (0.113)	-0.1242 -	0.0272 -	0.1849 -	-0.2745 -	0.45	0.084	1.44	2 step
Road freight	-38.097 (15.834)	-0.1669 (0.070)	-0.2267 (0.1789)	0.4730 (0.1964)	-0.0673 -	0.0445 -	-	-0.2954 -	0.57	0.051	1.79	2 step
Air transport	36.466 (8.137)	-	-	-	-0.0769 (0.054)	-0.0141 (0.0041)	-0.1879 (0.065)	-0.1172 (0.063)	0.62	0.068	2.11	static
Mail and telecomm.	3.141 (1.227)	-0.1530 (0.117)	-	0.5096 (0.199)	-0.2223 -	-	0.1191 -	-0.4130 -	0.38	0.089	1.87	2 step
Services rel. transport	1.388 (1.138)	-0.4060 (0.187)	-0.1618 (0.393)	0.2645 (0.214)	-0.4139 (0.410)	-	-	-	0.28	0.107	1.67	1 step
Sea transport	6.061 (0.034)	-	-	-	-0.1858 (0.096)	-	0.1725 (0.067)	-0.3281 (0.064)	0.80	0.089	2.20	static

Table 2.4.1 Estimation results for the individual transport branches
Standard error in brackets

-0.00 and -0.25 do not change the other estimates significantly, larger numerical values of b is compensated by slightly smaller estimates of γ and k. Statistically the first year coefficients are the important coefficients and a first difference equation might be satisfying.

The large trend is explained by three quite different developments, a shift towards larger and larger lorries, in the 1970s an increase in the kilometres driven per unit of output and in the 1980's a decrease in the capacity utilization rate, that is, for forecasts the trend should be decreased unless one expects a continued decrease in the capacity utilization rate.

Air transport: A reasonable estimate for this branch is very important as the branch experience a considerable growth and accounts for about 25 percent of the total energy consumption of the transport branches. Looking at the different specifications tested the following conclusions are fairly robust: The adjustment is almost instantaneous (estimating eq. 2.4.5 k becomes larger than 1.0 but not significantly larger and a_2 is not significantly different from zero), the price elasticity b is fairly little and there is a slightly negative trend. Estimating on a moving 15 years sample the coefficients given in table 2.4.1 are stable within two standard errors of the estimate.

Mail and telecommunication: For this branch estimating in one or two steps gives almost identical estimates, however the two step procedure gives slightly better statistical properties. The first step estimate of b is significant and surprisingly stable when estimated on a moving 15 years sample period (b varies between -0.16 and -0.28). Looking at the alternative estimates introducing a trend reduces the price coefficient and introducing the short term output variable implies a positive but not significant coefficient.

Services related to the transport branches: For this branch it is noticed, that the estimates are interpretable, but only the first year price coefficient is significant, and the standard error of regression is fairly large, that is, the equation has fairly poor statistical properties. From alternative specifications tested the general conclusion is, that the adjustment is slow and the price elasticity is estimated to be larger than for the other transport branches. Ignoring dynamics and estimating a static relation reduces the price elasticity, however the explanatory power of the static specification is quit low. A simple first difference specification gives a significant price coefficient of about the same size as the estimate given in table 2.4.1.

Sea transport: Keeping in mind that the energy consumption in this branch includes only the bunkering of Danish ships in Denmark, while the output includes the activity of Danish shipping companies all over the world, the estimation results for this branch are surprisingly good. Estimating the error-correction-model in one step indicate that adjustment is instantaneous (k is larger but not significantly larger than 1.0 and a_2 is approximately zero). Independent of the specification (static or dynamic, with or without a trend) b is about -0.2 and estimated on a moving 15 year sample period b is stable.

I.2.5 The share of fuels in the direct energy consumption of the transport branches

In order to be useful for calculations of emissions the direct energy consumption has to be divided into uses of different fuels. In general the energy consumption is divided into:

Solid fuels
District heating
Transport fuels
Natural gas
Electricity
and Other liquid fuels

and substitution between fuels is determined by an interfuel-substitution model presented in chapter I.3. For the transport branches transport fuels are by far the dominating fuel, and substitution to other fuels is limited. Therefore, for forecasting the share of fuels is assumed to be constant or exogenously determined. The share of fuels in the direct energy consumption in 1970, 1980 and 1990 is shown in table 2.5.1. Looking at this table, for rail transport electricity has become important and should be forecasted according to the plans for electrification of the rail roads. For the branches "mail and telecommunication" and "services related to transport" transport fuels are not dominating and substitution between the fuels has occurred. For these branches the substitution may be modelled using the model described in chapter I.3, however at present this has not been done. (The energy consumption of these branches is limited).

Branch	Year	Solid fuels	District heating	Other liquid	Transport fuels	Natural gas	Electricity
Rail transport	1970	0.059	0.005	0.040	0.834	0.000	0.063
	1980	0.000	0.007	0.029	0.856	0.000	0.108
	1990	0.000	0.008	0.013	0.804	0.001	0.174
Bus transport	1970	0.000	0.017	0.148	0.828	0.000	0.007
	1980	0.000	0.005	0.024	0.976	0.000	0.006
	1990	0.000	0.002	0.002	0.988	0.000	0.007
Ferries	1970	0.000	0.001	0.010	0.988	0.000	0.001
	1980	0.000	0.003	0.017	0.977	0.000	0.004
	1990	0.000	0.002	0.006	0.986	0.000	0.006
Tourist coaches	1970	0.000	0.001	0.027	0.971	0.000	0.001
	1980	0.000	0.001	0.069	0.928	0.000	0.002
	1990	0.000	0.001	0.009	0.987	0.000	0.003
Taxi	1970	0.000	0.001	0.085	0.913	0.000	0.001
	1980	0.000	0.003	0.278[1]	0.716	0.000	0.004
	1990	0.000	0.003	0.046	0.945	0.000	0.005
Road freight	1970	0.000	0.002	0.020	0.978	0.000	0.001
	1980	0.000	0.002	0.018	0.977	0.000	0.002
	1990	0.000	0.002	0.003	0.990	0.000	0.005
Air transport	1970	0.000	0.002	0.014	0.983	0.000	0.001
	1980	0.000	0.002	0.009	0.985	0.000	0.003
	1990	0.000	0.003	0.005	0.981	0.001	0.010
Mail and tele-comm.	1970	0.000	0.090	0.669	0.202	0.000	0.038
	1980	0.000	0.135	0.365	0.319	0.000	0.181
	1990	0.000	0.121	0.122	0.375	0.020	0.362
Services rel. transport	1970	0.000	0.071	0.515	0.385	0.000	0.030
	1980	0.000	0.105	0.305	0.450	0.000	0.141
	1990	0.000	0.097	0.105	0.492	0.016	0.290
Sea transport	1970	0.000	0.003	0.021	0.975	0.000	0.001
	1980	0.000	0.003	0.026	0.966	0.000	0.005
	1990	0.000	0.002	0.258[2]	0.734	0.000	0.005

Table 2.5.1 The share of fuels in the direct energy consumption of the transport branches

1: LPG used for transport

2: Gas oil used for transport

I.3 Interfuel substitution in ADAM branches

I.3.1 Introduction

In ADAM total demand for energy in each branch is determined in an estimated log-linear error correction equation. This relation determines the total energy coefficient of the branch by short run dynamics, the relative energy price and a trend. In the long run the elasticity of energy demand with respect to output is restricted to one. The demand for different fuels is not determined in ADAM. In environmental applications it is important to distinguish between different fuels.

This chapter presents econometric estimates of the substitution between three aggregate fuels (transport fuels, electricity and other fuels) for 13 ADAM branches. Two commonly used dynamic flexible forms are estimated; one which is especially useful if substitution effects are large and one which is especially useful if they are small. The theoretical foundation of the model is the neoclassical theory of production and is here stated in a KLEM framework. However the procedure used and the equations estimated are also theoretical valid for distributing the demand for total energy determined by the log-linear ad hoc equations in ADAM.

I.3.2 Theory

Weak separability in capital (K), labour (L), energy (E) and materials (M) implies that the production function for output Y

$$\textit{eq. } 3.2.1 \quad Y = y(K_1,K_2,\ldots,K_k, L_1,L_2,\ldots,L_l, E_1,E_2,\ldots,E_e, M_1,M_2,\ldots,M_m)$$

can be written as

$$\textit{eq. } 3.2.2 \quad Y = \tilde{y}(K(K_1,K_2,\ldots,K_k), L(L_1,L_2,\ldots,L_l), E(E_1,E_2,\ldots,E_e), M(M_1,M_2,\ldots,M_m))$$

where for example E is a function that aggregates all energy inputs $E_1,\ldots,E_e$ to one composite energy good.

According to standard neoclassical theory, producers minimize the costs of producing a given output.[1] Assuming the technology

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[1] Assuming constant returns to scale and abstracting from dynamics the supply curve is horizontal below capacity limit for given factor prices (i.e. in the short run) and the level of output in that sense determined by demand in the short run in macroeconometric models like ADAM.

eq. 3.2.1 and that the vector of factor prices, P, are not influenced by the producer, the cost function C(P,Y) can in general be written as

$$\textit{eq. } 3.2.3 \qquad C = f(P_{K_1},P_{K_2},\ldots,P_{K_k},P_{L_1},P_{L_2},\ldots,P_{L_l},\\ P_{E_1},P_{E_2},\ldots,P_{E_e},P_{M_1},P_{M_2},\ldots,P_{M_m},Y)$$

where subindex Z_i refers to factor *i* belonging to type Z = K,L,E,M. Under some mild regularity conditions, this cost function is a dual representation of the production function eq. 3.2.1, cf. Diewert (1974).

The dual representation of eq. 3.2.2 is

$$\textit{eq. } 3.2.4 \qquad C = \tilde{g}(P_K(P_K^*,Y), P_L(P_L^*,Y), P_E(P_E^*,Y), P_M(P_M^*,Y),Y)$$

where P_Z^* is an aggregated price index for the inputs belonging to category Z. These indices or sub cost functions depend on the level of production, but assuming further that all aggregator functions Z=K,L,E,M are homothetic, eq. 3.2.4 can be written as

$$\textit{eq. } 3.2.5 \qquad C = g(P_K(P_K^*), P_L(P_L^*), P_E(P_E^*), P_M(P_M^*),Y)$$

The interpretation of eq. 3.2.5 is a 2-stage optimization. First, the producer decides for each input category K,L,E,M the optimal mix of inputs per unit of output inside the group with reference to the prices of these inputs only, i.e. independent of the input prices of the three other groups and of the level of output. Second, the producer combines these four aggregates of inputs to obtain the output.

Under this assumption the energy unit cost function can be written as

$$\textit{eq. } 3.2.6 \qquad C_E = P_E(P_E^*) = P_E(P_{E_1},P_{E_2},\ldots,P_{E_e})$$

Using Shepards lemma, cf. Diewert (1971), the demand for energy input *i* per unit of output can be found by differentiating eq. 3.2.6 with respect to its price. Equivalently the share, S_i, of the expenditure on energy input *i* of total expenditures on energy, can be found by log-differentiating eq. 3.2.6:

$$\textit{eq. } 3.2.7 \qquad X_{E_i} = \frac{\partial C_E}{\partial P_{E_i}} \quad \Leftrightarrow \quad S_{E_i} = \frac{\partial \log C_E}{\partial \log P_{E_i}} \qquad \forall i=1,2,\ldots,e.$$

Under homothecity the total elasticity of demand for energy item *i* with respect to the price of energy input *j* is

$$\textit{eq. } 3.2.8 \qquad e_{ij}^T = e_{ij} + e_{EE}S_{E_j}$$

where e_{ij} is the partial fuel elasticity (for given use of the aggregated energy input) and e_{EE} is the own price elasticity of E (the aggregate energy input).

Finally, to be well behaved the cost function has to fulfil to properties of homogenity of degree zero in prices, adding-up, concavity in prices and Slutsky symmetry.

The assumption of homothetic separability is common in macroeconometric models, but somewhat problematic in the way it is implemented here. The assumption of homothecity is less problematic in the sense, that in order to assure reasonable long run properties in macroeconomic models, it is often necessary to impose constant returns to scale. If the model price index eq. 3.2.6 is not used at the KLEM-level (relying instead on for instance a national accounts Paasche index), adding up at this level does not strictly prevail, but this can be dealt with on an ad hoc basis (e.g. by defining suitable correction factors in the combined model). Then eq. 3.2.8 applies only approximately.

The main theoretical problem is the assumption of separability. From an energy point of view, it is a priori highly questionable, whether the different types of capital are separable from the different fuels. Different fuels are used with different capital goods. For example, in a given production process a producer might choose to use either an electric motor or a combustion engine. The demand for electricity and some liquid fuel then also depends on the price of electric motors and combustion engines. Thomsen (1994) estimated a dynamic Generalized Leontief KLEM production function and rejected that energy are separable from capital and labour.[2]

However, the available data do not allow specific modelling of such phenomena. All that can be done is to insert a trend in the cost share functions, and this will partly represent excluded explaining variables. The obvious short-coming is that excluded regressors need not be trended neither in sample nor in applications out of sample.

An even more obvious problem is that transport fuels (a subset of E) and the purchase of transport services (a subset of M) must be very close substitutes. Again data limitations and the consideration to keep ADAM manageable prevent imposing a more reasonable structure on the overall cost function.

Another consideration concerning transport fuels is, that in most cases the use of transport fuels fulfils a purpose (transportation) which is distinct from the purposes of other fuels (heating, processing). Therefore, a priori one should expect transport fuels to be separable from non-transport fuels, that is the marginal rate of

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[2] Thomsens investigation was carried out for an aggregate of the first 13 branches in table 3.5.1 in section I.3.5 below. In fact, Thomsen found capital and energy to be complementary in the long run in line with results from estimating dynamic Translog and nested CES functions, cf. Smidt and Hansen (1994).

substitution between any two non-transport fuels being independent of the level of transport fuels, cf. Green (1964).

In the rest of the chapter we shall concentrate on the energy cost function only (and therefore mostly disregard subindex E).

I.3.3. The static cost functions

The two applied cost functions are the Trancendental Logarithmic function (TL) of Christensen, Jorgenson and Lau (1973), cf. box 3.3.1, and the Generalized Leontief function (GL) of Diewert (1971), cf. box 3.3.2.

The TL cost function is a second order Taylor expansion around any arbitrary logarithmic twice differentiable cost function. It approximates the CES technology as a special case and further contains the Cobb Douglas technology as a special case, when all $b_{ij}=0$ for all $i \neq j$, implying constant cost shares, b_i.

The GL cost function is a second order approximation to any quadratic cost function containing only the quadratic terms. It contains the Leontief cost function as a special case when $g_{ij}=0$ for all $i \neq j$, implying constant intensities, g_{ij}.

For both cost functions the "off-diagonal" elements, b_{ij} and g_{ij}, $i \neq j$, take account of the cross price effects.

The theoretical restrictions of concavity and non-negativity of the cost shares can not be expressed as parameter restrictions which can be imposed at estimation, but must be checked afterwards.

A fundamental problem of flexible forms is whether they are well-behaved outside of the basic point, that is whether all the theoretical restrictions also apply outside of this point. The GL function is globally well-behaved if and only if all the parameters g_{ij} are positive, and the TL function is only globally well-behaved in the Cobb Douglas special case. Beside these special cases, the conclusion from the literature is broadly speaking, that if the price elasticities are numerically small the GL is well-behaved in a larger range than the TL, cf. Despotakis (1986). In practice it adds to the problems of global well-behavedness if some cost shares are small.

For the GL separability can only be imposed exactly for a given price vector and value of trend/dummy, and for the TL separability can only be imposed at the basic point.

The Allen partial elasticities of substitution, σ_{ij}, are calculated from the price elasticities, e_{ij}, using

$$eq.\ 3.3.1 \quad \sigma_{ij} = \frac{e_{ij}}{S_j}$$

The implications of separability are derived noting that

$$eq.\ 3.3.2 \quad \sigma_{ik} = \sigma_{jk} \quad \forall i,j \in E^a \quad \wedge \quad k \notin E^a$$

is a sufficient condition for factor *i* and *j* belonging to the group E^a to be separable from factor *k* not belonging to E^a, cf. Bremer (1992).

From the Allen elasticities of substitution expressed as

$$eq.\ 3.3.18 \quad \sigma_{ij} = C\frac{\partial^2 C}{\partial P_i \partial P_j} \ / \ (\frac{\partial C}{\partial P_i}\frac{\partial C}{\partial P_j})$$

it is seen that the elements h_{ij} of the Hessian matrix H of the cost function can be expressed as

$$eq.\ 3.3.19 \quad h_{ij} = \sigma_{ij}\frac{\partial C}{\partial P_i}\frac{\partial C}{\partial P_j}C^{-1}$$

A necessary and sufficient condition for concavity of C(P,Y) is negative semidefiniteness of H, cf. Sydsæter (1990), which as eq. 3.3.19 combined with eq. 3.2.7 shows is the same as negative semidefiniteness of the matrix of Allen elasticities of substitution. This can be checked by the identical condition that the eigenvalues of this matrix are all non-positive, cf. Sydsæter (1990).

For the present purpose, the parameters should be estimated in the budget share functions because they do not contain any measure of output. To elaborate this point consider first the aggregate energy bundle

$$eq.\ 3.3.20 \quad E^{\circ} = E(E_1, E_2,...,E_e)$$

defined by the energy sub production function of eq. 3.2.2. The energy inputs $E_1,...,E_e$ are measured by a common yard-stick, Tera Joules, cf. section I.3.5, which means that they can be added in physical terms to give the total amount of energy inputs measured in TJ.

$$eq.\ 3.3.21 \quad E^{TJ} = E_1 + E_2 +...+ E_e$$

The TJ equivalent of a given energy item is by definition equal to its maximum energy content, but the actual utilization rate is of course always less than 100 per cent. E° is clearly not equal to E^{TJ} but reflects some kind of "average utilization", and one can think of eq. 3.3.20 as mapping the process by which the potential maxi-

Box 3.3.1 The Translog (TL) cost function with trends

$$\text{eq. } 3.3.3 \quad \log C = a_0 + a_Y \log Y + \frac{1}{2} a_{YY} (\log Y)^2 + \sum_{i=1}^{n} b_i \log P_i + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} b_{ij} \log P_i \log P_j + a_T T + \frac{1}{2} a_{TT} T^2 + \sum_{i=1}^{n} b_{Yi} \log Y \log P_i + \sum_{i=1}^{n} b_{TY} T \log Y + \sum_{i=1}^{n} b_{Ti} T \log P_i$$

Share functions using Shepards lemma

$$\text{eq. } 3.3.4 \quad S_i = b_i + \sum_{j=1}^{n} b_{ij} \log P_j + b_{Yi} \log Y + b_{Ti} T \qquad i=1,\dots,n$$

Homothecity implies

$$\text{eq. } 3.3.5 \quad b_{Yi} = 0 \qquad i=1,\dots,n$$

Eq. 3.3.4 constrained by eq. 3.3.5 reduces to

$$\text{eq. } 3.3.6 \quad S_i = b_i + \sum_{j=1}^{n} b_{ij} \log P_j + b_{Ti} T \qquad i=1,\dots,n$$

The conditions of adding-up, homogenity of degree zero in prices and symmetry implies the parameter restrictions

$$\text{eq. } 3.3.7 \quad \sum_{i=1}^{n} b_i = 1, \quad \sum_{i=1}^{n} b_{Ti} = 0, \quad \sum_{i=1}^{n} b_{ij} = \sum_{j=1}^{n} b_{ji} = 0, \quad b_{ij} = b_{ji}$$

Cross price and own price elasticities

$$\text{eq. } 3.3.8 \quad e_{ij} = \frac{b_{ij} + S_i S_j}{S_i}, \; i \neq j; \quad e_{ii} = \frac{b_{ii} + S_i (S_i - 1)}{S_i}$$

Separability of factor 1 against factor 2,...,n

$$\text{eq. } 3.3.9 \quad b_{i1} = b_{j1} \frac{S_i}{S_j} \Rightarrow_{\text{basic point}} b_{i1} = b_{j1} \frac{b_i}{b_j} \qquad \forall i,j = 2,\dots,n$$

Variable definitions:

C	*Total costs*
Y	*Total output*
X_i	*Quantity of input i=1,...,n*
P_i	*Price of input i*
S_i	*Budget share of input i (= $(P_i X_i)/C$)*
SM_i	*Intensity of input i (= X_i/Y)*
T	*Time (or dummy)*

Lowercase roman and greek letters designates parameters and elasticities. Log designates natural logarithm.

Box 3.3.2 The Generalized Leontief (GL) cost function with trends in intensities

$$eq.\ 3.3.10 \qquad C = h(Y)\sum_{i=1}^{n}\sum_{j=1}^{n} g_{ij}P_i^{\frac{1}{2}}P_j^{\frac{1}{2}}\,, \qquad g_{ii} = g_{ii}^{x} + g_{Ti}T$$

where h(Y) is a continuous and monotonically increasing function.
Constant returns to scale (CRTS) implies

$$eq.\ 3.3.11 \qquad h(Y) = Y$$

Share functions using Shephards lemma:

$$eq.\ 3.3.12 \qquad S_i = \frac{\sum_{j=1}^{n} g_{ij}P_i^{\frac{1}{2}}P_j^{\frac{1}{2}}}{\sum_{k=1}^{n}\sum_{l=1}^{n} g_{kl}P_k^{\frac{1}{2}}P_l^{\frac{1}{2}}} \qquad i=1,\dots,n$$

Homothecity and homogenity of degree zero in prices are obtained by construction. Symmetry implies

$$eq.\ 3.3.13 \qquad g_{ij} = g_{ji}$$

A common, but arbitrary normalizing condition is

$$eq.\ 3.3.14 \qquad \sum_{i=1}^{n}\sum_{j=1}^{n} g_{ij}=1\,, \quad \sum_{i=1}^{n} g_{Ti}=0$$

Cross price and own price elasticities

$$eq.\ 3.3.15 \qquad e_{ij} = \frac{1}{2}\frac{g_{ij}P_j^{\frac{1}{2}}}{\sum_{j=1}^{n} g_{ij}P_j^{\frac{1}{2}}},\ i{\neq}j; \qquad e_{ii} = \frac{1}{2}\Bigg(\frac{g_{ii}P_i^{\frac{1}{2}}}{\sum_{j=1}^{n} g_{ij}P_j^{\frac{1}{2}}} - 1\Bigg)$$

Separability of factor 1 against factor 2,..,n

$$eq.\ 3.2.16 \qquad g_{i1} = g_{j1}\frac{\sum_{k\neq 1} g_{ik}P_k^{\frac{1}{2}}}{\sum_{l\neq 1} g_{jl}P_l^{\frac{1}{2}}} \quad \Rightarrow_{P_m=1} \quad g_{i1} = g_{j1}\frac{\sum_{k\neq 1} g_{ik}}{\sum_{l\neq 1} g_{jl}} \qquad \forall i,j=2,\dots,n$$

Intensity functions assuming CRTS

$$eq.\ 3.3.17 \qquad SM_i = \sum_{j=1}^{n} g_{ij}P_i^{-\frac{1}{2}}P_j^{\frac{1}{2}} \qquad i=1,\dots,n$$

mum energy contained in the input items is only partly utilized.[3] Therefore, E° is an unobserved entity as opposed to E^{TJ}. In most cases, we simply do not have a relevant measure of output.[4]

Trends represent either trended excluded explaining variables and/or "technical changes" in forms of steady shifts of the cost/production function. It is often relevant to assume that trends influence the intensities directly as it is done in box 3.3.2. In this formulation the trends are added to the own-price parameters in the model without trends, g_{ii}^x, cf. eq. 3.3.10.

$$eq.\ 3.3.22 \qquad g_{ii} = g_{ii}^{x} + g_{Ti}T$$

The trend parameters can either be interpreted as steady shifting the "diagonal" g_{ii} parameters of the production function or simple as representing the impacts of unknown trended variables added to the intensity function in this manner.

Generalizing the model to contain also a squared trend term, one gets

$$eq.\ 3.3.23 \qquad g_{ii} = g_{ii}^{x} + g_{1Ti}T + g_{2Ti}T^2, \qquad \sum_{i=1}^{n} g_{1Ti}=0, \sum_{i=1}^{n} g_{2Ti}=0, \Rightarrow$$

$$\frac{X_i}{Y} = g_{ii}^{x} + \sum_{j \neq i}^{n} g_{ij} P_i^{-\frac{1}{2}} P_j^{\frac{1}{2}} + g_{1Ti}T + g_{2Ti}T^2 \Rightarrow$$

$$\frac{\partial \frac{X_i}{Y}}{\partial T} = g_{1Ti} + 2g_{2Ti}T$$

---

[3] If E° were equal to E^{TJ} the production function were already known as eq. 3.3.21 and the cheapest way of obtaining E° would be to use only the energy input with the lowest absolute price per unit of TJ.

[4] If the actual utilization rate, α_i, for each energy input in a given process is known, E° can be identified from the production function

$$E^{\circ} = \sum_{i=1}^{e} \alpha_i E_i$$

The cheapest way of obtaining E° is to use only the energy input *j* with the lowest absolute price per unit of TJ divided by α_j - i.e. the cheapest input in efficiency terms. Estimates of α_j's exist for relevant energy inputs for many processes. For a given sector comprised of many different firms, the α_j's probably vary with the different production processes, so that the aggregate sector energy sub production function could still be quasi concave even though the individual process functions are linear. It follows, that when the sector is comprised of a few similar production processes, it is not relevant to estimate quasi concave sub energy production functions. Instead one should then work with the linear function. Danish examples are manufacturing of electric power and users of coal in some manufacturing branches, cf. section I.3.5.

The added square terms allow for the trend in the intensity to be increasing or decreasing depending on the signs of the trend coefficients.

In the TL function trends are "naturally" assumed to affect budget shares directly. From eq. 3.3.6

$$eq.\ 3.3.24 \quad \frac{\partial S_i}{\partial T} = b_{Ti}$$

which again is easily generalized to contain a squared trend term.

The restriction that the trend parameters sum to zero a priori rules out Hicks neutral technical changes, and the models can only describe biased technical changes. But this is precisely, what is needed in this context. In ADAM the estimated ad hoc energy demand equations contain negative trends, which - from an interfuel substitution point of view - can be interpreted as Hicks neutral technical change predetermined to the interfuel model, where only biased technical change (deviations from the neutral change) should then be estimated. As Hicks neutral technical changes leave the budget shares unaffected, these can not be estimated by budget share functions.[5]

In practice one might suspect that estimated significant trends represent both technical changes and unknown excluded variables in an unknown mix.

Finally, it should be noted that dummy variables might be entered analogous to trends (put "T" equal to the dummy in box 3.3.1 and 3.3.2).

I.3.4. Dynamics

A standard Error Correction Mechanism (ECM) for the budget shares can be written as

$$eq.\ 3.4.1 \quad S_{i,t} - S_{i,t-1} = k_1 (S^*_{i,t} - S^*_{i,t-1}) + k_2 (S^*_{i,t-1} - S_{i,t-1}) \quad i=1,..,n$$

where k_1 and k_2 are parameters. On an *ad hoc* basis the ECM specification describes how the short run shares, $S_{i,t}$, due to assumed adjustment costs gradually adapt to the static long run cost minimizing solution, $S_{i,t}^*$. Eq. 3.4.1 does not assure that costs are minimized in the short run. The demand that the fitted shares sum to unity both in the short and long term is satisfied by restricting k_1 and k_2 respectively to be identical for all shares.

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[5] Correspondingly a_T and a_{TT} in eq. 3.3.3 have disappeared from eq. 3.2.4.

Assuming that a long run equilibrium prevailed in all previous periods, it is seen that k_1 specifies the first period impact on actual shares of a change in the equilibrium shares, and as can be seen from eq. 3.4.3 below, k_2 is the adjustment speed of the coming periods.

The ECM contains several common dynamic specifications as special cases. For example, the partial adjustment model emerges as a special case for $k_1=k_2$. For $k_1=k_2=1$ the static model emerges as a special case. When imposed on budget share equations the generalisation from the partial adjustment model to the ECM model implies a significant gain as it distinguishes between the first year adjustment and following adjustments. In budget shares the first year change includes the initial price change while the following adjustments include only quantity changes.

The solution to eq. 3.4.1 can be found by writing it as

$$eq.\ 3.4.2 \qquad S_{i,t} = k_1 S^*_{i,t} - k_1 S^*_{i,t-1} + k_2 S^*_{i,t-1} + (1-k_2) S_{i,t-1}$$

By repeated substitution of $S_{i,t-1-v}$ the following solution to eq. 3.4.1 emerges

$$eq.\ 3.4.3 \qquad S_{i,t} = k_1 S^*_{i,t} + (1-k_1) k_2 \sum_{v=0}^{\infty} (1-k_2)^v S^*_{i,t-1-v}$$

A necessary condition for the existence of a stable solution to eq. 3.4.3 - no matter the value of k_1 - is

$$eq.\ 3.4.4 \qquad |1-k_2|<1 \Leftrightarrow 0<k_2<2 \Rightarrow \sum_{v=0}^{\infty} (1-k_2)^v = \frac{1}{k_2}$$

The solution path of the budget shares depends on the size of k_2:

$$eq.\ 3.4.5 \qquad \begin{array}{l} 0<k_2<1 \Rightarrow \textit{smooth path} \\ 1<k_2<2 \Rightarrow \textit{alternating path} \end{array}$$

Mathematically speaking k_1 might take on any value without conflicting with the existence of a long run solution, but values below 0 and above 1 implies, that there will be a first year overreaction of budget shares.

"A global smooth path" of quantities implies, that the first year demand elasticities should be lower than the equilibrium demand elasticities in absolute values and have the same sign, and in addition that the path of quantities does not alternate. As shown in Appendix I.3.1 eq. A3.1.7 and eq. A3.1.8 it turns out that this implies certain requirements on the size of k_1 depending on the signs of the equilibrium share elasticities, se_{ij}^*, and the equilibrium price elasticities, e_{ij}^*, (which of course are always negative for i=j), besides the demand that $0<k_2<1$.

From Appendix I.3.1 (eq. A3.1.2) it follows that the sign of the share elasticity has the following implications for the demand elasticity:

$$\begin{aligned} &\textit{eq. } 3.4.6 \quad && se_{ii}^{*}>0 \Leftrightarrow e_{ii}^{*}>(S_i^{*}-1) \Rightarrow e_{ii}^{*}>-1 \quad \textit{inelastic} \\ & && se_{ii}^{*}<0 \Leftrightarrow e_{ii}^{*}<(S_i^{*}-1) \\ & && se_{ij}^{*}>0 \Leftrightarrow e_{ij}^{*}>S_j^{*} \\ & && se_{ij}^{*}<0 \Leftrightarrow e_{ij}^{*}<S_j^{*} \end{aligned}$$

It follows that if the share elasticity is positive, demand is inelastic. If the cross share elasticity is positive, then the cross demand elasticity must also be positive, but the converse does not hold.

The restrictions on k_1 are sometimes contradictory and cannot be summarized in a simple way, cf. Appendix I.3.1 eq. A3.1.7 and eq. A3.1.8. For most fuels the relevant case is $se^{*}_{ii}>0$ and $se^{*}_{ij}<0$. Then the conditions on k_1 for global smoothness are $1<k_1<(1-S_i^{*})/se_{ii}^{*}$ and $k_1<-S_j^{*}/se_{ij}^{*}$. If some $(1-S_i^{*})/se_{ii}^{*}<1$ or $-S_j^{*}/se_{ij}^{*}<1$, no value of k_1 will satisfy these restrictions. If the restrictions are fulfilled in the sample period, there is no guarantee that k_1 will continue to satisfy the restrictions outside of the sample period. Smoothness during the regression period is checked via calculation of the short run and equilibrium demand elasticities, cf. Appendix I.3.1 eq. A.3.1.6.

Generalisations where the dynamic parameters are indexed over equations result in complicated expressions which are difficult to estimate, at least by the few observations available here without some a priori restrictions on the model. The simple partial adjustment for budget shares can not describe a smooth path of the quantities. Correspondingly Nielsen and Andersen (1985) found the ECM to be empirically superior to the partial adjustment model.

With only three different fuels the restriction of a common adjustment path is not severe. However as transport fuels are assumed separable from the other two fuels, it would have been interesting to test, whether the adjustment path of transport fuels is significantly different from the adjustment path of the other fuels.

I.3.5. Data

Basically we consider 6 energy goods aggregated from the energy balances of the national accounts system. These balances contain series for the consumption of 25 relevant fuels compiled for the years 1966-91, cf. Appendix I.3.2.

The 6 energy goods are:

1. Transport fuels
2. Electricity
3. Natural gas
4. District heating
5. Solid fuels
6. Liquid non-transport fuels

However, in order to save degrees of freedom and from theoretical considerations, for estimation purposes the groups 3-6 are aggregated to "other fuels". For estimation this gives the following classification:

1. Transport fuels
2. Electricity
3. Other fuels

This aggregation reflects a compromise between several considerations. Ideally, it would be nice to model the substitution between all 25 fuels. In general they have different emission coefficients. However, the quantity and quality of the data does not permit this. To keep the entire model manageable, we confine ourselves to consider 6 aggregate fuels. Even this is too much for estimation. Some fuels such as for example solid fuels are only used in a few branches, and even within the solid fuel using branches, most demand emanates from a few large plants questioning the assumption of a quasi concave energy technology for that branch. Also, political regulations and other supply rationing implies, that the use of natural gas and district heating can not be determined by reference to relative prices only. Natural gas came on stream in 1985 and the pipelines have been expanded considerably since then. The supply of district heating has also been expanded much during the estimation period.

Instead we aggregate these three difficult fuels together with liquid non-transport fuels. Formally, to make the model work, we assume "other fuels" to be a Leontief aggregate of the four fuels with the Leontief coefficients being either constant or trended (along with for example changed supply). Of course this is too simple. Relative prices certainly influence the demand for the four fuels as the four fuels are not perfect complements, but unfortunately we are not able to determine the price elasticities of demand.[6]

Values are defined as expenditures in 1000 DKK at purchasers prices. Quantities are measured as the direct energy consumption

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[6] In the final model one could choose to specify (some of) the substitution between the 4 fuels of "other fuels" with elasticities identified in foreign research. For example Holland has had an amplient supply of natural gas for several decades making it possible to estimate a demand elasticity for natural gas there.

in Tera Joules. Accordingly, prices are measured as 1000 DKK / TJ. However, all prices are indexed to 1 in 1980. Time ("T") is defined as equal to the year minus 1947 in GL regressions, but defined as equal to the year minus 1980 in TL regressions (assuring that 1980 is the base year).

Table 3.5.1 shows the sectoral aggregation in ADAM and the distribution of energy consumption at end users. Interfuel substitution models are estimated only for the first 13 branches. The remaining 6 branches are the fuel conversion branches (to be modelled in a different way[7]), the two transport branches (which use almost entirely transport fuels and are modelled separately in chapter I.2) and dwellings (production of rents which do not use energy).

Besides households who account for roughly 1/3 of total net energy consumption, the large energy consumers are public and private service industries, agriculture, food processing and construction sub suppliers. Public and private service industries consume relatively much electricity and district heating, and other transports and agriculture consume relatively much transport fuels. Solid fuels are used mainly by food processing and construction sub suppliers, and are essentially consumed by a few major production units.

This overall picture of Danish fuel consumption reflects (among a lot other things) the fact, that Denmark has very few energy-intensive productions.

Table 3.5.1 is displayed in terms of net energy consumption i.e. for the converted fuels, electricity and district heating, consumption is measured as the total amount of PJ imbedded in the manufacturing and distribution of the fuel (including losses in converting and distribution). This is the proper way of measuring the total amount of PJ used by the final consumers. However, for estimation purposes the consumed quantities are measured in direct terms (prices being redefined accordingly as expenditures are not affected), which are more relevant in that context as they reflect the entities which the consumer actually decides upon.

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[7] Electricity is produced by a number of large plants with relatively similar technologies. This implies that if the relative price passes a 'trigger value', it will induce a branch wide switch from one fuel to another. In fact the first oil price hike induced a substantial shift from oil to coal based electricity generation during a few years in the mid 1970s. In the future natural gas will be a relevant potential substitute for coal. A substitution elasticity estimated on historical data is therefore not very helpful for projections. For district heating the combustion of waste have become an important component, however waste is not included in the energy balances and the price of waste is not defined, i.e. a sensible production function for district heating cannot be estimated on the available data.

ADAM end user	Trans-port fuels	Elec-tricity	Na-tural gas	Di-strict hea-ting	Solid fuels	Li-quid fuels	Total
Business:							
1. Agriculture	12	5	5	2	11	3	7
2. Food processing	2	6	12	0	18	9	6
3. Man. of beverages and tobacco	0	0	2	0	2	3	1
4. Construction sub suppliers	0	3	6	0	50	6	5
5. Iron and metal industry	0	7	6	0	0	4	4
6. Man. of means of transportation	0	0	0	0	0	0	0
7. Man. of chemicals	0	5	5	0	0	5	3
8. Other manufacturing	0	4	9	0	8	3	3
9. Construction	5	1	0	0	0	2	2
10. Trade	8	7	1	4	0	2	6
11. Financial services	0	3	0	1	0	0	2
12. Other private services	2	12	2	5	0	3	6
13. Public services	2	10	5	11	0	7	7
Sub-total: Industries above	32	67	56	27	90	52	52
14. Oil and gas extraction	0	0	0	0	0	2	0
15. Oil refineries	0	0	0	0	0	0	0
16. Energy converting	0	0	0	0	0	0	0
17. Other transports	37	3	0	1	0	3	12
18. Sea transports	2	0	0	0	0	5	1
19. Dwellings	0	0	0	0	0	0	0
Sub-total: All industries	71	70	56	28	90	60	65
Households	29	30	44	72	10	40	35
Total economy	100	100	100	100	100	100	100
- *memo item:*							
Level, PJ	**198**	**280**	**54**	**59**	**37**	**115**	**744**
- share of total	27	38	7	8	5	15	100

Table 3.5.1 Total net energy consumption in 1991 in PJ distributed at end consumers, per cent.
Source: Denmark Statistiks energy matrices and own calculations.

I.3.6. Estimation and testing

It is safe to assume that the prices of different fuels basically are given from the world market or from Danish political decisions. The domestic profit margins on processed energy might only under very special circumstances depend (in part) on the level of domestic demand in the current year. Accordingly, purchasers prices are weakly exogenous as required for estimation.

Adding a white noise error term, $u_{i,t}$, to each share function eq. 3.4.2, it is assumed that the vector of error terms, U_t, forms a joint normal distribution with a variance covariance matrix, Ω, without any autocorrelations

$$eq.\ 3.6.1 \quad U_t \sim N(O,\Omega), \quad E(U_t,U_s) = 0, \ s \neq t$$

The adding-up restriction makes Ω singular. The standard solution is to estimate the system by deleting one equation. Under some regularity conditions which prevail here, Barten (1969) has shown, that the maximum likelihood estimator is invariant as to the equation deleted.

A FIML estimator is applied (by the LSQ command of the TSP 4.2 package, cf. Hall (1992)). It is consistent and therefore provides only consistent estimates of the variance-covariance matrix and various test statistics.

The testing is primarily performed by means of likelihood ratio tests for linear restrictions, although not all the hypothesis tested are linear. The use of the only asymptotic valid test criterias lead to rejections of the null hypothesis too often unless correcting for small sample bias, cf. Appendix I.3.3.

The test procedure runs as depicted at figure 3.6.1. The starting point is the general dynamic unrestricted model including squared trends as the specification of trends have important implications for estimation of the remaining parameters.

Testing on a lower level depends on the outcome at the higher levels.

TL:H$_0$	**GL:H$_0$**
linear trends	linear trends
no trends	no trends
separability of transport fuels	separability of transport fuels
static	static

preferred?

Figure 3.6.1 Test procedure.

Note: Trends and dynamics are tested conditioned on separability of transport fuels.

As TL and GL are not nested the choice between them can not be made by a likelihood ratio test. The non-nested Cox-test further developed by Deaton (1978) is very complicated to apply.

In practice however, this stringent testing procedure can only rarely be followed. First, it turns out, that in order to obtain useful results for some branches it is necessary to include a dummy variable (beside data break dummies) to deal with outliers. Second, some specifications have convergence problems or come out with such atheoretical results that is does not give much meaning to perform the standard testing procedure.

The belief that energy goods do not display initial overreactions and/or alternating adjustment paths is prior to the testing in the same way as concavity is a theoretical prior which - although it can not be imposed on the estimator - must be obeyed by the final results. Separability of transport fuels is always imposed, and complementarity is regarded as a dubious quality.

In some cases both TL and GL are rather sensitive to the initial conditions for the iterations in TSP's LSQ estimator. In general, the parameters are initialized as follows: First the static version without trends is estimated with all parameters initialized to zero or 0.1 in the case of separability (to avoid division by zero). Then the trend parameters are gradually introduced (initialized to zero) while the other parameters are initialized to the results of the earlier regression. Finally, the dynamic parameters are introduced initialized to k_1=1.5 and k_2=0.5 while all other parameters are initialized to the static outcome.

Convergence problems seem to occur, when there are clear specification problems. Such convergence problems are very discomforting, and in general there is no guarantee, that given an alternative set of initial conditions the algorithm would not find another solution.

Alternatively, the ECM-model eq. 3.4.2 can be estimated by a 2-step procedure parallel to the Engle and Granger 2-step estimation procedure for cointegrated time series in single equations: First the long run (static) share equations eq. 3.3.6 or eq. 3.3.12 are estimated. Second the dynamic parameters k_1 and k_2 in eq. 3.4.2 are estimated given the result of the first step. According to the Monto Carlo experiments performed by Banerjee et. al. (1986) the "superconvergence" property of the Engle and Granger 2-step procedure is not likely to show up in very small samples where instead the cointegration regression (step 1) might be biased because of excluded regressors (dynamics).[8] Our results some-

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[8] Although it should be noted that these Monto Carlo experiments assumed that the dynamic specification is correct. When the dynamics is misspecified the long run parameters could very well be estimated with less bias also in small samples by the static (step 1) regression. In 8 out of 13 branches the dynamic

times display a marked difference between the long run parameters in the static and in the dynamic specification. Following Banerjee et. al. (1986) we shall consider the latter as more reliable, except when the dynamics is clearly misspecified (i.e. not being smooth).

The variables are initially tested for the order of integration. The way prices enter the right hand side differ in TL and GL, although in both cases it is some sort of relative price measures. In GL the expression is rather complicated, whereas in TL it is just the logarithm to the relative prices. To clarify this, note that eq. 3.3.6 with eq. 3.3.7 inserted can be written as

$$eq.\ 3.6.2 \qquad S_i = b_i + \sum_{j \neq i}^{n} b_{ij} \log \frac{P_j}{P_i} + b_{Ti} T \qquad i=1,\dots,n$$

Therefore, it is chosen to test the order of integration of the explaining variables in TL only, hoping it has close relevance for GL.

The ECM contains lagged endogenous variables, i.e. the Durbin Watson statistic for first order autocorrelation is not strictly valid. On the other hand there are too few observations to apply other tests for autocorrelation as for instance Durbins *h*. The Durbin Watson statistic will be reported to give at least some indications on whether autocorrelation is a very serious problem.

When specified in budget shares the GL does not contain constant terms. In origo regressions the residuals do not sum to zero and R^2 can not be interpreted as showing the degree of explanation. The critical values for the Durbin Watson test for regressions with no intercept can be found in Farebrother (1980)[9], however as mentioned the Durbin Watson statistic is not strictly valid for the estimations presented.

I.3.7. Results

The described testing procedure implies a large amount of regressions. The results for total manufacturing excluding energy convertion are reported relatively thorough illustrating many of the problems encountered, whereas the results for all 13 branches are

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specification turns out to be so misspecified that it is preferred to estimate the long run parameters by the static (step 1) regression. Not in any case a dynamic (step 2) regression delivers a more sensible estimate of the dynamic parameters.

[9] With 25 observations and 5 regressors the indecisive range is .88-2.04 with no intercept present (relevant for the GL), cf. Farebrother (1980) and .95-1.89 with an intercept present (relevant for the TL), cf. Johnston (1984). Unfortunately many of the calculated DW statistics fall within these wide ranges.

only summarized with brief comments. The energy statistics is clearly most reliable for manufacturing although it has its problems there too.

I.3.7.1 Manufacturing excluding energy converting

Figure 3.7.1 displays some basic features (abstracting from the obvious break in the transport fuel series in 1973 to 1974[10]).

1. Electricity and other liquid fuels are the two dominating items accounting for more than 80 per cent of the total energy budget. In quantity terms electricity as a "refined" fuel accounts for much less, its price being correspondingly higher.

2. In most years the intensity of other fuels has been on a clear decreasing trend countervailed by a growing trend for the other two items especially electricity.

3. The relative price of other fuels was relatively high in the period from the first oil price hike in 1974 to the steep decline of oil prices in 1986. Again a somewhat opposite picture is found for the 2 other items although only electricity displays a marked relative price hike in 1986-1991.

4. As a sort of net outcome of the movements in prices and quantities, the trends in budget shares have been much less. One reading is the fact that other fuels immediately expanded the share at the first oil price hike but this was gradually reversed during the following four years. However, a much stronger feature is the considerable expansion of the budget share of electricity during the years 1986-1991 caused by an increased intensity in 1988 and an increased relative price during all the years 1986-1991. The counterpart of this is a steep decline in the shares of other liquid fuels in 1986-1991.

Figure 3.7.2 summarizes the historical correlation between intensities and relative prices. For all 3 items there are a negative long run correlation as theory suggests, but it is also clear that this correlation breaks down in a number of sub-periods comprising several years. One important example is the positive correlation between intensity and relative price for electricity and for other fuels in the last 6 years of the sample. In fact, the intensity of electricity has increased considerably since 1974 without a sustained decline of the relative price.

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[10] From 1973 to 1974 auto gasoline consumption almost halved in TJ terms and the 1973-level was not even obtained in 1990. This is clearly a break in the series due to a change in the compilation procedure. This break is common to all manufacturing sub-sectors. This break in the middle of the first oil price hike is most unfortunate and carries a heavy weight in the problems of estimation.

The regression model can only explain the last 6 years of the sample by a very slow speed of adjustment to earlier developments of relative prices and/or accelerating trends (positive for electricity, negative for other fuels). The declining trend of the relative price of electricity revitalized in the period from 1978 to 1985.

In a broader perspective, the considerable expansion in the intensity of electricity from 1974 onwards can in our model terms only be "explained" by an autonomous trend or extreme slow adjustment to the considerable relative price drop until 1974. Introducing trends in the model should then shorten the estimated adjustment speed and diminish the estimated price responses. The disequilibrium in 1966 and the price developments prior to 1966 are unknown to the regressions, which matters because the sample is so small. Therefore it is perfectly possible that trends are accepted by formal testing if for example the quantities in a lengthy first part of the sample still responds to price developments before sample start, i.e. pure formal testing leads us to underestimate the price sensitiveness in the very long run. The solution to this dilemma basically involves a theoretical choice.

Another obvious candidate for explaining the seemingly autonomous positive trend in electricity is the price of electric machinery relative to other machinery although this would clearly invalidate the fundamental KLEM separability assumption.

Figure 3.7.3 shows that this relative price is close to being a negative linear trend, i.e. it could well contribute to the explanations of why the intensity of electricity continued to increase after 1974. Statistically, the relative price of electrical machinery and the linear trend works much the same. In forecasting, they are in fact much alike in the ADAM framework too. An estimated historical trend should definitely not be extrapolated without any further reasoning, and ADAM is too aggregated to determine the price of different machineries.

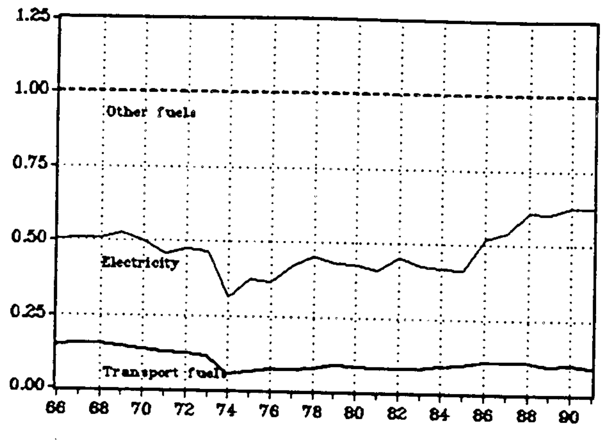


Figure 3.7.1.a Budget shares (stacked).

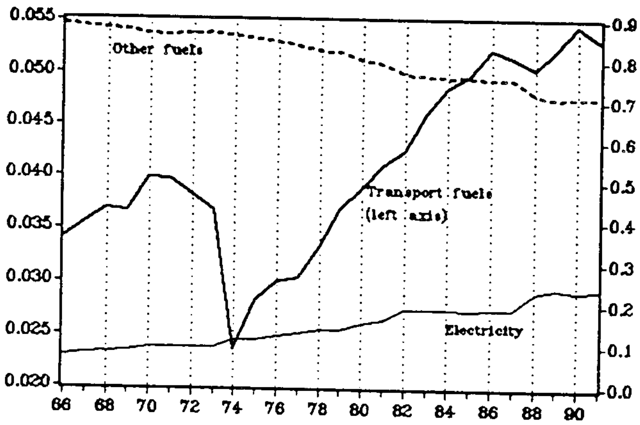
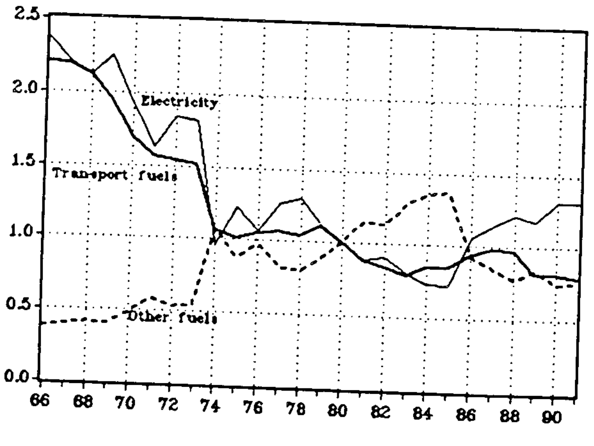
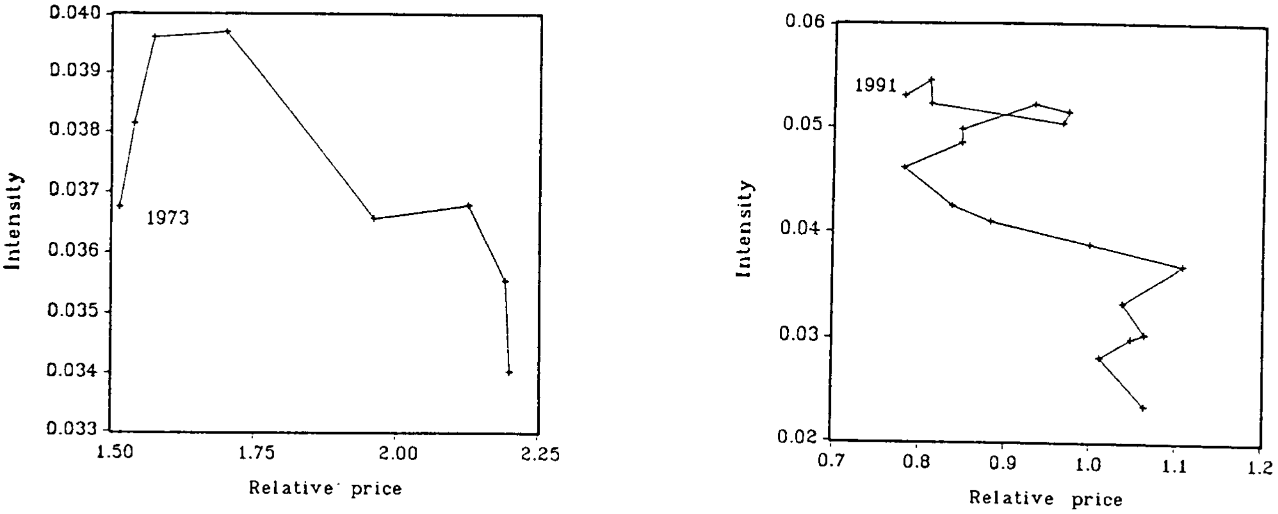


Figure 3.7.1.b Intensities.



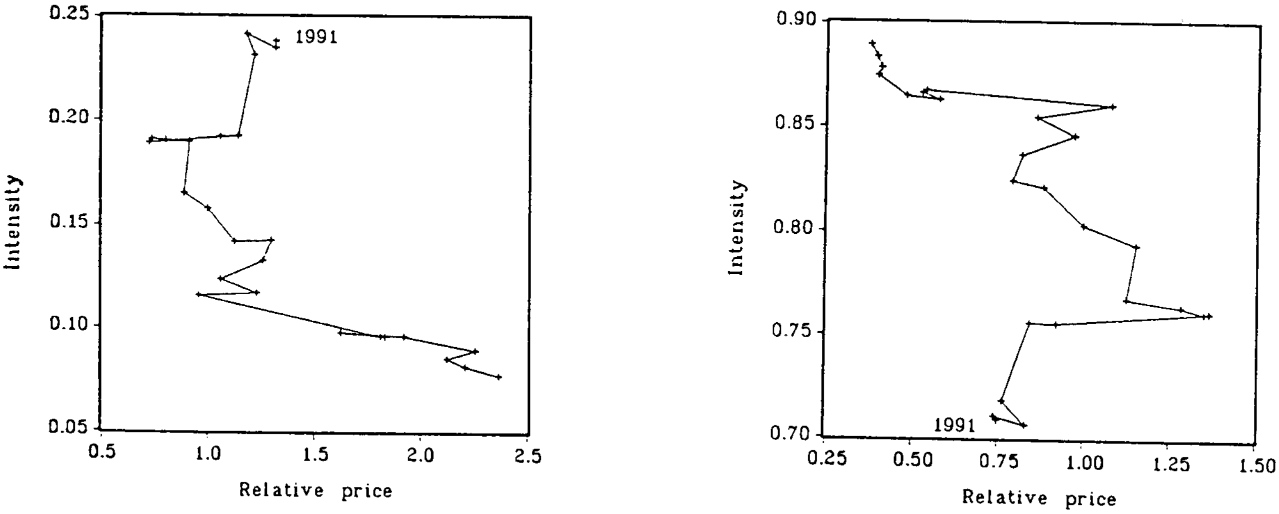
Figures 3.7.1c Relative prices

Figure 3.7.1 Total manufacturing excl. energy converting.



3.7.2.a Transport fuels 1966-73.

3.7.2.b Transport fuels 1974-91.



3.7.2.c Electricity 1966-91.

3.7.2.d Other fuels 1966-91.

Figure 3.7.2 Total manufacturing excl. energy converting. Correlation between intensities and relative prices.

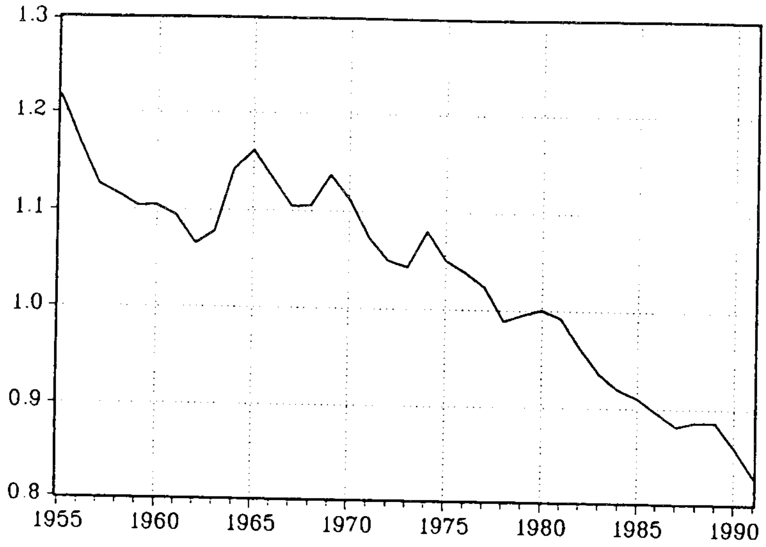


Figure 3.7.3 The price of electrical machinery relative to the price of other machinery, index 1980=1
Source: Wholesale price indices of Statistical Yearbook, Danmarks Statistik.

After grasping figure 3.7.1 it is not surprising, that it clearly can not be rejected by the formal Dickey Fuller test, that the budget share of electricity contains a unit root, i.e. is integrated of first order, I(1), cf. table 3.7.1. On a 5 per cent level it can not be rejected that the budget shares of the other two fuels are I(1) either, although only with a small margin especially for transport fuels. The null hypothesis of I(2) is clearly rejected for all variables. All absolute prices are tested to be I(1) (results not shown). Table 3.7.2 shows that all the relative prices (in logarithms) are tested to be I(1) on a 5 per cent level. For the price of electricity relative to transport fuels this conclusion is least clear cut: It is rejected to be I(1) (i.e. accepted to be I(0)) on a 10 per cent level, and excluding 1989-91 where it increases considerably, it is also tested to be I(0) on a 5 per cent level. In conclusion, the I(1) relative prices can in principle explain the I(1) budget shares.

	H_0:I(1)		H_0:I(2)		Conclusion
Budget share	C-term	Origo	C-term	Origo	
1. Transportation fuels	-2.95			-9.71	I(1)
2. Electricity		+1.50	-6.65		I(1)
3. Other fuels		-1.75	-7.68		I(1)
MacKinnon 5 percent crit. val.	-2.99	-1.96	-2.99	-1.96	

Table 3.7.1 Dickey Fuller statistics for budget shares, 1966-91
Note: The MacKinnon critical values are essentially Dickey-Fuller critical values calculated with a finer grid as inherent in MicroTSP, cf. Hall et. al. (1990). Insertion of the data break dummy variable D74 (equal to one in 1974, zero elsewhere) in the testing regressions is assumed not to influence the critical values. Augmented Dickey Fuller tests were also performed, but not reported as the agumented terms were clearly insignificant. Correspondingly the results for origo testing regressions are not reported when the constant term is insignificant and converse.

	H_0:I(1)		H_0:I(2)		Conclusion
Relative prices	C-term	Origo	C-term	Origo	
log (p_2/p_1)	-2.15			-4.40	I(1)
log (p_3/p_1)		+0.86		-5.33	I(1)
log (p_3/p_2)		-0.62		-5.36	I(1)
MacKinnon 5 percent crit. val.	-2.99	-1.96	-2.99	-1.96	

Table 3.7.2 Dickey Fuller statistics for log relative prices, 1966-91

Note: See note to table 3.7.1. (No dummy is applied in this table).
p_1 is the price of transport fuels
p_2 is the price of electricity
and p_3 is the price of other fuels

Table 3.7.3-6 give regression results for the maximum period 1967-91 for the dynamic ECM under the restriction of separability of transport fuels. For each specification 3 variants are presented: One without trends (marked "T^0"), one with linear trends ("T^1") and one with quadratic trends ("T^2").

Table 3.7.3 displays results for ECM GL. None of the three variants come out with smooth paths for all quantities throughout the entire sample period. Without trends the estimated first year own price elasticity of other fuels is positive in 1991. In case of a linear trend the first year cross price elasticity between transport fuels and electricity is negative contrary to the long run elasticity. In case of a quadratic trend the first year own price elasticity of electricity is positive in the early part of the sample (only the 1991 estimates are reported in the table).

At least the linear trend specification shows smooth paths for all own price effects. The long run price elasticity estimates are numerically much smaller in case of linear trends than in case of quadratic trends and especially zero trends.

A linear trend is statistically significant judged by a likelihood ratio test on a 5 per cent level, cf. table 3.7.4, without correcting for small sample bias, but not quite when correcting for small sample bias, cf. Appendix I.3.3. Adding further a quadratic term implies a smaller increase in the log likelihood value, however the quadratic terms are not significant. In both instances the trend is positive for electricity and negative for other fuels (except for the first part of the sample in case of quadratic trends). In the linear trend model the numerical size is one per cent a year. In the quadratic specification, the trend increases to around 1.4 per cent a year in 1991. In the linear specification the annual trend of 0.98 per cent for electricity accumulates to an increase in the intensity over the period 1967-91 at almost 20 percentage points leaving the combined impact of the relative prices, the dummy and the disequilibrium in 1991 to be little. For transport fuels the trend is small.

Table 3.7.5 reveals that in case of linear trends, the Leontief special case can not be rejected as opposed to the specifications with quadratic trends or zero trends. On purely statistical criterias (likelihood ratio testing) the long run movements of relative unit fuel demands can be "explained" by a mainly electricity expanding linear trend in this model. In some sense, a choice between linear trends and larger price sensitiveness has to be made. Given the spare degrees of freedom and important multicollinearity between trends and relative prices, the outcome of the likelihood ratio test is not a perfect criteria for the choice.

The non-smooth outcome suggests misspecified dynamics invalidating the long run estimates. However in pure static specifications concavity is not obeyed.

Figure A3.4.1 of Appendix I.3.4 displays a regression plot of the linear trend regression of table 3.7.3. It is seen that the model is in fact able to fit the considerable increase of the electricity budget share at the end of the period, although the sudden increase in 1988 is unexplained and leaves a major positive residual. Adding a dummy D8891 does not help the problems of non-smooth dynamics.

Figure A3.4.2 and A3.4.3 of Appendix I.3.4 show results of recursive regressions of the GL specification with linear trends of table 3.7.3 with variable end year and variable starting year respectively. The estimates are unstable, with the period around the second half of the 1970's causing much of the instability. On the other hand the spare degrees of freedom should be taken into account. Concerning dynamics, the recursive estimates point out that the first year effects are especially uncertain because the estimate of k_1 is especially unstable compared with the estimate of k_2. It seems rather random whether the estimated adaption process is smooth, i.e. whether the estimate of k_1 lies inside the domain allowing for smoothness. The large variance could be responsible for putting the estimate outside of this domain even though the "true" value lies within.

The TL does no come out with global smooth dynamics or even smooth paths of own price effects in the sample period, cf. table 3.7.6. In case of quadratic trends the first year own price elasticity of electricity again becomes positive in the early part of the sample (not reported). For the TL trends are not significant and the estimated long run price elasticities accordingly are numerically larger. Comparing table 3.7.3 and 3.7.6 it should be remembered that the interpretation of trends differs. For the TL pure static specifications also display non concavity.

Figure 3.7.4 and 3.7.5 concern the composition of other fuels. Figure 3.7.4 shows that the budget shares and the intensities of the 4 aggregate fuels within other fuels have varied considerably in the historical period. The intensity of the largest item, liquid (non-transport) fuels, has been on a declining trend since the first oil price hike accelerating after the second oil price hike.

The counterpart of the development of liquid non-transport fuels varies over the period. Solid fuels have increased their intensity along with a declining relative price up till the oil price drop of 1986. Natural gas came on stream in 1985 and has expanded its budget share and intensity considerably to around 1/4 in 1990 where the expansion stopped at least for a while. District heating is of little importance for manufacturing.

Although the increasing supply of natural gas since the mid-1980s dominates the picture it is still interesting to examine the correlation between intensities and relative prices, cf. figure 3.7.5. In fact the increasing supply of natural gas goes along with a marked decline of the relative price, which mainly reflects, that the price of natural gas follows the oil price as an institutional arrangement.[11] Although this relative price decline has popped up demand along with expanding supply, these data can not be used to determine the price elasticity of demand, as the disequilibrium in 1984 or the unsatisfied potential demand for natural gas before it came on stream is unknown. This matters because of the very few observations with natural gas on stream.

Figure 3.7.5 also reveals that the negative correlation between intensity and relative price of solid fuels (coal) hinges almost entirely on the observations for 1973-1974, where the relative coal price showed a marked decline and the intensity responded rather fast. The coal consumers of manufacturing mainly consists of a few large production units, and as described in section I.3.3 this might well invalidate the assumption of a quasi concave energy technology for the aggregate sector. It has been tried to estimate 4-factor interfuel substitution models with solid fuels as the fourth fuel for both the relevant ADAM-branches and the manufacturing aggregate, but the results (not reported) for various specifications repeatedly came out with non-smooth adjustment paths (improperly determined dynamic parameters) and also complementarity between solid fuels and the remaining other fuels, which is not a reasonable result.

In conclusion, it is not possible to estimate sensible price elasticities of demand for the four main sub groups of other fuels.

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[11] The suppliers of natural gas are subsidized by the government.

	e_{ij}			T^0, %						
Fuel	1	2	3	1970	1991			s	R^2	DW
1. Transport fuels	-.19	.04	.15			k_1 =	2.26	.0038	.982	2.06
	-.59	.32	.28				(.59)			
2. Electricity	.04	-.08	.04			k_2 =	.10	.0156	.956	1.06
	.07	-.30	.23				(.03)			
3. Other fuels	.04	-.10	.06			L =	177.27	.0138	.972	
	.07	.25	-.32							

	e_{ij}			T^1, %						
Fuel	1	2	3	1970	1991			s	R^2	DW
1. Transport fuels	-.03	-.01	.05			k_1 =	1.17	.0036	.983	1.83
	-.16	.07	.09	.17			(.17)			
2. Electricity	.00	-.02	.02			k_2 =	.25	.0130	.968	1.98
	.01	-.09	.07	.98			(.12)			
3. Other fuels	.01	.02	-.02			L =	180.47	.0119	.978	
	.02	.10	-.12	-1.14						

	e_{ij}			T^2, %						
Fuel	1	2	3	1970	1991			s	R^2	DW
1. Transport fuels	-.09	-.07	.16			k_1 =	1.80	.0033	.985	1.94
	-.46	.20	.25	-.06	.11		(.34)			
2. Electricity	.00	-.06	.07			k_2 =	.22	.0136	.964	1.93
	.04	-.24	.20	-1.01	1.35		(.05)			
3. Other fuels	.03	.00	-.02			L =	183.20	.0122	.977	
	.06	.24	-.29	1.08	-1.46					

Table 3.7.3 Regression results for ECM GL, D6673

Note: D6673 implies that to each equation is added a dummy which is equal to one in 1966-73 and zero elsewhere.
e_{ij} is cross-price elasticity in 1991 with the short run elasticity in the first line and the long run elasticity in the second line. e_{21} and e_{31} may differ as separability is only imposed exactly in the base year (1980).
T^0, T^1 and T^2 indicates whether the trend is excluded or added in a linear or quadratic form respectively. The numbers in the columns indicate the annual trend in 1970 and in 1991 (which of course are the same for the linear trend).
s is the standard error of regression of each equation, except for the suppressed equation 3 where it is the Root Mean Square Error of the fitted budget shares.
R^2 is the coefficient of determination.
DW is the Durbin-Watson statistic for the presence of 1. order autocorrelation.
Figures in brackets under k_1 and k_2 are the standard errors of the coefficient estimate.
L is the log of the likelihood function.

	T^2	T^1	T^0	No sep. (T^1)	Static (T^1)
Log likelihood	183.20	180.47	177.27	180.77	7.01
Difference		2.73	3.20	0.30	14.02
Difference x 2		5.46	6.40	0.60	28.04
Critical value		5.99	5.99	3.84	5.99
Outcome		A	R	Sep.: A	R

Table 3.7.4 Testing restrictions in table 3.7.3
Note: "A" indicates not rejected and "R" indicates rejected. See text for explanations of the testing.

	T^2	T^1	T^0
Log likelihood of H_1: GL with sep.	183.20	180.47	177.27
Log likelihood of H_0: Leontief	179.28	179.07	170.91
Difference	3.92	1.40	6.36
Difference x 2	7.84	2.80	12.72
Critical value	5.99	5.99	5.99
Outcome	R	A	R

Table 3.7.5 Testing restrictions in table 3.7.3
Note: "A" indicates not rejected and "R" indicates rejected. See text for explanations of the testing.

Fuel	e_{ij} 1	2	3	T^0, % 1970	1991			s	R^2	DW
1. Transport fuels	-.14 -.79	-.26 .41	.40 .38			k_1 =	6.29 (8.35)	.0040	.979	1.90
2. Electricity	.14 .10	-.43 -.46	.28 .36			k_2 =	.13 (.07)	.0156	.958	1.72
3. Other fuels	.14 .10	-.40 .39	.26 -.48			L =	175.87			

Fuel	e_{ij} 1	2	3	T^1, % 1970	1991			s	R^2	DW
1. Transport fuels	-.19 -.57	.08 .32	.11 .25	-.02		k_1 =	2.11 (1.58)	.0037	.981	1.71
2. Electricity	.05 .07	-.21 -.34	.16 .27	.84		k_2 =	.13 (.07)	.0141	.963	1.96
3. Other fuels	.01 .05	-.06 .25	.05 -.30	-.82		L =	178.61	.0127	.976	

Fuel	e_{ij} 1	2	3	T^2, % 1970	1991			s	R^2	DW
1. Transport fuels	-.14 -.55	.09 .33	.05 .23	-.40	.05	k_1 =	2.16 (.67)	.0036	.983	1.70
2. Electricity	.04 .07	-.17 -.33	.13 .26	-1.05	1.20	k_2 =	.22 (.05)	.0138	.964	1.92
3. Other fuels	.01 .05	.00 .29	-.01 -.34	1.45	-1.25	L =	180.10	.0125	.988	

LR test box	T^2	T^1	T^0	No sep. (T^0)	Static (T^0)
Log likelihood	180.10	178.61	175.87	178.65	128.29
Difference		1.49	2.74	2.78	47.58
Difference x 2		2.98	5.48	5.56	95.16
Critical value		5.99	5.99	3.84	5.99
Outcome		A	A	Sep.: R	R

Table 3.7.6 Regression results for ECM TL, D6673
Note: See note to table 3.7.3.

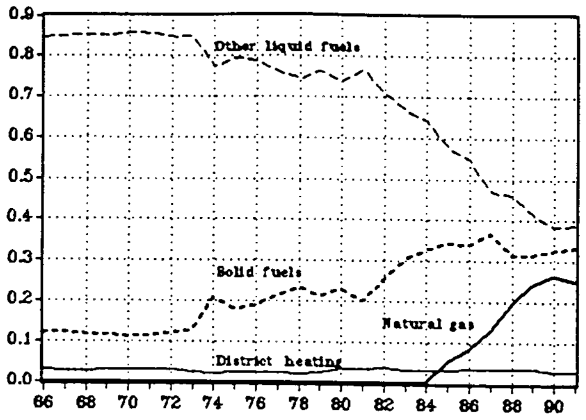


Figure 3.7.4a Budget shares (stacked).

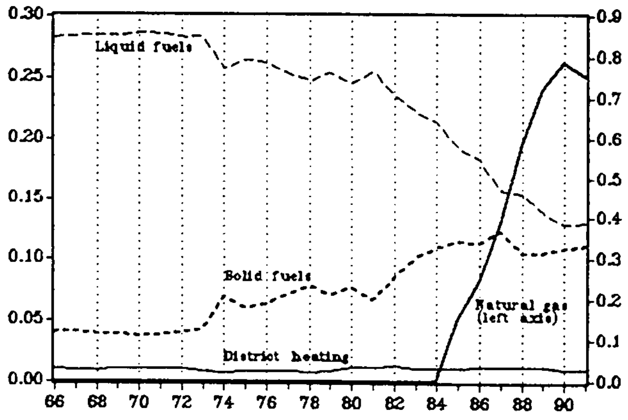


Figure 3.7.4b Intensities.

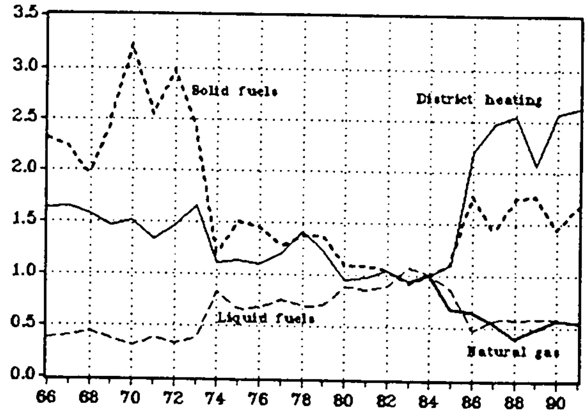


Figure 3.7.4c Relative prices.

Figure 3.7.4 Manufacturing excl. energy converting: Other fuels.

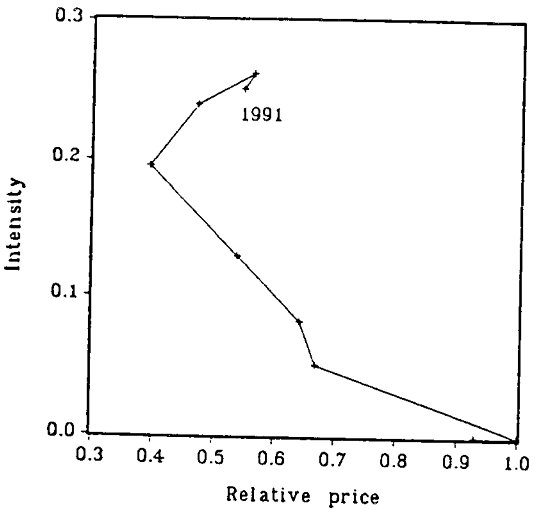


Figure 3.7.5.a Natural gas.

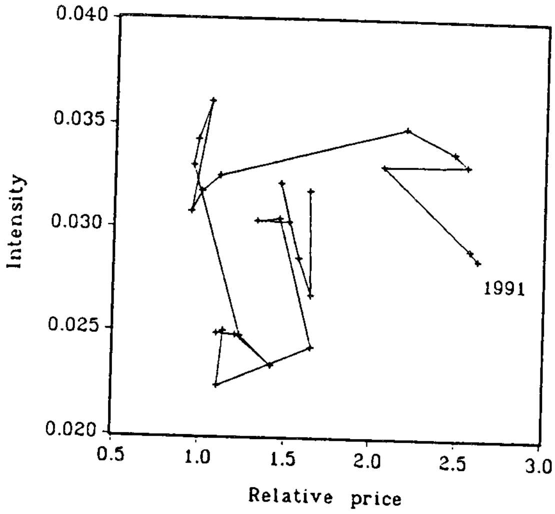


Figure 3.7.5.b District heating.

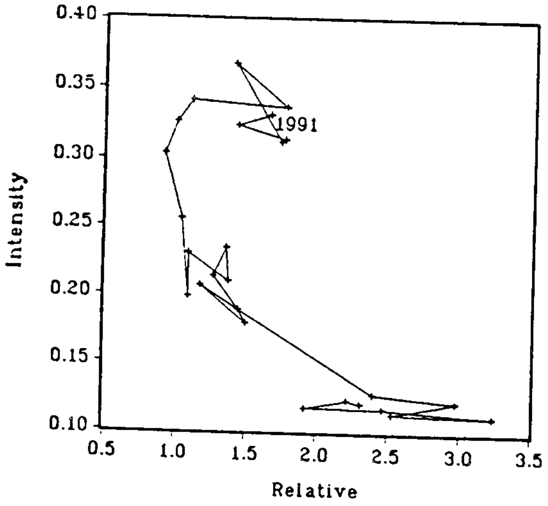


Figure 3.7.5.c Solid fuels.

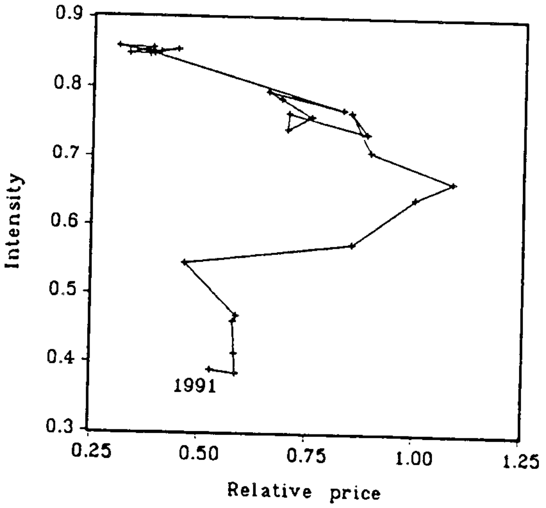


Figure 3.7.5.d Liquid fuels.

Figure 3.7.5 Manufacturing excl. enery converting: Other fuels. Correlation between intensities and relative prices.

I.3.7.2 Results for 13 ADAM branches

Table 3.7.7 and 3.7.8 give the regression results for the preferred GL and TL specifications respectively. Only regressions with separability of transport fuels imposed are shown. The preferred specification is not in any instance found as the outcome of pure likelihood ratio testing as the alternative hypothesis often imply atheoretical results (not concave, not smooth) or the estimated parameters seem unreliable judged by common sense (some fuels complementary, excessive elasticities, excessive trends). In fact, the preferred specifications generally only possess smooth paths of own price effects. For several branches no specification can be found obeying also smooth paths of all cross price effects.

In two instances it has been necessary to add a dummy to take account of sudden movements of fuel demand not connected to movements of relative prices.

For some branches the "preferred" specification is simply the only one displaying concavity and smooth paths of own price effects among all the tested specifications. For the TL even this can not be obtained for many branches as the many empty rows of table 3.7.8 reveal. The GL seems to be more compatible with the data than the TL probably because of the small price effects. We shall choose the GL regressions of table 3.7.7 as our preferred interfuel equations.

For the GL, in 5 out of 13 branches a dynamic specification is preferred. Separability of transport fuels is rejected for two branches but imposed anyway on theoretical reasoning. A linear trend is preferred for 7 branches and a quadratic trend is preferred for 2 branches. When trends are present they are always positive for electricity (in 1991). The Leontief special case can not be rejected in 6 branches. Of these 6 branches the Leontief special case is tested conditioned on zero trends in 2 instances.

For most branches the long run own price elasticities of electricity and other fuels are numerically below 1/3, but somewhat higher for transport fuels where it seems excessive for several branches, especially some service branches where it is clearly unreliable. An especially low relative price of transport fuels in 1991 is partly responsible, cf. eq. 3.3.15. The elasticities of transport fuels are probably especially poorly determined because transport fuels often amount to a small budget share of energy consumption and carry a small weight in the regressions.

An important explanation for the many insignificant substitution effects in manufacturing is probably the most unfortunate data break in 1973/74 at the time of the first oil price hike.

To these partial elasticities should be added the share-weighed price elasticity of total energy, cf. eq. 3.2.8, which Smidt and Knudsen (1995) has estimated to -0.25 on average.

The result that the long run interfuel price elasticities are small is in line with the earlier study of Nielsen and Andersen (1985) although the exact estimates of course differ. However, in contrast with our findings they concluded that TL and GL describe the Danish data equally well. This could be due to the fact that their regression period was cut off in 1980, so they did not have to explain the erratic movements of (especially the last part of) the 1980s, which is an acid test to the models. Also this might explain why they concluded, that the static models come out with long run elasticities close to the dynamic models' in sharp contrast with our findings.

It is not worthwhile to perform various mis-specifications tests which are only asymptotic valid anyway. We shall take the point of view, that the quality of the data, the number of observations and the required simplicity of the model do not allow for a much better model which is firmly based on economic theory. Given that some theory based model is necessary the one chosen is reasonable under the circumstances, but it must be admitted that the validity of the long run estimates is uncomforting low.

An important statistical problem concerns the dynamics. The ECM is chosen because it allows for global smooth adjustment of quantities even though the equations are estimated in budget shares. However, the short term parameter (k_1) of the ECM is often uncomforting unstable with a large standard error, so it often seems random whether the point estimate lies within the range compatible with smooth adjustment of quantities. This have probably in some instances led to rejection of specifications which anyway might have supplied us with good estimates of the long run elasticities. We have argued that the data does not allow estimation (of GL) in intensities (the output of the energy sub production function should be thought of as the observed total energy use corrected for its - unknown - utilization rate).

	Data dum-my	Other dum-my	e_{11}	e_{12}	e_{13}	e_{21}	e_{22}	e_{23}	e_{31}	e_{32}	e_{33}	Trend type	T_1	T_2	T_3	k_1	k_2	H_0: Sep.	H_0: Leon-tief
1. Agriculture			-.28	.15	.13	.24	-.42	.18	.32	.27	-.59	T^2	-.09	.72	-.63	2.18	.40	.09	12.76
2. Food processing			-.21	.09	.12	.04	-.36	.32	.03	.22	-.26	T^0				1.00	1.00	11.14	6.06
3. Man. of bev. and tobacco	D6673		-.03	.01	.02	.00	-.06	.06	.00	.06	-.06	T^1	.13	1.12	-1.26	1.00	1.00	7.45	1.52
4. Construction sub suppliers	D6673		-.59	.15	.44	.02	-.12	.09	.03	.05	-.08	T^1	.12	.33	-.45	1.16	.23	.76	10.73
5. Iron and metal industri	D6673	D8891	-.14	.07	.07	.01	-.09	.08	.02	.19	-.21	T^1	.19	1.46	-1.64	1.00	1.00	.02	18.28
6. Man. of means of transp.	D6673	D8391	-.04	.18	.02	.00	-.07	.07	.00	.12	-.12	T^0				1.00	1.00	.04	1.34
7. Man. of chemicals	D6673		-.44	.23	.21	.02	-.14	.12	.03	.29	-.32	T^1	.02	1.53	-1.56	1.45	.34	3.69	3.54
8. Other manufacturing	D6673		-.45	.23	.22	.04	-.19	.15	.04	.16	-.20	T^0				1.44	.23	1.85	5.07
9. Construction	D6674		-.15	.05	.11	.33	-.29	-.04	.37	-.02	-.35	T^0				1.23	.34	.85	10.65
10. Trade	D6676 D8991		-.12	.05	.07	.08	-.07	-.01	.18	-.01	-.17	T^1	.43	.67	-1.10	1.00	1.00	2.26	2.01
11. Financial services	D8991		-1.3	.54	.80	.01	-.08	.07	.04	.19	-.24	T^2	.37	1.78	-2.15	1.00	1.00	.82	9.05
12. Other private services	D8991		-.89	.39	.50	.08	-.12	.04	.31	.11	-.42	T^1	-.03	1.50	-1.47	1.00	1.00	.79	23.90
13. Public services	D8082		-.93	.43	.50	.04	-.09	.05	.06	.06	-.12	T^1	-.92	1.68	-.75	1.00	1.00	1.81	5.62

Table 3.7.7 An overview of the preferred GL specifications for the 13 ADAM branches

Note: The tests of the last columns have critical values of 3.84 and 5.99 respectively at a 5 per cent level, cf. Appendix I.3.3. Trends and elasticities are displayed for 1991.

	Data dummy	Other dummy	e_{11}	e_{12}	e_{13}	e_{21}	e_{22}	e_{23}	e_{31}	e_{32}	e_{33}	Trend type	T_1	T_2	T_3	k_1	k_2	H_0: Sep.
1. Agriculture																		
2. Food processing			-.16	.08	.07	.03	-.39	.36	.02	.25	-.27	T^0				1.00	1.00	12.24
3. Man. of bev. and tobacco																		
4. Construction sub suppliers	D6673		-.73	.26	.48	.04	-.37	.34	.03	.16	-.19	T^2	.13	.50	-.63	1.61	.22	2.00
5. Iron and metal industri																		
6. Man. of means of transp.																		
7. Man. of chemicals																		
8. Other manufacturing	D6673		-.27	.22	.05	.03	-.19	.16	.01	.20	-.21	T^1	.02	.56	-.59	1.29	.27	1.40
9. Construction																		
10. Trade																		
11. Financial services	D8991		-.44	.41	.02	.01	-.20	.19	.00	.35	-.35	T^1	-.12	1.65	-1.53	1.43	1.21	.10
12. Other private services	D8991		-.85	.63	.22	.14	-.16	.02	.14	.05	-.18	T^2	.80	.91	-1.72	1.00	1.00	1.06
13. Public services	D8082		-.32	.25	.07	.01	-.20	.22	.00	.27	-.28	T^1	-.97	1.69	-.71	1.36	.90	.04

Table 3.7.8 An overview of the preferred TL specifications for the 13 ADAM branches
Note: For branch 1,3,5,6,7,9,10 and 11 a theoretically sensible result has not been obtained for the TL. The test of the last column has a critical value of 3.84 at a 5 per cent level, cf. Appendix I.3.3. Trends and elasticities are displayed for 1991.

Appendix I.3.1

Price elasticities and share elasticities

I.3.1.1 Equilibrium elasticities

Elaborating on Bremer (1992, p. 16) the partial derivative of S_i with respect to log P_j can be written as (the superscript * designating equilibrium (long run) values is suppressed)

$$\frac{\partial S_i}{\partial \log P_j} = \frac{\partial\left(\dfrac{P_i X_i}{\sum_{h=1}^{n} P_h X_h}\right)}{\partial \log P_j}$$

$$= \frac{\left(\dfrac{\partial X_i}{\partial \log P_j} P_i + \dfrac{\partial P_i}{\partial \log P_j} X_i\right)\sum_{h=1}^{n} P_h X_h \; - \; X_i P_i\left(\dfrac{\partial \sum_{h=1}^{n} P_h X_h}{\partial \log P_j}\right)}{(\sum_{h=1}^{n} P_h X_h)^2}$$

$$= \frac{P_i X_i \dfrac{\partial \log X_i}{\partial \log P_j} + X_i \dfrac{\partial P_i}{\partial \log P_j}}{C} - \frac{P_i X_i\left(C \dfrac{\partial \log C}{\partial \log P_j}\right)}{C^2} \qquad \forall i,j=1,\ldots,n$$

Using Shepards lemma we obtain

$$eq.\ A3.1.1\text{-}a \qquad \frac{\partial S_i}{\partial \log P_i} = S_i(e_{ii}+1-S_i)$$

$$eq.\ A3.1.1\text{-}b \qquad \frac{\partial S_i}{\partial \log P_j} = S_i(e_{ij}-S_j) \qquad \forall i\neq j$$

where e_{ij} denotes the elasticity of X_i with respect to P_j. Define se_{ij} as the elasticity of S_i with respect to P_j, it is seen from eq. A3.1.1 that

$$eq.\ A3.1.2\text{-}a \qquad se_{ii} \equiv \frac{\partial \log S_i}{\partial \log P_i} = 1+e_{ii}-S_i\,,\ i.e.\ \ se_{ii}>0 \Leftrightarrow e_{ii}>(S_i-1)$$

$$eq.\ A3.1.2\text{-}b \qquad se_{ij} \equiv \frac{\partial \log S_i}{\partial \log P_j} = e_{ij}-S_j \qquad \forall i\neq j\text{: } se_{ij}>0 \Leftrightarrow e_{ij}>S_j$$

These formulas are very easily applied to the TL cost function where

$$eq.\ A3.1.3 \qquad \frac{\partial S_i}{\partial \log P_j} = b_{ij} \quad \forall i,j=1,\ldots,n$$

I.3.1.2 Short run elasticities

From eq. 3.4.2 it is seen that

$$eq.\ A3.1.4 \qquad \frac{\partial S_{i,t}}{\partial \log P^*_{i,t}} = k_1 \frac{\partial S^*_{i,t}}{\partial \log P^*_{i,t}}$$

Assuming that initially long run equilibrium prevails, so that $S_{i,t}=S_{i,t}^*$

$$eq.\ A3.1.5 \qquad \frac{\partial \log S_{i,t}}{\partial \log P^*_{i,t}} = k_1 \frac{\partial \log S^*_{i,t}}{\partial \log P^*_{i,t}}$$

Inserting (eq. A3.1.5) in (eq. A3.1.3) gives

$$\begin{array}{lllll} eq.\ A3.16\text{-}a & e^*_{ii,t} = se^*_{ii,t} - 1 + S^*_{i,t} & \Leftrightarrow & e_{ii,t} = k_1 se^*_{ii,t} - 1 + S^*_{i,t} & \\ eq.\ A3.1.6\text{-}b & e^*_{ij,t} = se^*_{ij,t} + S^*_{j,t} & \Leftrightarrow & e_{ij,t} = k_1 se^*_{ij,t} + S^*_{j,t} & \forall i \neq j \end{array}$$

From eq. A3.1.6 we derive the following inequalities which show the restrictions on k_1 necessary for obtaining a global smooth path of quantities.

First, the demand that the own and cross price impacts are smaller in the first year in absolute terms than the equilibrium impacts, leads to

$$\begin{array}{llll} eq.\ A3.1.7\text{-}a & & e_{ii,t} > e^*_{ii,t} & \\ & \Leftrightarrow & k_1 se^*_{ii,t} + S^*_{i,t} - 1 > se^*_{ii,t} + S^*_{i,t} - 1 & \\ & \Leftrightarrow & (k_1 > 1 \wedge se^*_{ii,t} > 0) \vee (k_1 < 1 \wedge se^*_{ii,t} < 0) & \\ eq.\ A3.1.7\text{-}b & & e_{ij,t} < e^*_{ij,t} & \forall i \neq j \\ & \Leftrightarrow & k_1 se^*_{ij,t} + S^*_{j,t} < se^*_{ij,t} + S^*_{j,t} & \\ & \Leftrightarrow & (k_1 < 1 \wedge se^*_{ij,t} > 0 \vee (k_1 > 1 \wedge se^*_{ij,t} < 0) & \end{array}$$

where the converse inequalities of course also apply. Accordingly, the proper restriction on k_1 depends on the size of se^*. For most fuels, $se^*_{ii}>0$ and $se^*_{ij}<0$ implying the lower bound $k_1>1$.

Second, the demand that the first year own price impact is negative and that most cross price impacts are positive leads to

$$\begin{aligned}
&\textit{eq. A3.1.8-a} & e_{ii,t} &< 0 \\
&& \Leftrightarrow\ k_1 se^*_{ii,t} + S^*_{i,t} - 1 &< 0 \\
&& \Leftrightarrow\ \left(k_1 < \frac{1-S^*_{i,t}}{se^*_{ii,t}} \wedge se^*_{ii,t} > 0\right) &\vee \left(k_1 > \frac{1-S^*_{ii,t}}{se^*_{ii,t}} \wedge se^*_{ii,t} < 0\right) \\
&\textit{eq. A3.1.8-b} & e_{ij,t} &> 0 \qquad \forall i \neq j \\
&& \Leftrightarrow\ k_1 se^*_{ij,t} + S^*_{j,t} &> 0 \\
&& \Leftrightarrow\ \left(k_1 > -\frac{S^*_{j,t}}{se^*_{ij,t}} \wedge se^*_{ij,t} > 0\right) &\vee \left(k_1 < -\frac{S^*_{j,t}}{se^*_{ij,t}} \wedge se^*_{ij,t} < 0\right)
\end{aligned}$$

i.e. giving the upper bounds $k_1 < (1-S^*_{i,t})/se^*_{ii,t}$ and $k_1 < -S^*_{j,t}/se^*_{ij,t}$ for most fuels. It is possible that $(1-S^*_{i,t})/se^*_{ii,t} < 1$ and/or $-S^*_{j,t}/se^*_{ij,t} < 1$ implying that no global smooth path exists for the own price impacts and/or the cross price impacts. This is a drawback of the dynamic model.

Appendix I.3.2

The energy data

Aggregate fuel	Disaggregated fuel in DS' 25 commodity energy balances
1. Transport fuels	8. Jet kerosine 9. Jet gasoline 10. Gasoline 11. Gasoline (tax free) 14. Auto diesel 16. Marine diesel
2. Electricity	22. Electricity
3. Natural gas to consumers	25. Natural gas to consumers
4. District heating	2. District heating
5. Solid fuels	3. Coal 4. Brown Coal 5. Briquettes 6. Coke 23. Wood 24. Tar oil
6. Liquid non-transport fuels	1. Town gas 12. Other gasoline 13. Kerosine 15. Gas oil 17. Fuel oil 18. Fuels for processing 19. LPG 20. Other gas

Table A3.2.1 Definition of fuels

Note: No. 21 (undistributed natural gas) and 7 (crude oil) are not used by industries per definition.
Source: The 25 commodity energy balances are documented in Danmarks Statistik (1994).

Appendix I.3.3

Testing restrictions

Assume n equations, m regressors and t observations. Assume that the null hypothesis is

$$RB=0$$

where R is an q x m matrix with rank q and B is the m x n matrix of parameters. Thus there are the same restrictions in each equation and the restrictions are linear. Under the usual regularity conditions the standard likelihood ratio test statistic is given as

$$-2(L(H_0)-L(H_1)) \quad \sim_{asy} \quad \chi^2(r)$$

where L(H) is the log likelihood under the hypothesis H and r=nq is the total number of restrictions in the entire system.

In small samples this asymptotic test statistic will lead to rejection of the null too often as shown in Otto (1989). To obtain the exact small sample distribution the number 2 should be replaced by a number < 2. Otto gives such "correction factors" for q=1 and for a limited variety of n,m and t. Otto's correction factors are used here by interpolating in - and extrapolating from - his table. The relevant intrapolated and extrapolated corrections factors are given in table A3.3.1. It is seen that the more degrees of freedom, the closer the correction factor is to 2 (which it approaches as t approaches infinity).

	t	
m	25	26
3	1.69	1.71
4	1.60	1.62
5	1.51	1.53
6	1.43	1.46
7	1.34	1.38
8	1.25	1.29
9	1.16	1.20
10	1.07	1.11

Table A3.3.1 Small sample corrections factors for the likelihood ratio test, q=1, n=2.

Source: Intrapolating in and extrapolating from the table in Otto (1989).

As one equation can be excluded in the estimation procedure, the three-factor case consists of two independent equations. The relevant total number of restrictions (the degrees of freedom in the chi^2-distribution) are given in table A3.3.2.

The GL is highly nonlinear in budget shares and the hypothesis to be tested can not be formulated as linear restrictions. The same applies even to the dynamic ECM TL and to separability in the static TL. However, the hypothesis are tested as if they were linear.

Table A3.3.1 shows that the small sample correction factor in the case of 1 restriction per equation is around 1.5 in the relevant cases. Otto does not give correction factors for more or less than one restriction per equation which is relevant for the separability of factor 1 hypothesis and the author has not succeeded in finding such correction factors in the literature.

Therefore, it was decided to use the asymptotic factor 2 in all instances. If application of this factor does not lead to rejection of H_0 at the chosen 5 per cent significance level, application of the small sample factor would of course not reject either. If H_0 is rejected by applying the asymptotic factor it should preferably do so by a margin of around 1/3 to rule out the possibility that applying the proper but unknown small sample factor would lead to the opposite result.

H_0	H_1	Number of restrictions		Relevant $chi_{.95}^2$
		Per equation	In total	
Linear trend	Quadratic trend	1	2	5.99
Zero trend	Linear trend	1	2	5.99
Separability of factor 1	Not separability	1/2	1	3.84
Static	Dynamic ECM	1	2	5.99
GL: Leontief with sep. of factor 1	GL: GL with sep.	1	2	5.99

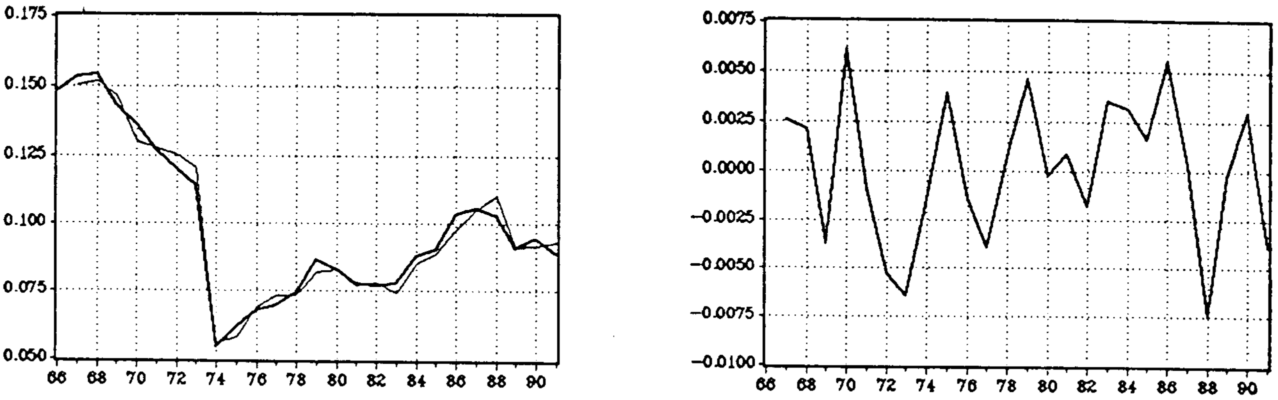
Table A3.3.2 Number of restrictions implied by H_0

Note: The degrees of freedom of the chi^2-distribution is equal to the total number of restrictions. All hypothesis are tested given separability of factor 1 except, of course, this separability restriction itself.

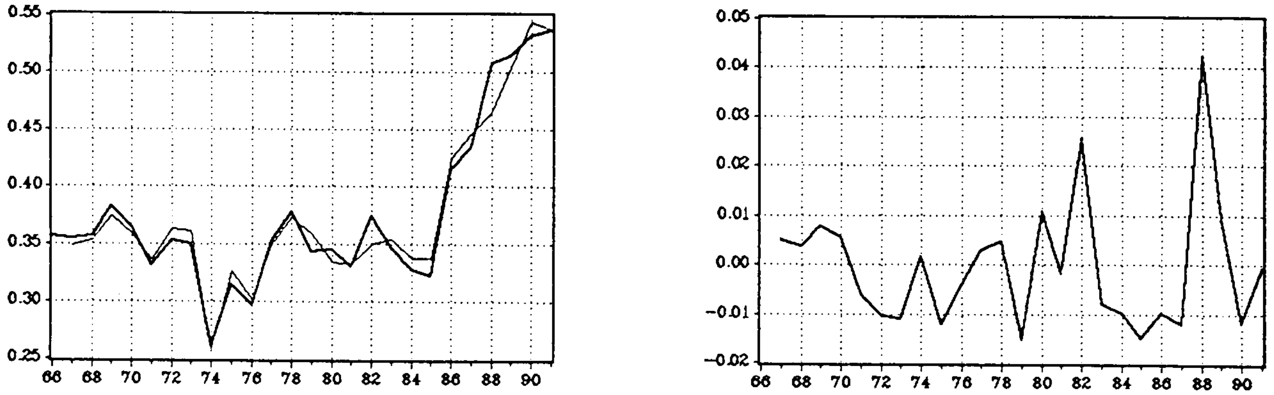
Appendix I.3.4

Regression plots

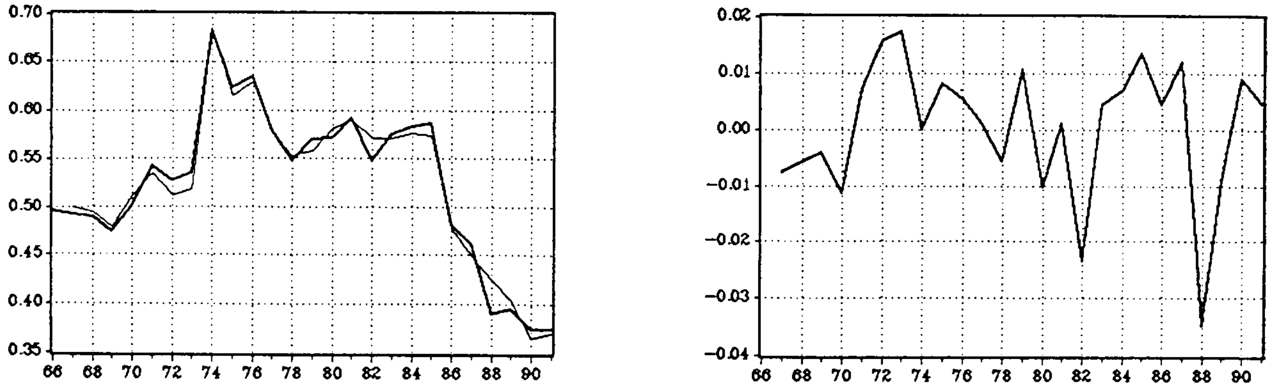
Actual (bold line) and fitted budget shares *Residuals*



Transport fuels



Electricity



Other fuels

Figure A3.4.1 Manufacturing excl. energy converting. Regression plots of table 3.7.3, T^1.

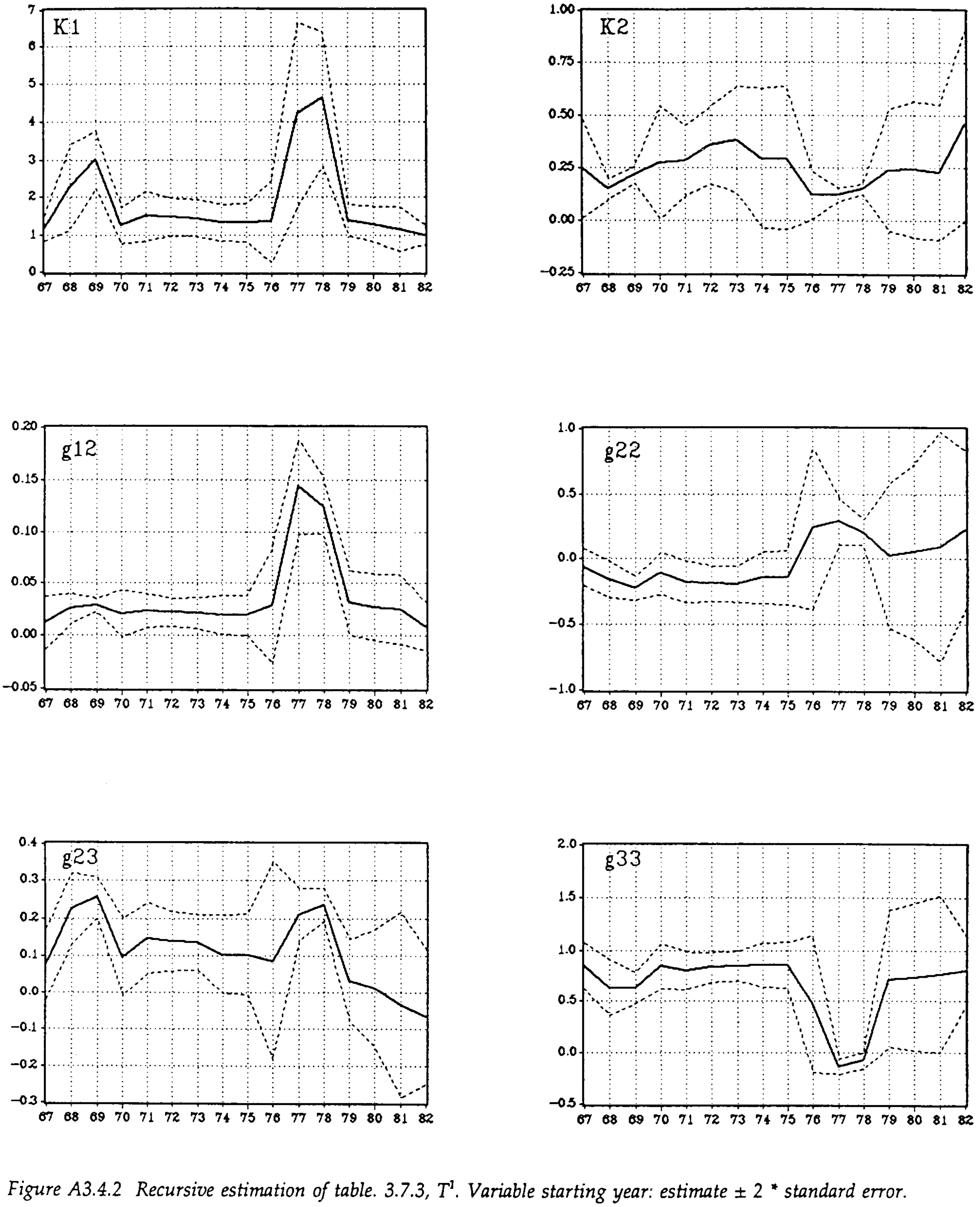
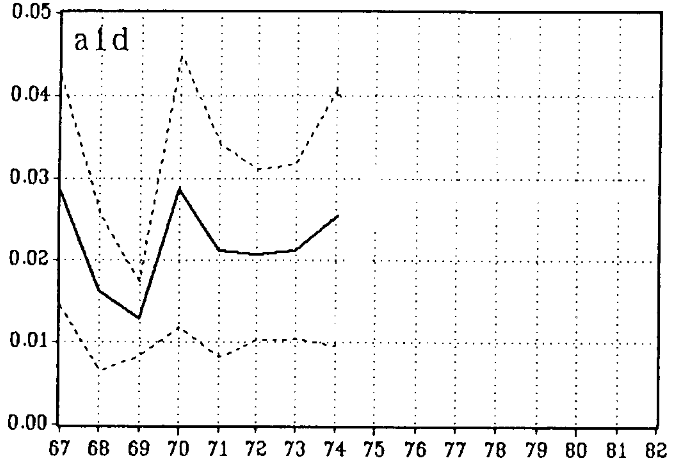


*Figure A3.4.2 Recursive estimation of table. 3.7.3, T^1. Variable starting year: estimate ± 2 * standard error.*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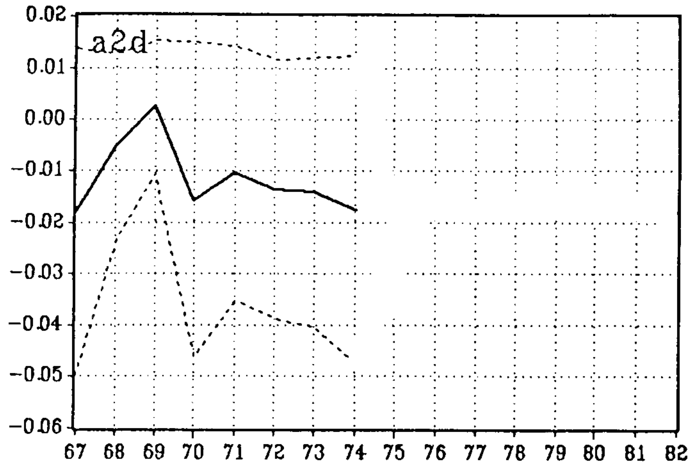
0.04
0.03
0.02
0.01
0.00
67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82


a2d
0.02
0.01
0.00
−0.01
−0.02
−0.03
−0.04
−0.05
−0.06
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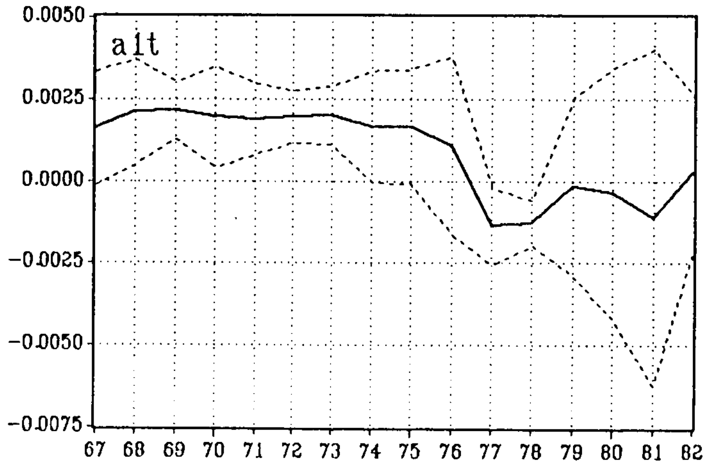
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0.0000
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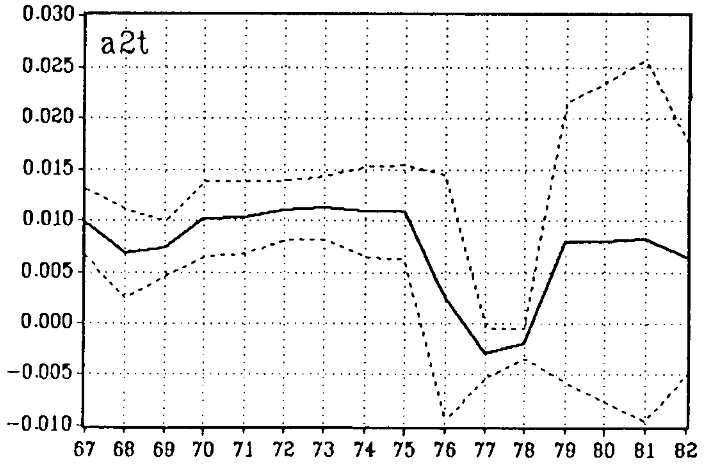
−0.0050
−0.0075
67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82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0.005
0.000
−0.005
−0.010
67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82

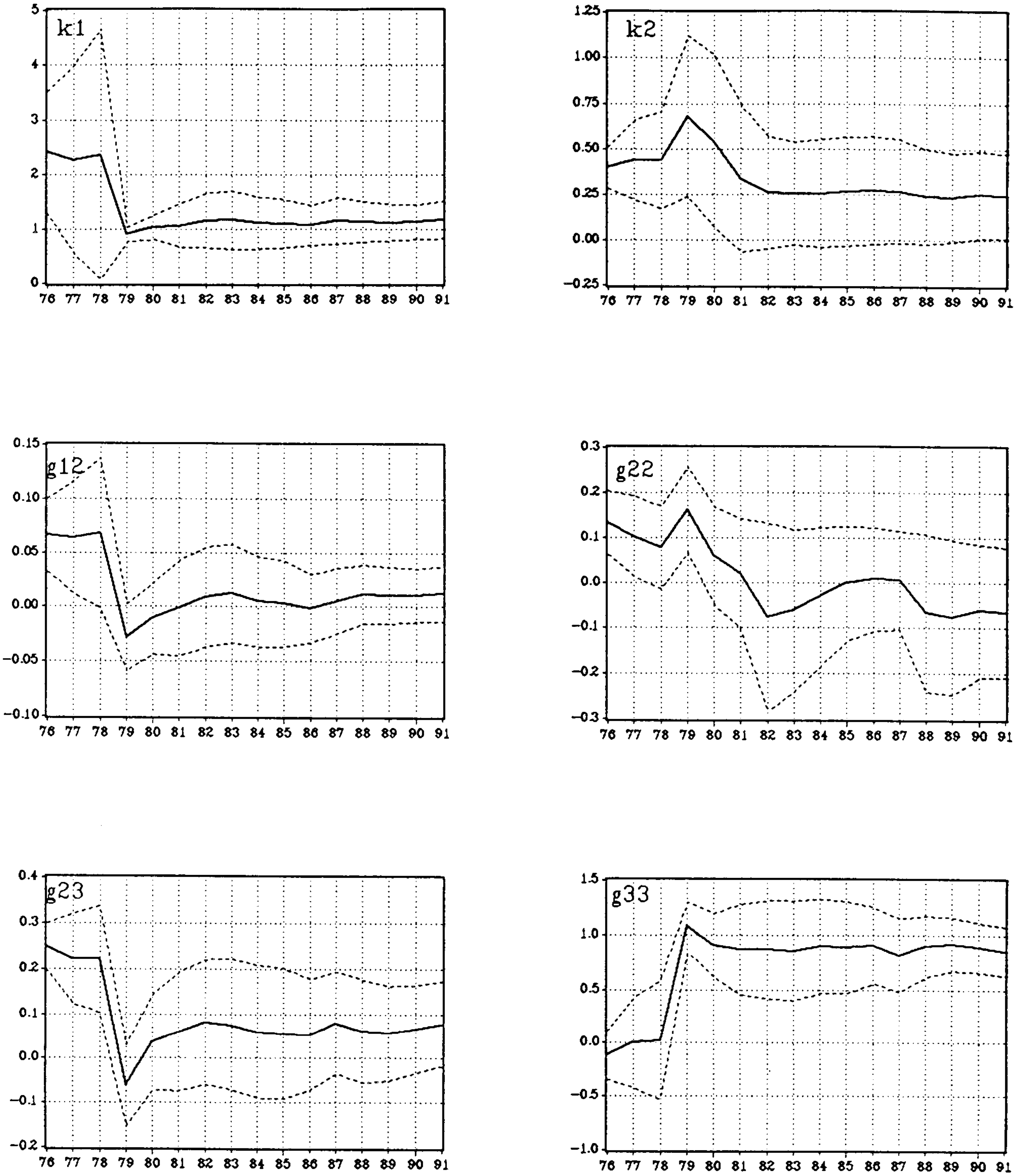
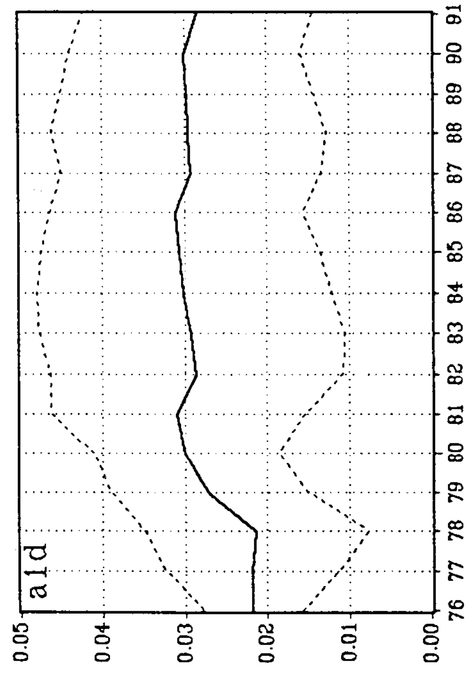


*Figure A3.4.3 Recursive estimation of table 3.7.3, T^1. Variable starting year: estimate ± 2 * standard error.*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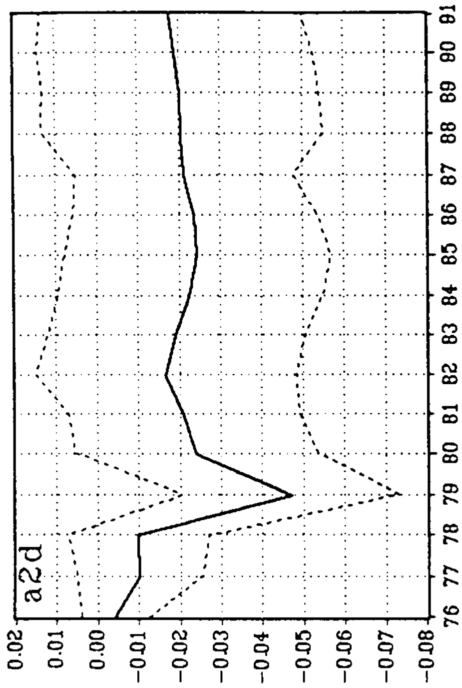
0.04
0.03
0.02
0.01
0.00
76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91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0.00
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−0.04
−0.05
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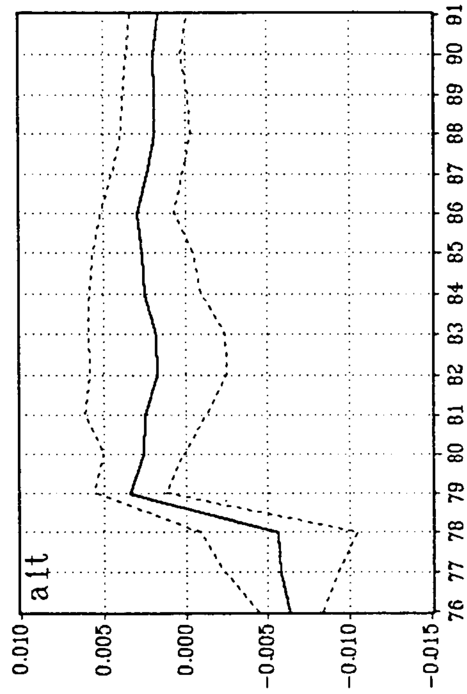
−0.07
−0.08
76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91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0.005
0.000
−0.005
−0.010
−0.015
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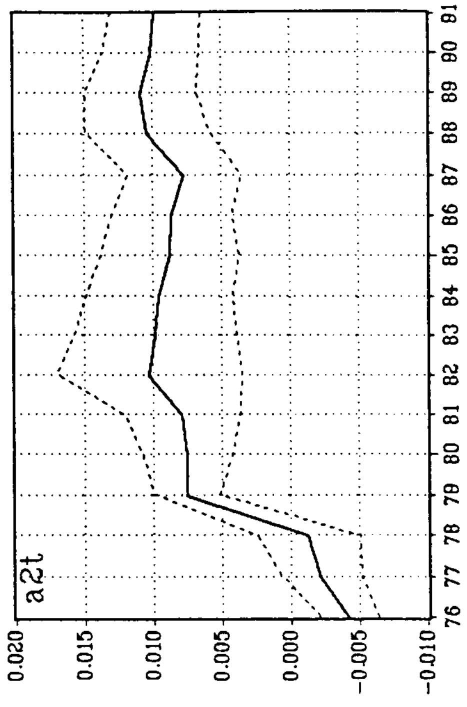
a2t
0.020
0.015
0.010
0.005
0.000
−0.005
−0.010
76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91

I.4. Aggregate household demand for energy

I.4.1. Introduction

In ADAM, the aggregate demand for energy by the households is specified in the two aggregates, "heating etc." and "gasoline and oil for transport equipment". This chapter contains an econometric determination of the allocation of expenditures of "heating etc." between heating and non-heating electricity, leaving expenditures on heating to be allocated between 5 fuels by a "technical model". The chapter also explores the room for a joint modelling of the demand for gasoline and purchased transport.

I.4.2. Theory

According to standard neoclassical theory, the consumer's preferences for the vector of n goods, $X=[X_1,X_2,\dots,X_n]$, can be represented by a twice differentiable, monotonically increasing and strictly quasi-concave utility function[12]

eq. 4.2.1 $U = U(X)$

Maximization of eq. 4.2.1 under the budget constraint

eq. 4.2.2 $P'X = Y$

where P is the price vector, and Y the total budget, leads to the (Marshall- or market-) demand functions

eq. 4.2.3 $X = X(Y,P)$

By log-differentiation the demand functions can be expressed in the Slutsky form decomposing the total price effect in a substitution effect and an income effect. Expressed in elasticities

eq. 4.2.4 $e_{ij} = e_{ij}^{k} - e_i S_j \qquad i,j=1,\dots,n$

where e_{ij} is the elasticity of X_i with respect to P_j, e^k_{ij} is the compensated price elasticity, e_i is the budget elasticity of *i*, and S_j is the budget share of *j*.

---

[12] See for example Deaton and Muellbauer (1980a) or Barten og Böhm (1982). For a condensed exposition, see Barten (1993).

There are three fundamental exact restrictions on the demand functions (from which others can be derived). Adding-up or Engel-aggregation

eq. 4.2.5 $$\sum_{i=1}^{n} S_i e_i = 1 ,$$

homogenity of degree zero in P and Y

eq. 4.2.6 $$\sum_{j=1}^{n} e_{ij} = -e_i ,$$

and Slutsky-symmetry

eq. 4.2.7 $$S_i e_{ij}^{k} = S_j e_{ji}^{k}$$

Finally the negativity condition: For every n-dimensional vector Z not equal to the null vector the inequality

eq. 4.2.8 $$\sum_{i=1}^{n}\sum_{j=1}^{n} Z_i S_i e_{ij}^{k} Z_j < 0 \qquad (\Rightarrow e_{ii}^{k} < 0)$$

applies. The matrix $[S_i e^k_{ij}]$ is negative semidefinite.

The indirect utility function is defined by insertion of eq. 4.2.3 into eq. 4.2.1

eq. 4.2.9 $$V(Y,P) = \begin{matrix} \max U(X) \\ s.t.\ P'X=Y \end{matrix}$$

and shows the maximum utility obtainable given Y and P.

The dual of eq. 4.2.9, the cost (or expenditure) function, shows the minimum costs necessary to obtain the utility U given P

eq. 4.2.10 $$C(U,P) = \begin{matrix} \min P'X \\ s.t. U(X)=U \end{matrix}$$

The cost function in P is monotonically increasing, homogenous of degree zero and concave.

An important result is Shepards lemma

eq. 4.2.11 $$S_i = \frac{\partial \log C}{\partial \log P_i}$$

where log denotes natural logarithm. In practice it is difficult to arrive at empirically operationable demand functions starting form a specified utility function, because it involves the solution of a constrained maximization problem. Alternatively it is often easier to start with a specified cost function arriving at the demand functions or share functions by applying Shepard's lemma (or to start with a specified indirect utility function and apply the so-called Roy's identity).

The restrictions eq. 4.2.5 - eq. 4.2.7 reduce the number of independent price and budget effects from n(n+1) to ½(n^2+n)-1. Although this is more than a halving, further restrictions often in the form of separability and multistep maximization assumptions are clearly necessary in many applications.

The utility function is weakly separable in the grouping 1,..,m, when it can be written as

$$\text{eq. 4.2.12} \qquad U(X) = f(U_1(X_1),...,U_r(X_r),...,U_m(X_m)) \,, \quad X_r = [X_{r_1},...,X_{r_{n_r}}]$$

where $U_r(X_r)$ r=1,...,m are sub utility functions. Eq. 4.2.12 implies the restrictions

$$\text{eq. 4.2.13} \qquad e_{ij}^k = \Phi_{ab} e_i e_j S_j \,, \quad i \in X_a \wedge j \in X_b \,, a \neq b$$

The utility function is strongly separable, when it can be written as

$$\text{eq. 4.2.14} \qquad U(X) = f(U_1(X_1) + ... + U_r(X_r) + ... + U_m(X_m))$$

which implies the restrictions

$$\text{eq. 4.2.15} \qquad e_{ij}^k = \Phi e_i(\delta_{ij} - e_j S_j) \,, \quad \begin{matrix} \delta_{ij} = 1, & i=j \\ \delta_{ij} = 0, & i \neq j \end{matrix} \quad i \in X_a \wedge j \in X_b \,, a \neq b$$

where Φ is the inverse "money flexibility".[13] Eq. 4.2.15 tells that substitution between two goods from different groups only reflects the two goods' budget dependency. The factor of proportionality, Φ, is the same regardless of the groups. This is a much stronger restriction than eq. 4.2.13, where the factor of proportionality varies with the groups.

The utility function is additive, if each group X_r in eq. 4.2.14 consist of one good only. In case of many goods the budget shares are small, and according to eq. 4.2.15 the compensated own price elasticities are then approximately proportional to the budget elasticities with a common factor of proportionality, Φ, while the compensated cross price elasticities are approximately zero. In case of more than a handful of goods the additivity assumption becomes very restrictive.

The utility function is homothetic if it can be written as a strictly monotone increasing function of a function, which is homogene

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[13] The money flexibility is defined as the elasticity of the marginal utility of money with respect to the budget.

of degree one. Then utility is "produced" under constant returns to scale and the corresponding cost function can be written as

$$\textit{eq. } 4.2.16 \qquad C(U,P) = Ub(P)$$

where b(P) is homogenous of degree zero and concave. This implies expenditure proportionality, i.e. $e_i=1$ for all *i*.

Two-stage maximization in a broad sense implies that the optimization problem of the consumer can be solved in two stages: First the total budget is allocated to broad groups of goods with reference to aggregate price indices for these groups, and second for each group the group's budget is allocated to the goods inside the group with sole reference to prices of these goods.

Weak separability is a necessary and sufficient condition for stage 2, i.e. for the existence of conditional demand functions, which determines the demand for each good inside a group as a function of the group budget, C_r, and the prices of the goods in that group. Then there also exists well-behaved group cost functions

$$\textit{eq. } 4.2.17 \qquad C_r(U_r,P_r)\,, \qquad P_r = (P_{r_1},\ldots,P_{r_{n_r}})\,, \qquad r=1,\ldots,m$$

Further conditions are necessary for the existence of perfect group price indices, P_r, i.e. for being able to describe stage 1 as maximization of a utility function, U, in group quantity indices, U_r, constrained by $\Sigma P_r U_r = Y$ and where $C_r = P_r U_r$. One possibility is that U_r are homothetic, whereby C_r, cf. 4.2.16, can be written

$$\textit{eq. } 4.2.18 \qquad C_r(U_r,P_r) = U_r P_r\,, \qquad P_r = b(P_{r_1},\ldots,P_{n_r})$$

but homothecity is nearly always an unacceptable restriction on consumer demand (expenditure proportionality), whereas it is a much more acceptable restriction on producer factor demand (constant returns to scale). The group indices should be defined by the functional forms eq. 4.2.17, which normally deviates from the national account indices. Or one might instead assume the more restrictive condition of strong separability of U(X) and that C_r in return take the less restrictive "generalized Gorman polar form" (a generalization of eq. 4.2.16). Alternatively one might impose restrictions on the variables instead of on the functional forms, for example that the relative prices or quantities inside a group are constant, but normally this is not reasonable.

In conclusion, the conditions for existence of perfect group indices are often too restrictive in consumer demand applications (as opposed to producer demand applications) and national accounts indices can be used as a hopefully useful approximation. But it is important that data are aggregated in accordance with (approximately) valid separability restrictions. However, these restrictions are often basically impossible to test empirically because demand equations obeying only the general restrictions eq. 4.2.5 - eq. 4.2.8 contain too many parameters.

In conditional demand functions only partial elasticities are identified. The total elasticities (superscript T) for good *i* and *j* belonging to group E are calculated by the formulas

eq. 4.2.19 $$e_i^T = e_i e_{EY}$$

eq. 4.2.20 $$e_{ij}^T \approx e_{ij} + e_i S_{E_j}(e_{EE}+1)$$

where e_{EE} is the own price elasticity of E,
e_{EY} is the budget elasticity of E,
S_{Ej} is *j*'s budget share of E.

To hold exactly, eq. 4.2.20 assumes that the group price indices are defined as geometric averages, cf. Appendix I.4.1.

Finally it should be stressed that the stated theory deals only with the individual (or single household) demand only. Without further and strong restrictions on the preferences of the individuals and/or the distribution of income the aggregate demand functions will not obey eq. 4.2.5 - 4.2.8. As is common in macro models, we shall ignore the problem of aggregation of individuals and simply assume, that the aggregate behaviour can be rationalized by means of a representative consumer obeying the theory of the individual. This also justifies our supplementary use of "ad hoc" specifications (such as log-linear forms) which are then in reality not more ad hoc than macro consumer demand systems.

I.4.3. Consumer demand systems

Two demand systems are considered: The very simple Dynamic Linear Expenditure System (DLES), cf. for example Phlips (1983), and the flexible Almost Ideal Demand System (AID) of Deaton and Muellbauer (1980b) dynamized by means of an Error Correction Mechanism (ECM).

I.4.3.1. The Dynamic Linear Expenditure System (DLES)

Maximizing the static Stone Geary utility function

eq. 4.3.1 $$U = \sum_{i=1}^{n} \beta_i \log(X_i - \gamma_i)\ , \quad 1 > \beta_i > 0\ , \quad \sum_{i=1}^{n} \beta_i = 1\ , \quad X_i > \gamma_i$$

given the budget constraint eq. 4.2.2, leads to the expenditure functions

$$eq.\ 4.3.2 \qquad P_iX_i = P_i\gamma_i + \beta_i(Y-\sum_{j=1}^{n} P_j\gamma_j)$$

linear in prices and the budget. A common interpretation is, that first the consumer decides to buy the "minimum" quantities of each good represented by the γ-vector, and then divides the remaining "supernumerary" income among goods in fixed proportions shown by the β-vector, cf. the last term of eq. 4.3.2. However, it is not fruitful to restrict all the elements of γ to be non-negative, as this would imply that the demand for all goods were inelastic, and that all cross-price elasticities were negative, cf. eq. 4.3.4 below.

The LES is additive and quasi-homothetic containing the homothetic Cobb-Douglas function as a special case for γ=0. In short, there are only 2n-1 free parameters, which severely restricts behaviour. This is also reflected in the budget and price elasticities

$$eq.\ 4.3.3 \qquad e_i = \frac{\beta_i}{S_i}, \qquad e_i>0$$

$$eq.\ 4.3.4 \qquad e_{ij} = \frac{(P_j\gamma_j)(\delta_{ij}-\beta_i)}{P_iX_i} - \delta_{ij}, \qquad e_{ii}<0$$

where δ_{ij} is the Kronecker delta as usual. The matrix of substitution effects is given by

$$eq.\ 4.3.5 \qquad c_{ij} = \frac{-(\delta_{ij}-\beta_i)}{P_i}(X_j-\gamma_j), \qquad c_{ii}<0, \qquad c_{ij}>0,\ i\neq j$$

In statistical estimation on time series, the normally strong correlation between budget and expenditures normally determines the marginal budget shares. The prices on other goods enter the expenditure functions only in a uniform way working through the "supernumerary" budget and accordingly the β_i's. Therefore the estimated compensated price effects virtually do not reflect much more than the estimated budget effects (the β_i's), cf. eq. 4.3.5. An implication of additivity is that all goods are restricted to be Hicks-substitutes ($c_{ij}>0$, $i \neq j$).

The static utility function can be dynamized by assuming that the minimum consumption of good *i* is a linear functions of lagged consumption interpreted as habit formation, cf. Phlips (1983). In the simplest version, there is only one lag. Entering at the same time an additional explaining variable, F_i, linearly in the expression for minimum consumption (to preserve the linearity properties)

$$eq.\ 4.3.6 \qquad \gamma_i = \gamma_i^0 + \gamma_i^1X_{i,t-1}^1 + \gamma_i^2F_{i,t}$$

the dynamic utility function becomes

$$eq.\ 4.3.7 \quad U_t = \sum_{i=1}^{n} \beta_i \log(X_{i,t} - \gamma_i^0 - \gamma_i^1 X_{i,t-1} - \gamma_i^2 F_{i,t}) ,$$

$$1 > \beta_i > 0, \ \sum_{i=1}^{n} \beta_i = 1, \ X_i > \gamma_i$$

Maximizing this subject to the budget constrain leads to the contemporaneous expenditure functions here expressed in budget shares

$$eq.\ 4.3.8 \quad S_{i,t} = \frac{P_{i,t}(\gamma_i^0 + \gamma_i^1 X_{i,t-1} + \gamma_i^2 F_{i,t})}{Y_t} + \beta_i \left[1 - \frac{\sum_{j=1}^{n} P_{j,t}(\gamma_j^0 + \gamma_j^1 X_{j,t-1} + \gamma_j^2 F_{j,t-1})}{Y_t} \right]$$

The long run budget shares (marked by an asteric) are given by

$$eq.\ 4.3.9 \quad S_{i,t}^* = \frac{P_{i,t}^*(\gamma_i^{0*} + \gamma_i^{2*} F_{i,t}^*)}{Y_t^*} + \beta_i^* \left[1 - \frac{\sum_{j=1}^{n} P_{j,t}^*(\gamma_j^{0*} + \gamma_j^{2*} F_{j,t}^*)}{Y_t^*} \right]$$

and can be conceived as derived from constrained maximization of the long run utility function

$$eq.\ 4.3.10 \quad U_t^* = \sum_{i=1}^{n} \beta_i^* \log(X_{i,t}^* - \gamma_i^{0*} - \gamma_i^{2*} F_{i,t}^*) ,$$

$$\sum_{i=1}^{n} \beta_i^* = 1 , \quad X_i^* > \gamma_i^{0*} + \gamma_i^{2*} F_{i,t}^*$$

and where the long run parameters are derived from the short run following

$$eq.\ 4.3.11 \quad \gamma_i^{0*} = \frac{\gamma_i^0}{(1-\gamma_i^1)} , \quad \gamma_i^{2*} = \frac{\gamma_i^2}{(1-\gamma_i^1)} , \quad \beta_i^* = \frac{\beta_i/(1-\gamma_i^1)}{\sum_{j=1}^{n} \beta_j/(1-\gamma_j^1)}$$

If the budget, the prices and other explaining variables remain unchanged, the budget shares will gradually adapt to their long run values eq. 4.3.9 with the adjustment speeds $(1-\gamma_i^1)$. For all $\gamma_i^1=0$, the adjustment is instantaneous. Delayed adjustment is seen as consistent with rational utility maximizing behaviour, where habit formation affects the consumers preferences in the short run.

If the additional explaining variable is trended, the negativity condition might be abandoned. For example in forecasts, a linear positive trend will eventually result in the "minimum consumption" exceeding actual consumption for that good. The short run elasticity of X_i with respect to F_i is

$$\text{eq 4.3.12} \qquad e_{iF} = \gamma_1^2(1-\beta_i)\frac{F_i}{X_i}$$

The long run elasticities are again found by substituting the long run parameters.

I.4.3.2 The Almost Ideal Demand System (AID)

In general, dynamization by assuming habit formation does not lead to share (demand) functions which can be rationalized by constrained maximization of a long run utility function, as it does in the simple case of the DLES, cf. Pollak and Wales (1992, p. 110). The AID is significant more flexible in describing the budget and price effects, but at least until now less elegant dynamizations have been offered for the AID. This is an important matter, as it is often the long run elasticities, which are of the greatest interest, and because in small samples the statistical estimation is often very dependent on the chosen dynamization.

The starting point for the static AID is the cost function

$$\text{eq. 4.3.13} \qquad \log C(U,P) = (I-U)\log a(P) + U\log b(P)$$

where *log*a(P) represents the cost at zero utility ("subsistence") and U*log*b(P) represents the cost of achieving additional utility. If a(P) and b(P) are both positive and homogenous of degree zero, the same also applies to the cost function.

Demanding that all the first and second order partial derivatives of eq. 4.3.13 in a basic point is equal to that of any arbitrary cost function, one ends up with the following expressions for *log*a(P) and *log*b(P)

$$\text{eq. 4.3.14} \qquad \log a(P) = \alpha_0 + \sum_{k=1}^{n} \alpha_k \log P_k + \frac{1}{2}\sum_{k=1}^{n}\sum_{l=1}^{n} \gamma_{kl}^{*} \log P_k \log P_l$$

$$\text{eq. 4.3.15} \qquad \log b(P) = \log a(P) + \beta_0 \prod_{k=1}^{n} P_k^{\beta_k}$$

Applying Shepards lemma on the resulting cost function, substituting for U and generalizing α_i to be a log-linear function of an extra variable, F, ($\alpha_i = \alpha^o_i + \alpha^1_i \log F$), the budget share functions can be derived as

$$eq.\ 4.3.16 \qquad S_i = \alpha_i^0 + \alpha_i^1 \log F + \sum_{j=1}^{n} \gamma_{ij} \log P_j + \beta_i \log(Y/P^o)$$

where P^o is an aggregate price index defined by

$$eq.\ 4.3.17 \qquad \log P^o = \alpha_0 + \sum_{k=1}^{n} \alpha_k \log P_k + \frac{1}{2}\sum_{k=1}^{n} \sum_{l=1}^{n} \gamma_{kl} \log P_k \log P_l$$

taking $\gamma_{ij}=(\gamma_{ij}^* + \gamma_{ji}^*)/2$. Approximating P^o by the geometric average (Stones index)

$$eq.\ 4.3.18 \qquad \log P^o = \sum_{k=1}^{n} S_k \log P_k$$

simplifies the model considerably.

The expenditure elasticities are given by

$$eq.\ 4.3.19 \qquad e_i = 1 + \beta_i/S_i$$

while the price elasticities given eq. 4.3.18 are

$$eq.\ 4.3.20 \qquad e_{ij} = -\delta_{ij} + (1/S_i)(\gamma_{ij} - \beta_i S_j)$$

where again δ_{ij} is the Kronecker delta. The elasticities with respect to F are

$$eq.\ 4.3.21 \qquad e_{iF} = \alpha_i^1/S_i$$

The adding-up restriction requires

$$eq\ 4.3.22 \qquad \sum_{i=1}^{n} \alpha_i = 1\,, \quad \sum_{i=1}^{n} \beta_i = 0\,, \quad \sum_{i=1}^{n} \gamma_{ij} = 0, \qquad \forall j=1,\dots,n$$

Homogenity is satisfied if

$$eq.\ 4.3.23 \qquad \sum_{j=1}^{n} \gamma_{ij} = 0, \quad \forall i=1,\dots,n$$

while symmetry demands

$$eq.\ 4.3.24 \qquad \gamma_{ij} = \gamma_{ji} \quad \forall i \neq j$$

The negativity condition requires, that the matrix $[c_{ij}]$ of compensated cross price effects for each period is negative semidefinite:

$$eq.\ 4.3.25 \qquad c_{ij} = \gamma_{ij} + \beta_i \beta_j \log(Y/P^o) - \delta_{ij} S_i + S_i S_j$$

The AID shares the quality of all flexible forms that there are sufficient parameters to describe a variety of interactions. Eq. 4.3.16 can describe luxuries ($ß_i>0$), unitary budget elasticities

($\beta_i=0$), and necessities and even inferior goods ($\beta_i<0$). The own and cross price effects are also much less restricted than in the LES as each (log-) price enters each share equation separately with its own parameter γ_{ij}. The α_i's are equal to the budget shares when all prices are equal to 1 (as in the base year) and the budget is equal to α_0, i.e. the "subsistence" budget.

In the case of two goods there are only three free parameters (given the theoretical restrictions) or the same as for the LES reflecting that the additivity assumption of the LES is not so compelling in the case of only two goods. The AID might still provide a more fruitful functional form. It also allows for a more flexible determination of budget effects.

As for other flexible forms there is no guarantee that negativity and non-negative budget shares will prevail at some distance from the basic point. For example, these two inequality restrictions can be tested and accepted in-sample, but still break down in out-of-sample applications.

The capability to approximate any arbitrary cost function by second order implies that the corresponding demand functions approximate any arbitrary demand system by first order.

The static AID eq. 4.3.16 will be dynamized by means of a standard error correction mechanism (ECM), cf. chapter I.3.4. This assumes that utility maximization only prevails in the long run, while inertia and adjustment costs imply a gradual adaption in the short run specified in this essentially ad hoc manner.

The simple ECM assumes the same adjustment speed for all goods. In the application below with only two goods this is not restrictive.

I.4.4. Ad hoc specifications

Complete consumer demand systems based on utility maximization in a sense work as a straight-jacket to the specification: Changing some of the basic assumptions might easily lead to complicated equations which can not be estimated. As we want to test some of these basic assumptions (especially reversibility) we shall then resort to specifications not based on exact utility maximization. We name them "ad hoc" specifications although the practice of assuming a representative consumer is clearly also of ad hoc nature, cf. section I.4.2. The "ad hoc" specifications are interpreted as crude approximations to the unknown aggregate demand functions.

Assume that the long run demand for energy, E^*, can be written as a function of the total budget (or income), Y, and the price of energy, P_E, both relative to some general non-energy price index, P, and some measure of the climate (degree-days or the like), G, in the convenient log-linear model exhibiting constant elasticities (denoted by greek letters)

$$eq.\ 4.4.1 \quad \log E^* = \alpha + \beta \log(Y/P) + \Phi \log(P_E/P) + \pi \log G$$

We want to examine whether this long run demand schedule is subject to shifts so that a given price-budget combination leads to different long run levels of demand depending on the time period and/or earlier price-budget movements. Two different types of shifts are examined: Exogenous shift of the long run schedule and non-reversible long run schedule. We shall also discuss asymmetric short run adaptions to a given long run schedule which is a related subject. Some of these models can be mixed but are discussed separately for clarification.

I.4.4.1 Exogenous shifts of the long run demand schedule

The simplest way to model such shifts is to add an additional explaining variable, T,

$$eq.\ 4.4.2 \quad \log E^* = \alpha + \beta \log(Y/P) + \Phi \log(P_E/P) + \pi \log G + \tau T$$

which produces shifts in the demand schedule which - due to the log linear functional form - do not affect the price and budget elasticities but only the constant term. If T is time, τ marks a constant rate of shifts of the demand schedule. It is trivial to modify this constant rate by adding for example a quadratic trend term or sudden exogenous shifts by means of dummy variables or "economic" exogenous variables such as the stock of relevant capital equipment. Contrary to non-reversibility, such modifications can often also be easily entered in most utility based demand systems.

A negative trend in eq. 4.4.2 can often be interpreted as some kind of fuel conserving "technological progress". An important and difficult question is, to what extent the energy conserving measures are determined from the supply side (the producer) or from the demand side (the consumer), i.e. to what extent they are exogenous to consumer demand. For example, on one hand the oil price hikes of the 1970s increased the supply of more fuel efficient automobiles which were not available before at a corresponding quality. This marked a technological progress from the supply side exogenous to consumer demand. On the other hand, the consumers were still free to demand less fuel efficient automobiles which were still supplied and to perform less fuel efficient (faster and less gentle) driving. Enhanced fuel efficiency often goes along with smaller vehicles. Increased average fuel efficiency of the automobile stock is therefore also a consequence of consumers responding to past relative fuel price hikes. In econometric terms, the impact of inserting a trend or other variables representing enhanced fuel efficiency as in eq. 4.4.2 would then often be to underestimate the long run price elasticity of demand numerically.

In one respect consumers are always free to demand less fuel efficient equipment. All fuel conserving measures are in the last resort a consequence of consumers responding to relative fuel prices. On the other hand, in some areas there seem to be a rather steady increase of fuel efficiency, which runs relatively independent of the course of fuel prices, and which looks more like a "general" technological progress stemming from the supply side. If so, it is proper to treat fuel efficiency as exogenous to demand. If in addition data for fuel efficiency in fact exists, it is more appropriate to utilize this information and formulate consumption and prices in efficiency terms. Eq. 4.4.2 is then replaced by

$$eq.\ 4.4.3 \quad \log E^{\circ *} = \alpha + \beta\log(Y/P) + \Phi\log(P_E{}^{\circ}/P) + \pi\log G$$

where $E^{\circ} = E/I$

$P_E{}^{\circ} = P_E I$

I = index of inverse fuel efficiency.

I.4.4.2 Differential responses

An interesting question is, whether the demand for energy responds different to energy price rises and drops. A priori it might be expected that the price elasticity is numerically larger for price rises than for price drops. Price rises induce endogenous "technological changes", which may not be fully reversed in case of price drops. In the case of heating, examples are increased insulation and implementing more fuel efficient technologies which increase the utilization rates of the various fuels.

In a structural model one would operate with two equations. First the "technological variable" (as for example some measure of the average insulation standard) is entered in the ordinary energy demand schedule (put T in eq. 4.4.2 equal to this variable), where it is probably virtually uncorrelated with the current price. Such energy saving measures mostly involve investments which only influence the relevant capital stock after some time. This is reflected by the second equation linking the "technological variable" to past and expected real energy prices and other variables. This "technological variable" might react diversely to energy price increases and declines, which should be accounted for in the reduced form single equation model where the "technological variable" is eliminated. The reduced form is preferred when the "technological variable" is too difficult to measure or to model.

Two patterns of diverse price impacts are distinguished:

(i) Non-reversibility: Shifts of the long run demand schedule. This occurs if for example the cost of developing energy saving measures are covered during a period of high energy prices, and -

when it first exists - the new technology is not more expensive to implement for the consumer. Examples could be more fuel efficient heating appliances or more fuel efficient automobiles.

(ii) Asymmetry: Different adjustment speeds to a given long run demand schedule. This might occur if expectations steadily are, that the trend of long run real energy prices is surely upward, for example because most fuels are exhaustible resources and because steady increases of environmental taxes on most fuels seem likely. A drop in energy prices is then expected to be temporary having only minor short run effects on demand for fuels, whereas price rises just stimulates the expectations of further rises.

If the relevant capital equipment is long lasting and gross investments and scrapping only amounts to little of the total stock, it might be difficult empirically to distinguish between asymmetry and non-reversibility in short samples. Heating and insulation is one example. The average durability of the residential stock is several times larger than the maximum regression period of 26 years on our data.

I.4.4.2.1 Non-reversible demand schedules

Jackson and Smyth (1985) have specified non-reversibility in a way which contains earlier specifications such as the "ratchet" and the "jagged ratchet" as special cases. Their model is described in box 4.4.1, where for simplicity it is assumed, that the demand for energy, E, depends only on the price of energy, P_E, abstracting at the moment from other explaining variables (D is the difference operator). The sample is divided into three segments according to the change of the energy price: One where the price is increasing and each new observation marks a maximum, $P_{Et}^{(1)}$, one where it is increasing but still below an earlier maximum, $P_{Et}^{(2)}$, and one where it is declining, $P_{Et}^{(3)}$. By estimating separate parameters for each of the three segments, it can be tested whether they all differ significantly, whether some of them are identical collapsing to either the ratchet of the jagged ratchet as special cases, or whether they are all identical as in the reversible specification.

If both prices and quantities are entered in log terms the slope is equal to the price elasticity. The intercept is seldom of any interest in itself. However, inappropriate restrictions on the intercept lead to a biased estimate of the slope. This is a serious drawback of the conventional simple dummy variable approach of dealing with differential responses.

The bottom figures of box 4.4.1 give a graphical illustration of the model based on a numerical example. Figure E shows the assumed path of the energy price in this example which roughly pictures the actual development in 1966-1991. Depending on different parameter restrictions, figure A-D depict the corresponding demand schedules. Figure D is the ordinary reversible

Box 4.4.1 A log-linear version of Jackson and Smyth's (1985) non-reversible specification

Eq. 4.4.4.
$$\log E_t = \Phi_0 + \Phi_1 \log P_{E_t}^{(1)} + \Phi_2 \log P_{E_t}^{(2)} + \Phi_3 \log P_{E_t}^{(3)}$$

$$\text{where} \quad P_{E_t}^{(1)} = \begin{Bmatrix} P_{E_0} + \sum_{v=1}^{t} DP_{E_v} \;\; \text{if} \;\; P_{E_v} = P_{E_t}^{\max} \\ 0 \quad \text{otherwise} \end{Bmatrix}$$

$$P_{E_t}^{(2)} = \begin{Bmatrix} \sum_{v=1}^{t} DP_{E_v} \;\; \text{if} \;\; P_{E_{v-1}} \leq P_{E_v} < P_{E_t}^{\max} \\ 0 \quad \text{otherwise} \end{Bmatrix}$$

$$P_{E_t}^{(3)} = \begin{Bmatrix} -P_{E_0} + \sum_{v=1}^{t} DP_{E_v} \;\; \text{if} \;\; P_{E_v} < P_{E_{v-1}} \\ 0 \quad \text{otherwise} \end{Bmatrix}$$

$v=1,\ldots,t;\;\; t=1,\ldots,T.$

Segment of sample	Intercept	Slope
s=1: Peak to peak increases	$\Phi_0 + \Phi_2 \log P_{E_t}^{(2)} + \Phi_3 \log P_{E_t}^{(3)}$	Φ_1
s=2: Trough to peak increases	$\Phi_0 + \Phi_1 \log P_{E_t}^{(1)} + \Phi_3 \log P_{E_t}^{(3)}$	Φ_2
s=3: Declines	$\Phi_0 + \Phi_1 \log P_{E_t}^{(1)} + \Phi_2 \log P_{E_t}^{(2)}$	Φ_3

Null hypothesis	Parameter restriction	Graphical illustration
Acceptable	$\lvert\Phi_2\rvert \geq \lvert\Phi_3\rvert$	Figure A
Jagged ratchet	$\Phi_1 = \Phi_2$	Figure B
Ratchet	$\Phi_2 = \Phi_3$	Figure C
Reversible	$\Phi_1 = \Phi_2 = \Phi_3$	Figure D

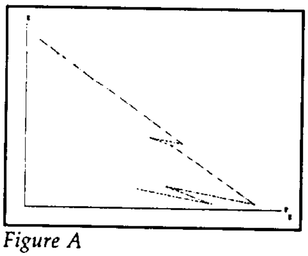

Figure A

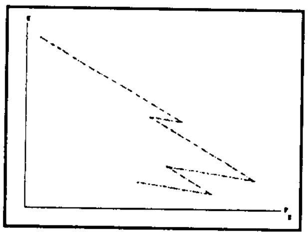

Figure B

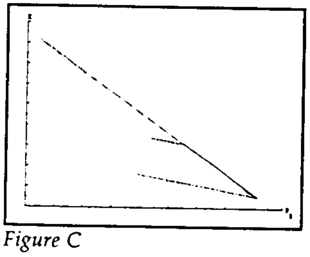

Figure C

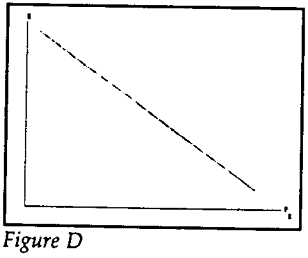

Figure D

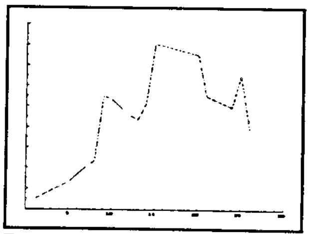

Figure E

Note: Figure A-D, log P_E on abcisse, log E on ordinate. Figure E, T on abcisse, log P_E on ordinate. See text for further explanations.

demand curve (with axis reversed) displaying a constant price elasticity (as the axis are displayed in log scale).

The ratchet (figure C) assigns a lower numerical price elasticity to price movements below earlier maximum, but assumes the same demand curve for all price increases above earlier maximum. In that respect, the ratchet is not a true irreversible model. On the contrary, the jagged ratchet (figure B) allows for enduring shifts of the long run demand curve each time the sign of the price change shifts. Finally, the most general model (figure A) allows for the demand curve to shift also according to whether the price increase occurs below earlier maximum or not. The condition $|\Phi_2| \geq |\Phi_3|$ for the most general model to be acceptable rules out "walk overs", i.e. that the demand curve can cross itself which contradicts non-reversibility.

I.4.4.2.2 Asymmetric short run adaptions to a given long run demand schedule

Assuming the long run equilibrium eq. 4.4.2, the long run equilibrium error is

$$\textit{eq. } 4.4.5 \qquad u_t = \log E_t - (\alpha + \beta \log(Y_t/P_t) + \Phi \log(P_{E_t}/P_t) + \pi G_t + \tau T)$$

Asymmetric adjustment can be modelled by splitting the sample according to whether the long run equilibrium errors are positive or negative and estimate separate error correction parameters, γ^+ and γ, to each

$$\textit{eq. } 4.4.6 \qquad D\log E_t = \beta^k D\log(Y_t/P_t) + \Phi^k D\log(P_{E_t}/P_t) + \pi^k D\log G_t + \gamma^+ u^+_{t-1} + \gamma^- u^-_{t-1}$$

where

$$\textit{eq. } 4.4.7 \qquad u_t^+ = \begin{Bmatrix} u_t & \textit{if } u_t \geq 0 \\ 0 & \textit{otherwise} \end{Bmatrix} \qquad u_t^- = \begin{Bmatrix} u_t & \textit{if } u_t < 0 \\ 0 & \textit{otherwise} \end{Bmatrix}$$

Escribano and Pfann (1990) have proposed a different specification of the same main idea. They substitute u_t^+ and u_t^- with u_t^g and u_t^d defined as

$$\textit{eq. } 4.4.8 \qquad u_t^g = \begin{Bmatrix} u_t & \textit{if } u_t \geq u_{t-1} \\ 0 & \textit{otherwise} \end{Bmatrix} \qquad u_t^d = \begin{Bmatrix} u_t & \textit{if } u_t < u_{t-1} \\ 0 & \textit{otherwise} \end{Bmatrix}$$

i.e. focusing on whether the deviations from the long run equilibrium are increasing or declining.

The model can be estimated by the Engle Granger two step procedure for cointegrated time series provided the series in levels are integrated of first order. If it can not be rejected that $\gamma_t^+=\gamma_t^-$ in the step two regression the model collapses to the standard symmetric error correction model.

I.4.5. Modelling strategy and specification

Figure 4.4.1 gives an overview of the determination of total private consumption and its distribution on 11 groups of goods in ADAM. The figure also indicates the sub model for "heating etc." presented in this report.

Real disposable income and wealth are arguments in a macro consumption function determining total private consumption defined as to include depreciations of the automobile stock instead of automobile purchases.

Gross rents are determined by the residential stock (formulated in absolute changes) reflecting the compilation of the national account figures. Historically, the Danish housing market has been heavily regulated. The remaining part of the total budget is allocated to 8 aggregates including "heating etc." and "transport" in a DLES specification, i.e. it is assumed, that the goods belonging to each of the two energy aggregates are strongly separable from all goods outside of that aggregate. Consumption of "transport" is allocated on automobile depreciations, gasoline and purchased transport in ad hoc equations.

Automobile purchases are determined by a capital adjustment model in real disposable income and wealth as well as the real

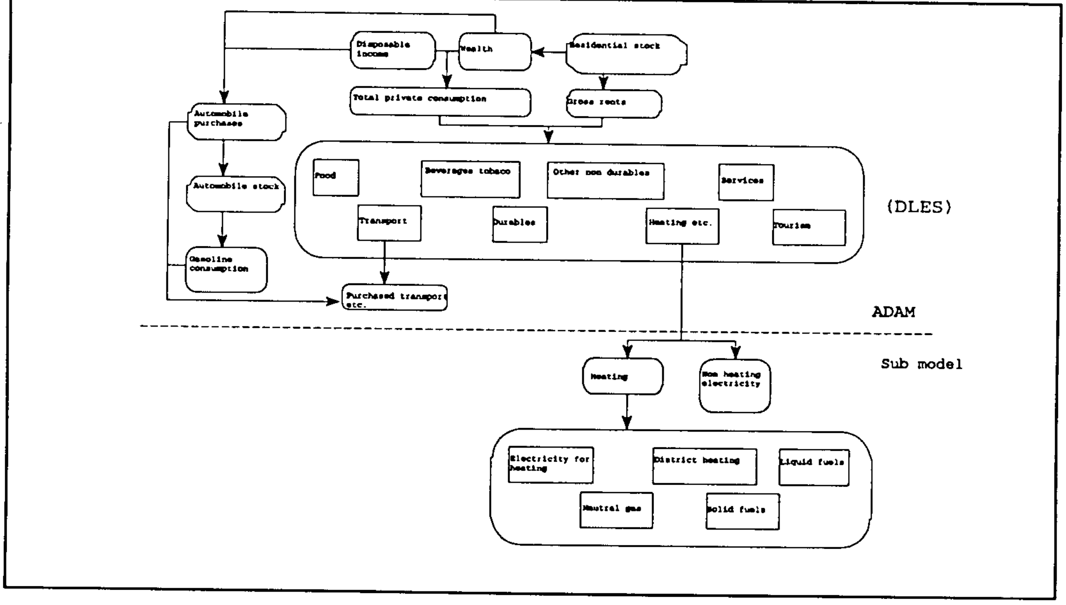

Figure 4.4.1 Determination of private consumption in ADAM
Source: Based on Danmarks Statistik (1993a).

rate of interest and user costs relative to the price of purchased transport. Automobile depreciations are calculated by applying a fixed depreciation rate. Gasoline consumption is determined in an estimated linear ad hoc demand function with the relative gasoline price, the automobile stock and a trend as arguments. Purchased transport etc. is determined as a residual.

The necessity of determining automobile purchases as an investment which cannot be dealt with by the DLES, while at the same time avoiding durables in the macro consumption function, have lead to this hybrid allocation system.[14]

Our aim is to arrive at equations allocating the demand for heating etc. as determined in ADAM on its sub components, cf. figure 4.4.1, and also explore the room for a joint determination of the allocation of transport expenditures on gasoline and purchased transport in a demand system. Given that the fundamental separability conditions are assumed in ADAM anyway both tasks constitute the problem of identifying the proper conditional demand functions. We will not worry much about whether these conditional demand functions are based on sub expenditure (utility) functions, which makes it possible to calculate perfect aggregate group indices and rely exclusively on national accounts indices, cf. the discussion in section I.4.2.

With 8 aggregates, the untested assumption of strong separability in ADAM might be too restrictive, and in general the DLES might be too simple a model of aggregate consumer behaviour, as the literature often indicates. In any case, a combined model of two stage maximization will, of course, be too poor. For comparison direct "ad hoc" demand equations are also estimated. It is much easier to vary an "ad hoc" specification for example to examine the explanatory power of additional explaining variables violating the separability assumptions, allowing for differential responses etc.

If the estimated elasticities of the total utility based model of two stage maximization deviate from those of the direct ad hoc models, the problem might of course lie solely with the ad hoc models being misspecified. We shall however choose to interpret such deviations as a serious indication that the utility based model might be misspecified. This model is estimated by a more complicated estimation procedure where misspecification for other items of private consumption affects the estimates for the energy items. As the two stage and "ad hoc" models are not nested, an assessment of which model leads to the most valid

---

[14] The purchase of durable goods other than automobiles are however essentially treated like a non-durable in the macro consumption function. The DLES is specified so it is able to deal with the purchase of durables, cf. Phlips (1983), contrary to the more simple specification of section I.4.3.1.

elasticity estimates must essentially be performed by means of judgment.

I.4.5.1. Heating etc.

Heating etc. is disaggregated into the items

I. Electricity for non-heating
II. Heating

where heating consists of the 5 fuels

1. Electricity for heating
2. Natural gas to consumers
3. District heating
4. Solid fuels
5. Liquid non-transport fuels

The allocation of total expenditures on heating etc. on the two sub groups I-II is to be determined by econometric estimated demand functions. The total expenditures on heating can not be allocated on the subgroups 1-5 in this way as this allocation is determined from the supply side to a significant extent, cf. section I.4.7.1.4.

The separability assumptions in ADAM imply that the residential stock does not influence consumption of heating etc. directly. Also, the purchase or stock of durable goods (electrical household appliances) is assumed not to influence consumption of heating etc. (which contains consumption of electricity) directly.[15] These separability restrictions are obviously made for convenience and are empirically doubtful.

I.4.5.2. Transport

As mentioned above the treatment of automobile purchases in ADAM restricts the scope for modelling of transports. Our aim is to investigate, whether joint modelling of the demand for gasoline and purchased transport, keeping the automobile stock as weakly exogenous to the problem, leads to other results.

I.4.6. Data

This section only gives an overview of the nature of the data which are further documented in Appendix I.4.2.

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[15] The purchase of durable goods is determined in ADAMs DLES. The stock of durable goods (or just electrical appliances) are not variables in ADAM.

Data for the single items of heating etc. are based on the energy matrices consistent with national accounts. Data for the distribution of electricity consumption on consumption for non-heating and heating are compiled by DEFU (1993).

Values are defined as expenditures in mill. kr. at purchasers prices inclusive value added tax. Quantities are defined in TJ. Accordingly prices are measured in mill. kr./TJ. However, all prices are rebased to 1 in 1980.

Data for transport consumption are all national account figures from ADAM's data base. Quantities are indicated by values in 1980 prices. The automobile stock is measured in 1000 units.

Data for total consumption and the general consumer price deflator stem from ADAM's database based on national accounts.

All variables for consumption, income, stocks etc. are measured per 1000 residents.

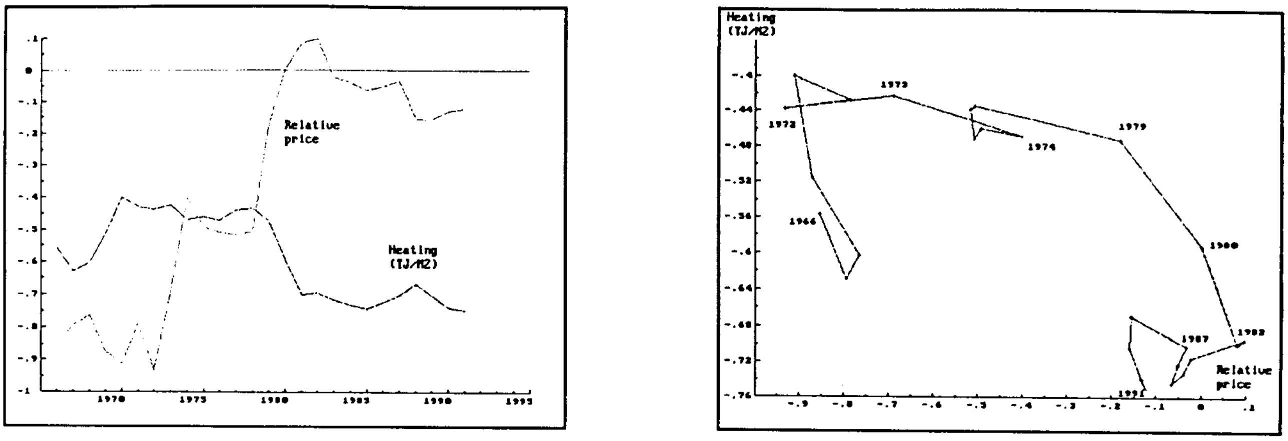
I.4.7. Results

I.4.7.1 Non-transport fuels

I.4.7.1.1 Heating

Figure 4.7.2.a illustrates that the climate and efficiency adjusted consumption of heating per square meter of residential stock have shown two major changes of level, around 1970 and around 1980. Between these major shifts the annual fluctuations have been comparably smaller but not negligible.

The climate and efficiency adjusted consumption of heating per square meter ("unit consumption") increased by more than 25 per cent from 1967 to 1970. The efficiency adjusted price of heating relative to the general private consumption deflator decreased by 11 per cent during the same period, i.e. the increase of consumption cannot be explained by a moderate (short run) price elasticity alone. From 1966 to 1971 the use of solid fuels for heating was virtually phased out from the initial level of more than 25 per cent of direct heating consumption and replaced primarily with liquid fuels, cf. figure 4.7.8 below. This development was a response not only to the current price development but probably also to the development prior to 1966 where real oil prices showed a marked declining trend.



4.7.2.a. *Times series plot.*

4.7.2.b. *Cross plot.*

Figure 4.7.2 Households' efficiency and climate adjusted consumption of heating in TJ/m² and the index of the efficiency adjusted price of heating relative to a general private consumption deflator, 1980=1, 1966-1991. Log scale.

The first oil price shock pushed the relative heating price in 1974 almost 70 per cent above its 1972 level, whereas unit consumption declined only 3 per cent.

On the contrary, the second oil price shock resulted in an increase in the relative heating price of 83 per cent from 1978 to 1982 while unit consumption declined by 23 per cent.

From 1982 to 1991 the real heating price declined by one fifth with practically no lasting effect on unit consumption.[16]

Figure 4.7.2.b displays the short run demand curve for unit consumption.[17] If there were no additional explaining variables, adaptions were instantaneous and the price elasticity were constant, the observations would lie along a straight line with a slope equal to the price elasticity. Even if some moderate delays in the response are accounted for, the first and the last years of the period look like outliers.

The first few years could be accounted for by special factors, cf. above, while the last years could be an example of an irreversible response with much less impact of price declines, as a comparison with the graphs of box 4.4.1 suggests.

An alternative hypothesis is that the adjustment time is so long, that the development in the first years are basically determined by pre-sample price developments, while the impacts of the real price decline during the 1980s primarily will show up in the post-sample period.

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[16] In Denmark, the large oil price drop of 1986 was countervailed by a marked increase of energy taxes for households.

[17] Although the relative price is along the horizontal axis.

A third hypothesis is, that movements in other variables might have shifted the demand curve, although there are not many obvious candidates. One is total private consumption or income. The increase in unit consumption around 1970 goes along with strong economic growth, and the seemingly lacking response of unit consumption to the price decline since 1987 goes along with a long period of recession.

Also, the elasticity with respect to the residential stock might not be unity. These hypotheses are not mutually excluding. We shall investigate these although the short sample and the marked correlation between potential explaining variables make it difficult to choose the preferred hypothesis by statistical testing only. Multicollinearity rules out the strategy of first setting up a general specification including all or just several potential explaining variables and then test down to the preferred parsimonious model.

Figure 4.7.2.c shows the index of fuel efficiency of heating. The average annual increase of fuel efficiency is 1.4 per cent a year. This reflects both a steady increase of the local utilization rates and decline of local conversion losses of most fuels and substitution towards the more efficient fuels district heating and natural gas (from 1983). Because the increased use of district heating and natural gas is primarily determined from the supply side, cf. section I.4.7.1.4, it is appropriate to treat this enhanced fuel efficiency as exogenous to demand, as the prior fuel efficiency adjustment of heating consumption and price implicitly assumes.

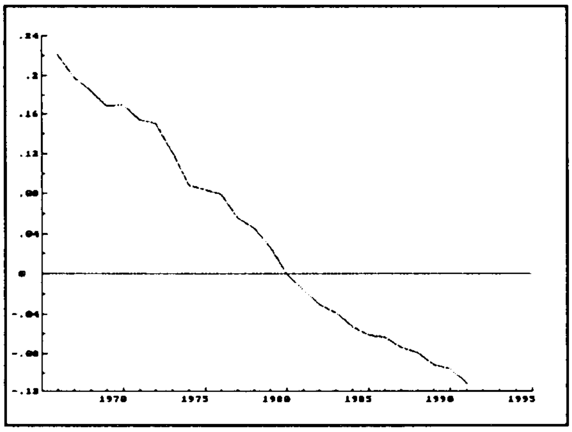

Figure 4.7.2.c Index of fuel efficiency of households' heating consumption, 1980=1, 1966-1991. Log scale.

Figure 4.7.3 displays the path of various "income" expressions, which are potential candidates for explaining variables. Hardly surprising, households real consumption is more volatile than households' real disposable income which is more volatile than the residential stock. The trend of the residential stock is far more pronounced when measured according to national accounts (NA) definitions[18] in 1980 prices than when measured in physical m^2. Quality improvements which inflates the NA measure is one explanation. However, measurement errors probably also take their toll.[19] The m^2 measure is theoretically more relevant, but the NA measure is nevertheless also included in the analysis partly because the m^2 numbers are somewhat uncertain prior to 1980, cf. Appendix I.4.2.2, and partly because ADAM only determines the NA measure.

From figure 4.7.3 it is tempting to infer, that the long run income or budget elasticity of the residential stock measured in m^2 is 1 and exceeds 1 when the stock is measured according to NA definitions. Econometric research indicates, that the income elasticity of the residential stock measured according to NA definitions has declined and is equal to one in the last part of the period, cf. Danmarks Statistik (1993a) and Det økonomiske Råds sekretariat (1994).

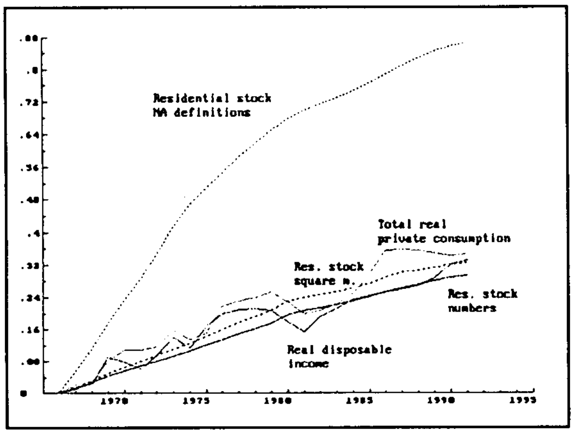

Figure 4.7.3 Different measures of the "income" variable per capita, index 1966=1, log scale.

Our most general standard ECM model for climate and efficiency adjusted consumption of heating, E°G, relative to the residential stock, K, is[20]

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[18] The "NA measure" is not an official NA figure. It is ADAM's measure based on accumulated past net investments in 1980 prices calculated from NA gross figures.

[19] As indicated in Appendix I.4.2.4 the m^2 numbers are especially uncertain prior to 1980. Møller (1983 p. 66) calculates that the stock of m^2 increased by 46 per cent from 1965 to 1980 which is 8 percentage points more than our figures imply.

[20] It is easy to show that eq. 4.7.1 is a more reparametrisized version of eq. 3.4.1 of section I.3.4 with $\gamma=k_2$ (except for the special treatment of trends and dummies). The advantage of the present formulation is that it is linear in the parameters and accordingly can be estimated by OLS.

$$
\begin{aligned}
Dlog\left(\frac{E^{\circ}G}{K}\right)_t &= \alpha + (\beta_K - 1)DlogK_t + \beta_Y Dlog\left(\frac{Y}{P}\right)_t + \Phi Dlog\left(\frac{P_E{}^{\circ}}{P}\right)_t \\
&+ (\pi^* + 1)DlogG_t + \beta_D^* Dummy_t \\
\textit{eq. } 4.7.1 \qquad &- \gamma(\log\left(\frac{E^{\circ}G}{K}\right)_{t-1} - (\beta_k^* - 1)\log K_{t-1} - \beta_Y^*\left(\frac{Y}{P}\right)_{t-1} \\
&- \quad \Phi^* \log\left(\frac{P_E{}^{\circ}}{P}\right)_{t-1} - (\pi^* + 1)G_{t-1} - \beta_D^* Dummy_{t-1} \\
&- \quad \tau_1^* T - \tau_2^* T^2)
\end{aligned}
$$

The presence of *log*K_t and *Dlog*K_t on the right hand side allows for testing whether the parameters (elasticities) $ß_K$ and $ß_K^*$ are unity in an OLS regression. The formulation ensures that the short and long run impact of the dummy are both equal to $ß_D^*$. Similarly, it is imposed that the elasticity with respect to the climate variable, π^*, is the same both in the short run and in the long run and it can be tested whether it deviates from -1.[21]

Table 4.7.1 tests for the order of integration of the main regression variables. Unit consumption, relative heating price and total private consumption are all integrated of first order, I(1). Possessing the same order of integration they have a potential for forming a long run relationship.

The results from estimating the standard ECM for the climate adjusted consumption of heating are displayed in table 4.7.2. The table concentrates on illustrating the implications of using the three alternative "income" variables, various trend specifications and a dummy for 1967-1968 as regressors along with the relative price.

Regression no. 1-8 use the residential stock measured in m^2 as the variable K. The dependent variable is the absolute change in the log of climate adjusted unit consumption. No, 1 and 2 show, that it is not possible to estimate a sensible elasticity with respect to the residential stock neither in the short run nor in the long run.

It clearly cannot be rejected that this elasticity is significant different from 1 on a 5 per cent level in the short run and in the long run, but the confidence interval is large. The residential stock is I(2) questioning the usefulness of this testing. Multicollinearity between the level of the relative price and the residential stock is

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[21] As P_E enters the general consumption deflator, P, we ought to use a general non-heating deflator for P. However, the weight of heating in total private consumption is small and we shall ignore the problem for simplicity. The same applies for the other energy items below.

	H_0:I(1)		H_0:I(2)		Conclusion
	C-term	Origo	C-term	Origo	
1. Climate and efficiency adj. consumption of heating per m^2	-1.19			-3.37	I(1)
2. Relative efficiency adjusted price of heating		-1.77		-4.05	I(1)
3. Total real private consumption per capita	-1.85		-3.71		I(1)
MacKinnon 5 percent crit. val.	-2.99	-1.96	-2.99	-1.96	

Table 4.7.1 (Augmented) Dickey Fuller statistics for regression variables, 1966-91
Note: The MacKinnon critical values are essentially Dickey-Fuller critical values calculated with a finer grid as inherent in MicroTSP, cf. Hall et. al. (1990). The C-term and/or augmented lags are included unless clearly insignificant.

probably also important. The partial coefficient of correlation between them is 0.90. It is therefore preferred to restrict the elasticity with respect to the residential stock to unity both in the short and long term in regression 3-8. This is also a precondition for getting sensible results for trend specifications, as the residential stock and the linear trend are strongly correlated too.

Restricting the elasticity with respect to the residential stock to unity also produces some nicer Chow stability tests, cf. regression no. 3. There is no break in 1974. Introducing a dummy, which is 1 in 1967-68 and zero elsewhere (no. 4) decreases the standard error of the regression by 11 per cent with little impact on price elasticity estimates. Alternative dummies for 1966-68 or 1966-69 also have small impacts on the other estimated parameters.

Regression no. 5 and 6 show that total private consumption posses no additional explanatory power. Also the estimated budget elasticities seem high given that the residential stock already has been assigned a unitary elasticity. Judged by the numerical much higher price elasticity, multicollinearity with the relative price seems important. According to regression no. 7 a quadratic trend gives absurd results and no. 8 shows that a linear trend is insignificantly positive and again interacts in an discomforting way with the relative price.

Regression no. 9-12 replicates some of the former regressions except that the residential stock is now measured according to NA definitions. Unit consumption defined this way show a much stronger negative trend over the sample which can only be explained by stronger negative trends or a much higher numerical price elasticity. None of these regressions passes all the Chow stability tests on a 5 per cent level.

Regression no. 13-14 only use total real private consumption as "income" variable.[22] The results looks much like the results for the m^2-specifications also concerning trends, which are not repor-

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[22] As the note to table 4.7.2 indicates, regression no. 13-14 were performed by entering private consumption analogous to the variable K in eq. 4.7.1.

ted (the residential stock measured in m^2 and private consumption share practically the same trend, cf. figure 4.7.3). The standard error of the restricted regression no. 14 is smaller than for the m^2-specification no. 3, which suggests that unit consumption to some extent follows the general movements of private consumption. However multicollinearity prevents a sensible estimate of this.

Table 4.7.3 tests the reversibility of regression 3 of table 4.7.2 repeated as no. 4 in table 4.7.3. No matter how it is tested, the reversible model clearly cannot be rejected, as the *F*-tests in the last column of table 4.7.3 reveal. The most general non-reversible model (no. 1) is not acceptable as $|\Phi_2^*| < |\Phi_3^*|$. The jagged ratchet and the ratchet indicate (insignificantly) a higher numerical long run price elasticity for price drops, which does not make sense.

Table 4.7.4 tests the symmetry of adjustment. For this purpose specification 3 of table 4.7.2 has been reestimated by the Engle Granger two step procedure for cointegrated time series, cf. regression no. 1 and no. 4 of table 4.7.4, which is potentially valid here as both unit consumption and the relative price are I(1). The Dickey Fuller cointegration test of the step one regression indicates lacking cointegration questioning the whole exercise. This level regression entails a much smaller numerical long run price elasticity estimate. There is some indication, that the adjustment speed is slower in case of negative or larger negative deviations from the long run equilibrium, but the differences are totally insignificant.

Finally, table 4.7.5 investigates the implications of measuring some variables differently. Regression 1 repeats no. 3 of table 4.7.2 for comparison. In addition, it is shown, that by free estimation it can not be rejected, that $\pi^*=1$. In regression no. 2 the climate adjustment factor is computed on the assumption, that the climate independent share is zero.[23] As a result the estimate of π^* is significantly different from -1. Regression no. 3 alternatively utilizes the inverse number of frost days as the climate variable. This resembles the way climate adjustment is traditionally performed in ADAM but is less sophisticated than the degree days based measure of regression 1 and 2. The standard error of the regression increases accordingly. Regression no. 4 and 5 investigates the sensitivity of the regression to the assumption concerning the climate independent share of heating consumption, cf. the discussion in Appendix I.4.2. The alternative assumptions all result in a larger standard deviation of the regression. In sum, the variations in the climate measures have only little impact on the point estimates of the other parameters but more substantial impact on the estimated variance - as one should also expect.

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[23] R^2 is much higher for regression no. 2 and 3 than for the other regressions. This is because the regressands differs, cf. the note to the table.

Finally, regression no. 6 replicates no. 1 except that consumption of town gas and LPG is now included in the definition of heating consumption, cf. Appendix I.4.2. It makes next to no difference for the regression. The long run price elasticity increases a little numerically, because the negative trend in this measure of unit consumption is slightly stronger.

	Short run elasticities			Adj. speed	Long run elasticities			Annual trend, %		Dum-my	Regression statistics			Tests on residuals			Chow stability tests		
	Φ	β_K	β_Y	γ	Φ^*	β_K^*	β_Y^*	1970	1991	D6768	s	R^2	L	DW	LM(1)	ARCH(1)	1974	1979	1983
1	-.22	3.10^{*a}		.21	-.81	2.33^{a}					.0411	.486	47.72	1.66	.10	.64	.01 .00	.26 .04	.20 .03
2	-.19	1.64^{*a}		$.19^{*}$	-.52	1.00					.0417	.445	46.76	1.54	.21	.14	.02 .00	.70 .47	.94 .86
3	-.19	1.00		.18	-.56	1.00					.0407	.443	46.72	1.52	.26	.24	.44 .26	.81 .69	.94 .54
4	-.20	1.00		.25	-.49	1.00				-.084	.0351	.607	51.08	1.60					
5	-.18	1.00	.70	$.14^{*}$	-.90	1.00	1.33^{*}				.0379	.563	49.76	1.73	.00	1.25	.05 .00	.60 .26	.21 .03
6	-.15	1.00	$.61^{*}$	$.13^{*}$	-.58	1.00					.0390	.512	48.36	1.60	.06	1.05	.42 .18	.98 .95	.94 .86
7	-.23	1.00		.61	-.58	1.00		7.3	-5.8		.0312	.705	54.66	1.61	1.05	1.09	.07 .00	.62 .28	.15 .01
8	-.20	1.00		$.16^{*}$	-.80	1.00		1.1^{*}			.0412	.457	47.03	1.55	.25	.45	.01 .00	.10 .02	.11 .02
9	-.20	2.80^{*a}		.31	$-.42^{*}$	1.00^{a}					.0376	.516	49.98	1.52	1.07	1.53	.05 .00	.22 .03	.06 .00
10	-.22	1.00		.25	-.73	1.00					.0370	.481	49.10	1.53	.59	.53	.18 .07	.28 .13	.02 .00
11	-.23	1.00		.71	-.47	1.00		$-.04^{*}$	-6.0^{*}		.0305	.681	55.21	1.50	2.72	0.80	.06 .00	.88 .67	.39 .10
12	-.18	1.00		.55	-.40	1.00		-1.5			.0344	.574	51.59	1.31	2.72	1.41	.04 .00	.27 .08	.15 .03
13	-.17		$.76^{a}$	$.14^{*}$	-.82		1.86^{a}				.0377	.576	49.90	1.69	.00	.90	.02 .00	.55 .22	.23 .03
14	-.13		1.00	.16	-.52		1.00				.0374	.348	48.82	1.64	.01	1.04	.51 .33	.94 .90	.62 .45

Table 4.7.2 Climate and efficiency adjusted consumption of heating: Regression results for the simple ECM model eq. 4.7.1, 1967-1991.

Note: a) Not significant different from 1.00 at a 5 per cent level.
Regression 1-8: Dependent variable Dlog(climate and efficiency adjusted heating per of residential stock in m^3).
Regression 9-12: Dependent variable Dlog(climate and efficiency adjusted heating per unit of residential stock in 1980-prices).
Regression 13-14: Dependent variable Dlog(climate and efficiency adjusted heating per unit of private consumption in 1980-prices).
See also note to table 4.7.3 below.

		Short run price elasticities			Adj. speed	Long run price elasticities			Regression statistics			Tests on residuals			Chow stability tests			Prob. value of H_0
		Φ_1	Φ_2	Φ_3	γ	$\Phi_1^{\cdot}$	$\Phi_2^{\cdot}$	$\Phi_3^{\cdot}$	s	R^2	L	DW	LM(1)	ARCH(1)	1974	1979	1983	
1.	General	-.23$^{\cdot}$	-.01$^{\cdot}$	.28$^{\cdot}$	.20$^{\cdot}$	-.67$^{\cdot}$	-.43$^{\cdot}$	-.81$^{\cdot}$	.0436	.484	47.66	1.55	.61	.18		.02 .00	.18 .00	
	H_0: Jagged ratchet																	.81
	H_0: Ratchet																	.77
	H_0: Reversible																	.85
2.	Jagged ratchet	-.17$^{\cdot}$	-.17$^{\cdot}$	-.29$^{\cdot}$	.20$^{\cdot}$	-.69	-.69	-1.04	.0417	.470	47.34	1.56	.97	.85	.09 .00	.14 .01	.15 .01	
	H_0: Reversible																	.62
3.	Ratchet	-.21$^{\cdot}$	-.19$^{\cdot}$	-.19$^{\cdot}$	.15	-.67	-.67	-1.31$^{\cdot}$	.0419	.467	47.27	1.56	.27	.20	.00 .00	.02 .00	.14 .00	
	H_0: Reversible																	.66
4.	Reversible (= table 4.7.2 no. 3)	-.19	-.19	-.19	.18	-.56	-.56	-.56	.0407	.443	46.72	1.52	.26	.24	.44 .26	.81 .69	.94 .54	

Table 4.7.3 Climate and efficiency adjusted consumption of heating per m^2: Testing non-reversibility cf. box 4.4.1 in the ECM model, 1967-1991.

Note: Superscript $^{\cdot}$ at a coefficient marks that the coefficient is not significant different from zero at a 5 per cent level (one-sided *t*-test except for the trend and the dummy where the test is two-sided). For the long run elasticities (including the trend and the dummy) it is marked whether γ times the elasticity is significant different from zero.
Underscored coefficients are fixed a priori.

s is standard error of regression. R^2 is the coefficient of determination. L is log likelihood.
DW is the Durbin Watson statistic for the presence of 1. order autocorrelation.
LM(1) is the Chi^2-distributed LaGrange multiplier statistic for the presence of 1. order autocorrelation. The 5 per cent critical value is 3.84.
ARCH(1) is the Chi^2-distributed LaGrange multiplier statistic for the presence of first order autoregressive conditional heteroscedasticity. The 5 per cent critical value is 3.84.
The LM and ARCH test statistics can not be calculated when dummies are applied.
The Chow test is used in the "break point" version where the last subset begins at the marked year. The first line indicates the *F*-test and the second line indicates the dummy-based Chi^2-test.
The table displays the significance levels at which the null hypothesis of stability is rejected, i.e. a value lower than .05 implies rejection at a 5 percent level. The use of dummy variables and/or too few degrees of freedom sometimes rule out the use of the stability tests and no figures are quoted.
The "Prob. value" of H_0 designates the significance level at which the parameter restriction(s) of the null is rejected by the standard *F*-test.

		Adjustment speed					Regression statistics			Tests on residuals		
	Φ	γ^+	γ	γ^g	γ^d	Φ^*	s	R^2	L	DW	LM(1)	ARCH-(1)
1. Step 1 cointegration regression DF-cointegration test: -1.29						-.27	.0881	.542	27.32	0.28		
2. Step 2 EC regression *F*-test H_0: $\gamma^+=\gamma$, prob.val=.65	-.13*	.26*	.16*			-	.0440	.321	44.22	1.20	3.32	.04
3. Step 2 EC regression *F*-test H_0: $\gamma^g=\gamma^d$, prob.val=.22	-.14*			.40	.14*	-	.0395	.438	45.08	1.29	3.52	.41
4. Step 2 EC regression (Standard)	-.14	.21	.21	.21	.21	-	.0432	.314	44.10	1.23	2.76	.12

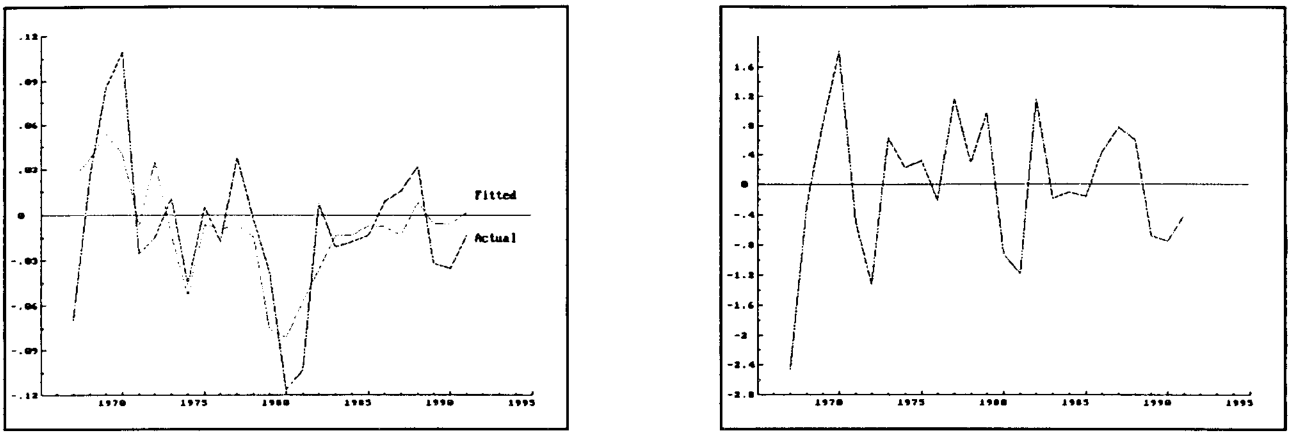
Table 4.7.4 Climate and efficiency adjusted consumption of heating per m^2: Testing asymmetry, cf. eq. 4.4.5 - 4.4.8, using the Engle-Granger two step procedure for cointegrated series, 1966-1991.[a]

Note: a) The time period is 1966-91 for no. 1, 1967-91 for no. 2 and 4 and 1968-91 for no. 3.
See also note to table 4.7.3.

					Free π^* estimate (standa. error)	Regression statistics			Tests on residuals			Chow stability tests		
	Φ	γ	Φ^*	π^*		s	R^2	L	DW	LM(1)	ARCH(1)	1974	1979	1983
1. Standard prior climate adjustment, cf. table I.4.2, no. 3. Climate independent share = 37 per cent)	-.19	.18	-.56	-1.00	-1.14 (.16)	.0407	.443	46.72	1.52	.26	.24	.44 .26	.81 .69	.94 .54
2. Climate independent share = 0	-.18	.19	-.54	-.72	-.72 (.10)	.0411	.790	57.12	1.54					
3. No prior climate adjustment Climate measured by inverse number of frost days	-.10*	.24	-.48	-.18	-.18 (.04)	.0495	.695	42.47	1.40					
4. Climate independent share declines from 54 per cent to 29 per cent by 1 percentage point a year	-.20	.18	-.55	-1.00	-1.17 (.19)	.0440	.432	44.80	1.50	.14	.15	.50 .32	.79 .67	.99 .97
5. Climate independent share = 50 per cent	-.19	.18	-.52	-1.00	-1.44 (.21)	.0442	.420	44.68	1.50	.23	.11	.53 .35	.75 .61	.94 .89
6. Standard aggregation of energy items (town gas and LPG included as used for heating)	-.19	.19	-.61	-1.00	-1.12 (.16)	.0383	.467	48.25	1.60	.09	.46	.28 .13	.93 .88	.92 .86

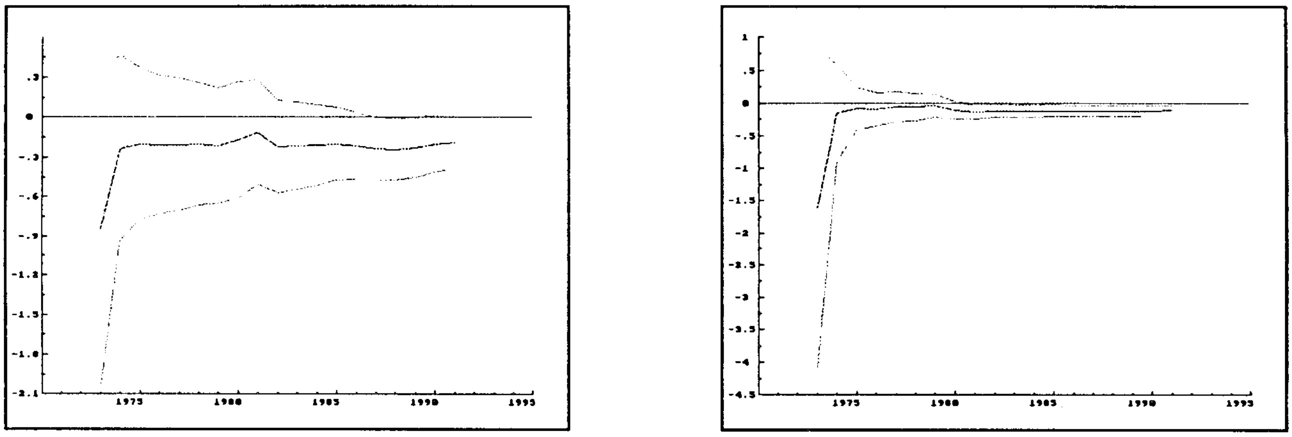
Table 4.7.5 Climate and efficiency adjusted consumption of heating per m²: Measuring the variables differently, 1967-1991.

Note: Regression number 2 and 3 are performed with Dlog(efficiency adjusted unit consumption) at the left hand side. To impose the restriction $\pi^k=\pi$, the nonlinear least squares estimator was applied. MicroTSP does not calculate various diagnostic statistics for this estimator. See also note to table 4.7.3.



4.7.4.a. Log change of efficiency and climate adjusted unit consumption.

4.7.4.b. Standardized residuals.



4.7.4.c. Recursive estimation: $-\gamma \pm 2$ *SE.*

4.7.4.d. Recursive estimation: $\gamma\Phi^* \pm 2$ *SE.*

Figure 4.7.4 Heating: Regression plots for table 4.7.5 no. 6

Figure 4.7.4 displays actual, fitted, standardized residuals and recursive estimates of coefficients to the level variables of the regression of table 4.7.5 no. 6. The residuals are especially large for the sixties and around the second oil price hike. Also the equation overshoots in the last few years, as the declining relative price does not derive an expansion of demand. However, when the observations of the first oil price hike are included in the sample, the long run parameter estimates are rather stable to additional observations.

Excluding the obvious multicollinearity affected regressions and dismissing the relevance of the NA measure of the residential stock, some rather robust conclusions stand up in spite of the large variance. The short run price elasticity is -0.1 - -0.2 and the long run price elasticity is -0.5 - -0.6. The elasticity with respect to the residential stock is virtually impossible to measure by any operational precision, but it can safely be assumed to be 1 both in the short run and in the long run. Equally, one might prefer to say, that the budget elasticity or the income elasticity is unity (the residential stock probably has a unitary income elasticity), but there is not room for two "income" variables as explanatory variables. The adjustment speed is more sensitive to the specification, but is rather slow probably around 0.2. Trends should not be included. The impact of excluding trends is primarily to reduce the estimated adjustment speed, but it does also affect the estimate of the long run price elasticity. Irreversibility and asymmetry are not important phenomena perhaps because of the relatively small historical price drops.

I.4.7.1.2 Electricity for non-heating

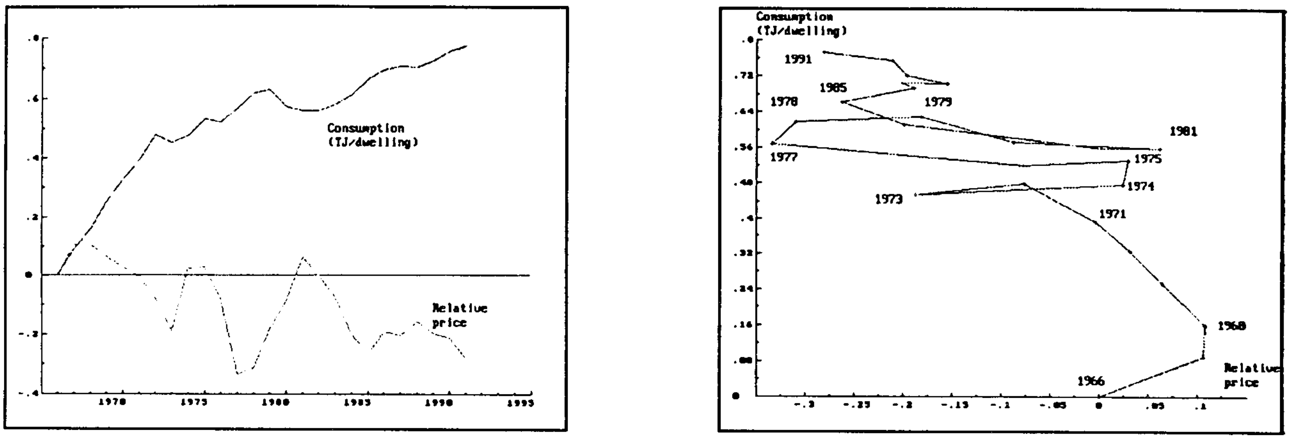
According to DEFU (1993) the number of dwellings is an important determinant of the demand for electricity. Figure 4.7.3 illustrates, that the number of dwellings exhibits a trend, which is only slightly lower than the trend of total real private consumption (income), whereas there is a marked difference concerning the annual changes. For the explanation of the long run demand for electricity there is only little difference between these two variables as opposed to the short term fluctuations.

Figure 4.7.5.a illustrates, that households' efficiency adjusted consumption of non-heating electricity relative to the number of dwellings has been on an increasing trend during the period 1966-91. The efficiency adjustment is performed by dividing direct consumption in TJ by the index of weighted electricity use of electrical household appliances (excluding heating appliances) depicted at figure 4.7.6. Correspondingly the efficiency adjusted price is defined as the price in mill. Kr./TJ multiplied by this index. According to the index, the weighted stock of electrical appliances decreased its electricity use per appliance by 0.86 per cent a year during the period 1966-91. The annual decrease was steady, indicating that it might reasonably be regarded as a "general" technological trend exogenous to consumer demand for electricity.

In 1966-72, there was a strong positive trend in efficiency adjusted consumption, which declined markedly around 1973 and stopped around 1979. In the early 1980s the trend resumed again. During the period 1966-91 the efficiency adjusted relative price fluctuated much. In 1991 it still has not recovered from the decline of the early 1980s. By any reasonable price elasticity the development of electricity consumption can only be fully explained, if the elasticity with respect to the number of dwellings exceeds unity, or there is a positive trend or the like.

Figure 4.7.5.b reveals some relationship between the relative price and relative consumption. Especially the period 1968-1972 showed a strong negative immediate correlation.

According to the formal testing of table 4.7.6, electricity consumption is I(1), although it is only narrowly rejected to be I(2), i.e. it is virtually uncertain, whether this series is I(1) or I(2). The number of dwellings is I(2), whereas total real private consumption above was found to be I(1). The relative electricity price is I(0).



4.7.5.a. Times series plot

4.7.5.b. Cross plot Figure

4.7.5 Households' efficiency adjusted consumption of non-heating electricity in TJ relative to the number of dwellings and the efficiency adjusted price of electricity relative to a general private consumption deflator, indices 1966=1. 1966-1991. Log scale.

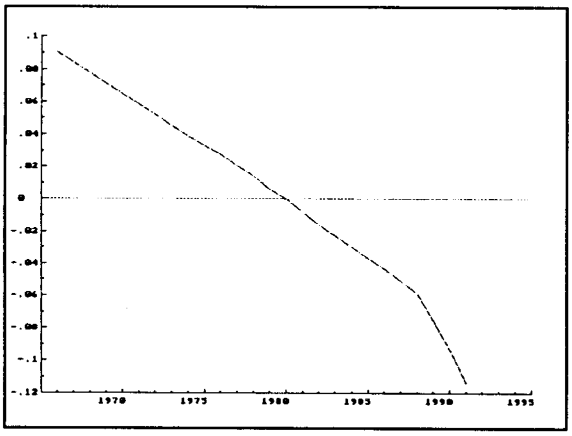


Figure 4.7.6 Index of weighed electricity use of electrical household appliances, 1980=1. Log scale

	H_0:I(1)		H_0:I(2)		Conclusion
	C-term	Origo	C-term	Origo	
1. Consumption of efficiency adjusted non-heating electricity	-2.31[a]		-3.07		I(1)
2. Relative efficiency adjusted price of electricity		-2.81			I(0)
3. Number of dwellings	-0.92[a]		-1.42		I(2)[b]
MacKinnon 5 percent crit. val.	-3.60	-1.96	-2.99	-1.96	

Table 4.7.6 (Augmented) Dickey Fuller statistics for regression variables, 1966-91

Note: a) Trend inserted in the DF-regression.

b) H_0:I(3) rejected with a DF-statistic of -5.01 against the critical value of -2.99.

See also note to table 4.7.1.

Table 4.7.7 shows the results of estimating variants of the specification

$$eq.\ 4.7.2\quad DlogE_t^{\circ} = \alpha + \beta_K DlogK_t + \beta_Y Dlog\left(\frac{Y}{P}\right)_t$$

$$- \gamma(\log E_{t-1}^{\circ} - \beta_K^{*}\log K_{t-1} - \beta_Y^{*}\log\left(\frac{Y}{P}\right)_{t-1} - \Phi^{*}\log\left(\frac{P_E^{\circ}}{P}\right))$$

where K is the number of dwellings, and Y as usual is total private consumption.The short run price elasticity, Φ, is restricted to $\gamma\Phi^{*}$ This form is chosen because the relative price is I(0).

The first three regressions are performed with efficiency adjusted variables. The annual log change of the number of dwellings, D*log*K_t, looks much like a negative linear trend, which there is no significant room for in the regressions, and $ß_K$ is set to zero a priori in regression no. 1. In regression no. 1 all estimated parameters are significant different form zero contrary to all other regressions in the table. However the Chow tests detect instability of this specification. The long run elasticity with respect to the number of dwellings is estimated to 1.51, and the long run price elasticity is estimated to -.45. Both are rather large numerical estimates. Using total real private consumption as an alternative "income" variable, the long run "income" elasticity is still estimated to around 1.50, but the long run price elasticity estimate drops numerically to around -0.30, cf. regression 2 and 3. The insignificance of the parameter estimates, when private consumption is used as "income" variable, might stem from multicollinearity with the relative price even though they posses different orders of integration. Comparing figure 4.7.3 and 4.7.5.a it is seen, that in several important sub periods the relative electricity price has deviated negatively from its average when private consumption deviated positively from its trend and conversely.

	Short run elasticities			Adj. speed	Long run elasticities			Regression statistics			Tests on residuals			Chow stability tests		
	Φ	β_K	β_Y	γ	Φ^*	β_K^*	β_Y^*	s	R^2	L	DW	LM(1)	ARCH(1)	1974	1979	1983
1.	-.14			.32	-.45	1.51		.0258	.602	58.10	2.06	.07	.56	.03 .00	.19 .08	.65 .49
2.	-.07*		.27*	.24	-.29*		1.50*	.0272	.580	57.43	2.21	.74	.19	.33 .12	.20 .05	.62 .38
3.^{a}	-.06*		.33*	.22	-.28*		1.46*	.0266	.578	57.36	2.28	.64	.32	.19 .07	.72 .58	.50 .33
4.	-.13			.30	-.44	1.15		.0252	.637	58.70	2.15	.31	.66	.02 .00	.29 .14	.80 .68
5.^{a}	-.07*		.28	.25	-.27*		1.14	.0254	.633	58.56	2.36	1.10	.79	.12 .04	.61 .44	.74 .60

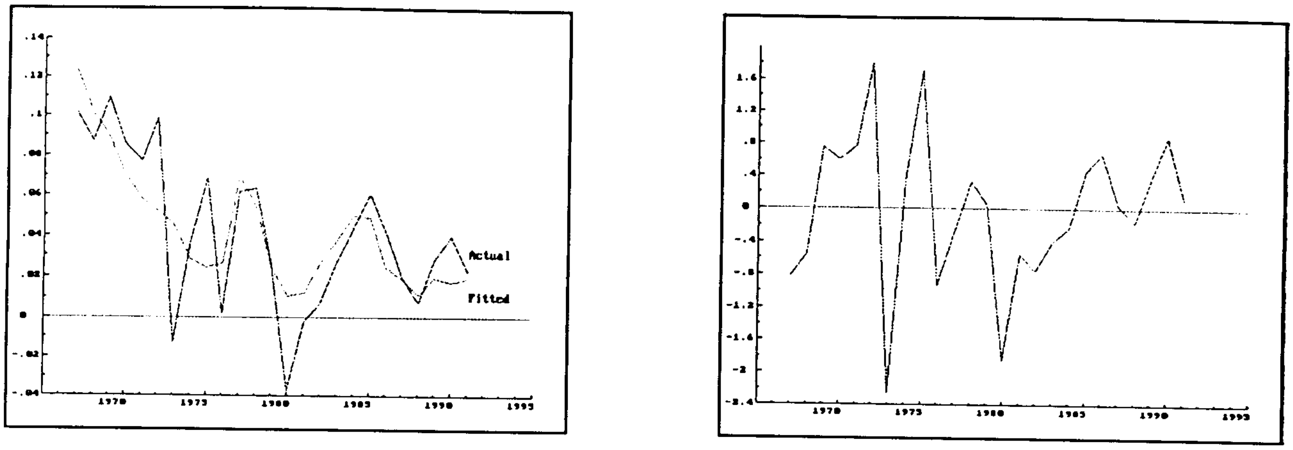
Table 4.7.7 Consumption of non-heating electricity: Regression results for the simple ECM model eq. 4.7.2, 1967-1991.

Note: a) β_y restricted to $\gamma\beta_y^*$.

Regression 1-3: Consumption and price are efficiency adjusted.

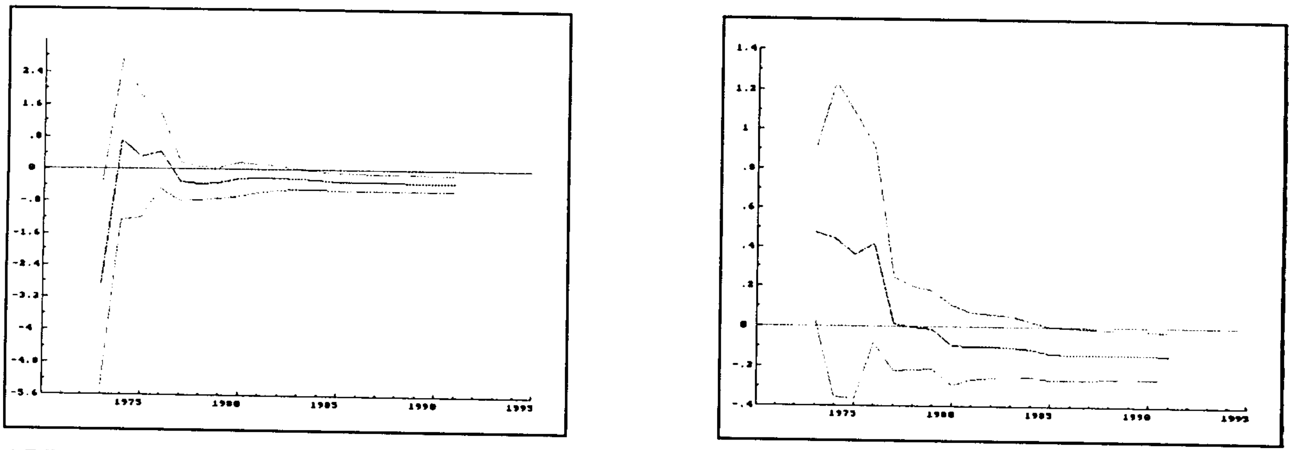
Regression 4-5: Consumption and price are not efficiency adjusted.

See also notes to table 4.7.3.



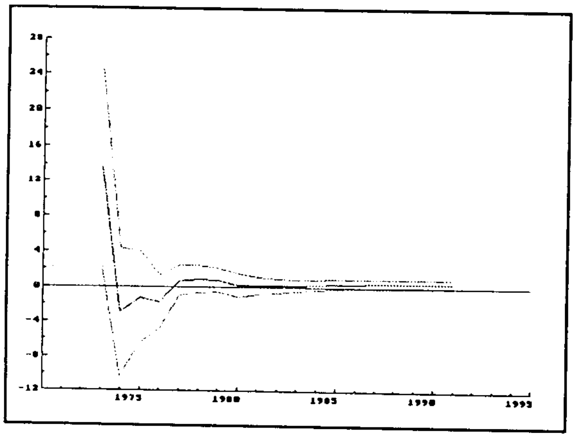
4.7.7.a. *Log change of efficiency adjusted consumption*

4.7.7.b. *Standardized residuals*



4.7.7.c. *Recursive estimation:* $-\gamma \pm 2\,\hat{S}E$

4.7.7.d. *Recursive estimation:* $\gamma\Phi^{*} \pm 2\,\hat{S}E$



4.7.7.e. *Recursive estimation:* $\gamma\beta_K^{*} \pm 2\,\hat{S}E$

Figure 4.7.7 Non-heating electricity: Regression plots for table 4.7.7 no. 1.

Regression 4 and 5 of table 4.7.7 are performed with electricity consumption and relative price not adjusted for efficiency. The main impact is a much lower estimate of the "income" elasticity at around 1.15, whereas it does not affect the price elasticity estimate. Over the sample period the efficiency adjusted consumption grows almost 1/4 more than the unadjusted. Adding the log of the efficiency index to for example regression no. 4 (not reported) it clearly cannot be rejected, that its long run coefficient (elasticity) is either zero or obeys the implicit parameter restriction of no. 1 (using an *F*-test). Its standard error is large as there is severe multicollinearity with the "income variable". Whether prior efficiency adjustment should be preferred or not must therefore be decided by theoretical reasoning.

Figure 4.7.7 shows that regression no. 1 of table I.4.7 is only able to catch the broad tendencies of consumption, and the parameter estimates are unstable.

The estimated elasticities are comparably uncertain. It seem rather well founded to conclude, that the long run "income" elasticity exceeds unity, whereas the price elasticity could well be numerically much smaller than
-0.3 - -0.5.

I.4.7.1.3 Heating and electricity for non-heating modelled together

Table 4.7.8 shows the results of estimating the allocation of total heating etc. spending on electricity and heating, in static and dynamic versions of the LES and the AID. Consumption of heating has been adjusted for climatic variations by assuming, that the estimated response of total heating etc. in ADAM can be attributed to heating consumption alone, cf. Appendix I.4.3, but the basic results also show up if heating consumption is not adjusted for climate by applying the method of Appendix I.4.3 (not reported here). The static hypotheses are very clearly rejected cf. their much lower log likelihood values, but the DLES violates the stability condition (as $\gamma_1^1>1$) giving a useless result. The ECM AID (not reported) also violates the condition for smooth adjustment of quantities (as $k_1<1$), and the partial adjustment (PA) special case is preferred.

The LES ranks electricity as the most budget sensitive contrary to the AID.

The estimated elasticities for consumption of heating etc. in ADAM's DLES are listed in table 4.7.9. Assuming that the long run income elasticity of total private consumption is unity and ignoring gross rents we consider these long run elasticities as total elasticities.

Table 4.7.10 displays the long run total elasticities of heating and non-heating electricity calculated by applying eq. 4.2.19 and eq. 4.2.20 to the LES estimates and compares them with the preferred ad hoc estimates. The elasticities differ between the two models. An outstanding discrepancy is, that the long run price elasticity of non-heating electricity is numerically 1.7 times as large in the combined ADAM-LES model than the already high estimate of the ad hoc model. This result is not much affected using static AID instead of LES. Using PA AID a main problem would be a small budget elasticity.

A major explanation of the differences is, that in any case the consumption of electricity is poorly determined. In a demand system the results for this item is probably dominated by the results for the other item, especially as the share of non heating electricity in the total heating etc. budget is only 0.29 on average. Another explanation is probably that the ADAM price elasticities are too poorly determined, due to the additivity assumption of the DLES being too restrictive for the aggregation applied in ADAM, cf. section I.4.5. Also, ADAM does not utilize the efficiency adjustments, and this would in any case be a problem for the interpretation of the combined two stage model.

	$ß_i$	γ_i^0	γ_i^1			s	R^2	DW	L	e_i^*	e_{ii}^*
1. LES											
Heating	.70 (.05)	.90 (.40)				.0239	.63	.71	59.44	.95	-.88
Electricity	.30 (-)	.22 (.04)								1.15	-.82
2. DLES											
Heating	.93 (.04)	-.22 (.80)	1.24 (.44)			.0072	.97	2.44	90.77	.15	-.75
Electricity	.07 (-)	.04 (.01)	1.00 (.05)							-240	169
	α_i	γ_{ii}	$ß_i$	k_2		s	R^2	DW	L	e_i^*	e_{ii}^*
3. Static AID											
Heating	.73 (.06)	.07 (.02)	.004 (.05)			.0254	.57	.73	60.22	1.01	-.91
Electricity	.27 (-)	.07 (-)	-.004 (-)							.98	-.72
4. PA AID											
Heating	.60 (.11)	.06 (.03)	.12 (.10)	.60 (.17)		.0214	.72	1.71	62.82	1.17	-1.04
Electricity	.40 (-)	.06 (-)	-.12 (-)							.56	-.67

Table 4.7.8 Results for LES and AID estimated for 1966(7)-91 for heating etc. Heating and electricity are efficiency adjusted

Note: Heating is climate adjusted as in ADAM using ADAM's implicit adjustment, cf. Appendix I.4.3. Standard errors in brackets.

Elasticities are partial and shown for 1991.

e_i	e_i^*	e_{ii}	e_{ii}^*	Adj. speed
.65	.94	-.18	-.89	.12

Table 4.7.9 *ADAM elasticities and adjustment speed of heating etc. in 1988*
Note: The elasticities are calculated for DLES with total private consumption expenditures minus gross rents (per capita) as budget constraint.
Source: Danmarks Statistik (1993a).

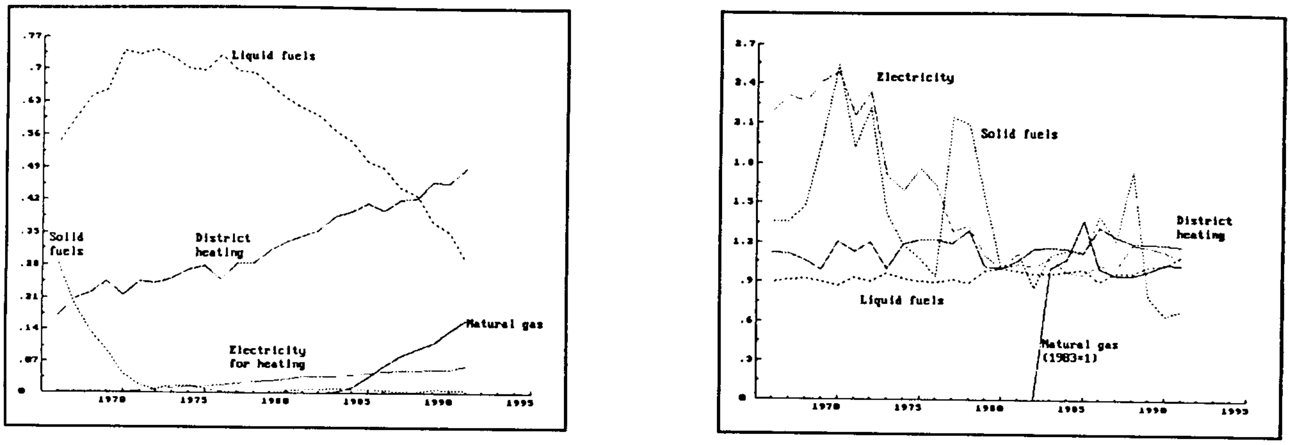
	e_i^*		e_{ii}^*	
	Heating	Non-heating electricity	Heating	Non-heating electricity
ADAM (table 4.7.9) and LES (table 4.7.8) cf. eq. 4.2.19 and 4.2.20	.89	1.08	-.81	-.78
Ad hoc (table 4.7.5 nr. 6 and table 4.7.7 no. 1)	1.00	1.51	-.61	-.45

Table 4.7.10 *Total long run elasticities for heating and non-heating electricity in 1991*
Note: It is assumed that the long run income elasticity of the residential stock is 1 implying also a unitary budget elasticity in the ad hoc equation for the demand for heating.

I.4.7.1.4. The single items of heating

Figure 4.7.8.a. reveals the major developments of 5 aggregate fuels as shares of total heating in TJ. From a share of more than 1/4 in the mid 1960s, solid fuels were virtually phased out during the end 1960s. District heating - and less marked electricity - showed steadily increasing shares throughout the period, and the same applies for natural gas, after it came on stream in 1983. These movements add up to the opposite movements for the share of liquid fuels. Comparing with figure 4.7.8.b it is seen, that these movements of the shares do not have much counterpart in the movements of the relative prices of the fuels. The main explanation for the increasing share of district heating and of natural gas is the increased supply and cannot be identified by a demand function alone. The quick decline in the share of solid fuels is probably connected with the declining relative oil prices prior to the sample period.

In the combined model, efficiency adjusted consumption of these 5 fuels should be determined by exogenous shares of efficiency adjusted total heating consumption.



4.7.8.a. Shares of total heating in TJ

4.7.8.b. Prices relative to the price of total heating, 1980=1

Figure 4.7.8 Households' efficiency adjusted consumption of 5 heating fuels: Share of total and relative prices, 1966-1991

I.4.7.2 Transport

I.4.7.2.1 Transport fuels

The identity

$$eq.\ 4.7.3 \qquad \frac{X_g}{N} = \frac{K_b}{N}\frac{X_g}{km}\frac{km}{K_b}$$

where X_g = private consumption of transport fuels
N = number of inhabitants
K_b = stock of automobiles with the households
km = total kilometres driven with private automobiles

lists three factors determining private consumption of transport fuels per capita.

In ADAM, the purchase of vehicles in 1980-prices is determined in an independent stock adjustment equation as a function of real income, real wealth, the real interest rate and relative user costs, which depends on vehicle prices, gasoline prices and excise taxes relative to the price of public transports. The number of automobiles ultimo the year is then found by adding to the primo stock the net purchase of vehicles converted from 1980 prices to numbers of automobiles by applying a conversion factor. The gasoline price relative to the price of public transports influences only the future automobile stock, and the present automobile stock (per capita) should be considered as weakly exogenous to fuel consumption.

The average consumption of transport fuels per kilometre, X_g/km, contains an exogenous supply determined item and an endogenous demand determined item, cf. the discussion in section I.4.4.1.

If fuel efficiency is exogenous to demand, the average kilometres driven per automobile, km/K_b, is basically the variable to be modelled in a behavioral demand equation. In conclusion, the demand for gasoline is derived from the demand for transport kilometres.[24] It presumably depends on a list of variables such as the real budget (income), the marginal cost of travelling one kilometre by using your own automobile, P_{km}, relative to prices of other goods and in particular to the price of public transports, P_k, etc.

This leads to a long run ad hoc demand equation for transport kilometres, which can be formulated in log-linear terms as

$$\textit{eq. } 4.7.4 \quad \log\left(\frac{km}{K_b}\right) = \alpha + \beta_Y^* \log\left(\frac{Y}{P}\right) + \Phi^* \log\left(\frac{P_{km}}{P}\right) + \Phi_k^* \log\left(\frac{P_k}{P}\right)$$

Assuming that the marginal costs of driving a kilometre with a given automobile consist of gasoline expenses only

$$\textit{eq. } 4.7.5 \quad P_{km} = \frac{P_g X_g}{km} = P_g I$$

where P_g is the gasoline price and $I = X_g/km$ is the inverse fuel efficiency. Insertion of eq. 4.7.3 and eq. 4.7.5 in eq. 4.7.4 gives

$$\textit{eq. } 4.7.6 \quad \log\left(\frac{X_g}{K_b I}\right) = \log\left(\frac{km}{K_b}\right)$$

$$= \alpha + \beta_Y^* \log\left(\frac{Y}{P}\right) + \Phi^* \log\left(\frac{P_g I}{P}\right) + \Phi_k^* \log\left(\frac{P_k}{P}\right)$$

A generalization hereof is

$$\textit{eq. } 4.7.7 \quad \log X_g = \alpha + \beta_K^* K_b + \beta_Y^* \log\left(\frac{Y}{P}\right)$$

$$+ \Phi^* \log\left(\frac{P_g}{P}\right) + \Phi_k^* \log\left(\frac{P_k}{P}\right) + \theta^* \log I + \tau_1^* T + T_2^* T^2$$

where eq. 4.7.6 occurs as the testable special case

$$\textit{eq. } 4.7.8 \quad \beta_K^* = 1, \ \theta^* = (1 + \Phi^*), \ \tau_1^* = \tau_2^* = 0.$$

If eq. 4.7.8 holds, the impact of I on X_g is positive if $\Phi^* > -1$, i.e. for a given automobile stock an increased fuel efficiency leads to fuel savings if the demand for gasoline is price inelastic, which is normally the case. The presence of T in eq. 4.7.7 compensates for

---

[24] Strictly speaking the demand for person kilometers is the relevant variable, which does not provide much utility in itself, but services other ends (mobility of labour, leisure etc.).

the measure of I being uncertain, but of course also represents trended missing explaining variables. Examples are the supply of infrastructure, the frequency and durability of congestions etc.

If the marginal non-fuel costs of driving a kilometre with a given automobile develops roughly in line with the general price index it does not matter their impact is assumed away.

For transport it is possible to expand the estimation period back to 1948 (because the energy matrices are not utilized here). However, to avoid the post-war years of rationing, it is decided to start the estimation period in 1955 as in ADAM.

Figure 4.7.9 reveals that the partial correlation between fuel consumption per vehicle and relative fuel price has been weakly positive in the period 1955-1993. By closer inspection 3 subperiods emerge.

In the first subperiod running until the beginning of the 1960's there is virtually no correlation between price and consumption. The real fuel price showed a declining trend, but fuel consumption per automobile was untrended.

In the second sub-period running for the next two decades there is a clear negative correlation between price and consumption per vehicle. The first oil price hike marked an end to the long era of declining real fuel prices, but consumption per vehicle in fact stopped to increase some years before. The second oil price hike resulted in an increase in the relative fuel price of more than 40 per cent from 1978 to 1981 which sparked a reduction of consumption per vehicle of more than 1/4 from 1978 to 1984.

The third subperiod comprised of the last decade or so again breaks the pattern of negative correlation. From 1981 to 1991 the relative price fell by almost 40 per cent, but only the 17 per cent rise of consumption per vehicle in 1991-93 took this series 6 per cent above the low 1981 figure. Lagged adjustment is clearly responsible, but irreversibility or asymmetry might also play their part, although such phenomena can not explain, why consumption accelerated so much in the last two years.[25] Another potential explanation is the enhanced fuel efficiency of automobiles, although fuel efficiency is not fully exogenous to demand.

Figure 4.7.10 shows the series for average consumption of fuel per kilometre calculated by Bjørner (1994) based on estimates of total

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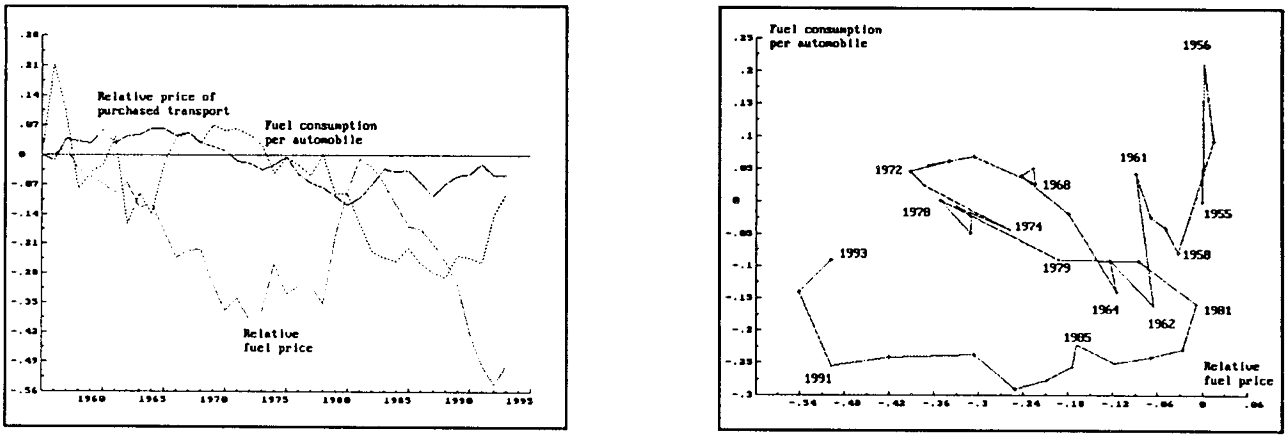
[25] It should be noted that large variations in the direction and size of cross-border trade in the last 10 years or so affects the figures in a way that the rough adjustment for foreigners share of consumption, cf. Appendix I.4.2, can not correct. These fluctuations of cross-border trade stem from significant variations in the Danish excise taxes compared with the German. Data for cross-border trade are comparably unreliable.

kilometres driven and gasoline consumption. As the annual variations in the series reveal, this is not a purely "technical" variable exogenous to consumers gasoline demand. According to Bjørners calculations the average fuel efficiency increased from 10.4 kilometre per litre in 1970 to 13.3 kilometre per litre in 1991. In the regressions below a 5 year moving average of this series will be used as the expression for inverse fuel efficiency, and we shall be careful to examine the consequences of treating it as exogenous to demand.



4.7.9.a. Times series plot

4.7.9.b. Cross plot

Figure 4.7.9 Households' consumption of transport fuels in 1980 prices per vehicle and the price of transport fuels relative to a general private consumption deflator, 1955=1. 1955-1991. Log scale.

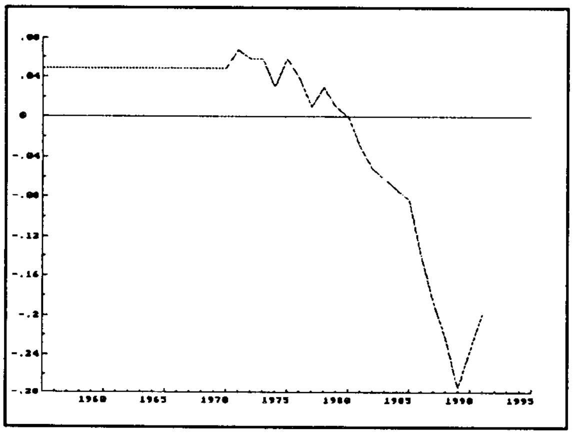


Figure 4.7.10 Average consumption of transport fuels per kilometre, index 1980=1, log scale.

Source: Based on Bjørner (1994). The numbers for 1955-69 are assumed equal to the number for 1970.

	H_0:I(1)		H_0:I(2)		
	C-term	Origo	C-term	Origo	Conclusion
1. Efficiency adj. consumption of transport fuels per automobile	-3.24				I(0)
2. Efficiency adj. relative price	+0.28		-4.33		I(1)
3. Relative price of purchased transport	-1.30			-5.86	I(1)
MacKinnon 5 percent crit. val.	-2.94	-1.95	-2.94	-1.95	

Table 4.7.10 (Augmented) Dickey Fuller statistics for regression variables, 1955-91
Note: See note to table 4.7.1.

Figure 4.7.9.a. indicates, that the price of purchased transport relative to the general price index is not able to explain, why fuel consumption per automobile did not rise in the 1980s. Although the relative price of purchased transport reached its historical minimum in 1980, it was on an increasing trend during the remaining years.

According to the formal tests of table 4.7.10 the (log of the) efficiency adjusted fuel consumption per automobile, *log*$(X_g/(K_bI))$, is I(0). The efficiency adjusted relative fuel price, *log*$((P_gI)/P)$, is I(1), i.e. it cannot explain the former I(0) variable alone.

Table 4.7.11 shows the regression result for eq. 4.7.7 dynamized by the simple ECM model (analogous to eq. 4.7.1). Regression no. 1-4 indicate, that multicollinearity with the trend and the fuel efficiency variable makes the point estimate of β_K^* very uncertain. As D*log*K_t shows a clear negative trend, the point estimate of β_K comes out with a reasonable value only when the trend and the expression for the fuel efficiency variable are both excluded, cf. regression no. 4. It is however clear from the sharp drop of the log likelihood and poor stability tests of no. 4, that at least one of these two variables should be included.

In most specifications it can not be rejected that $\beta_K=\beta_K^*=1$. These restrictions are imposed at regression no. 5-11. Regression no. 5 illustrates, that a quadratic trend specification comes out with an increasing negative trend however not significantly. No. 6 shows that it can be rejected that either (or in fact both) the linear trend coefficient or the fuel efficiency coefficient are zero. Including only the trend leads to approximately the same estimate of the long run price elasticity (no. 8), while including only the fuel efficiency variable (no. 9) leads to a poorer result, where the estimate of the short run price elasticity is numerically higher than the long run estimate.

Adding the relative price of purchased transport as an explaining variable leads to either an incorrect negative sign or a clearly insignificant positive elasticity (not reported). If the general price index is replaced by the price index of public transports, in the simple ad hoc ECM the variance grows markedly, cf. no. 7, questoning the usefulness of a conditional demand function, where the automobile stock operates as the "income" variable.

In regression no. 10 and 11 the additional restrictions $\theta=(1+\Phi)$ and $\theta^*=(1+\Phi^*)$ are imposed. They are clearly accepted by an *F*-test. However the linear trend is still significant. If this is because the linear trend basically compensates for an unprecise measurement of I (especially before 1970), the restrictions $\theta=(1+\Phi)$ and $\theta^*=(1+\Phi^*)$ are not proper. The unrestricted estimate of no. 6 implies $\theta^*/(1+\Phi^*)=.23>2$. The presence of the annual trend of -.81 per cent adds to this gab if interpreted as reflecting also increased fuel efficiency. An obvious alternative interpretation of the trend is, that the restriction $\beta_K=\beta_K^*=1$ is simply wrong (β_K^* is lower). Unfortunately, due to multicollinearity we are unable to estimate β_K^* freely and unity is a natural choice.

Regression no. 11 illustrates, that the total real budget does not possess additional explanatory power. The short run elasticity with respect to the real budget always become insignificant in various specifications (not reported). The automobile stock is a sufficient "income" variable.

This is further confirmed by regression no. 12-14 where the automobile stock is replaced by the real budget. If some trend variable is included multicollinearity with the real budget leads to absurd large estimates of the long run budget elasticity.

These results indicate, that it is difficult to model gasoline consumption reasonably in a standard consumer demand system.

As figure 4.7.9 shows, the relative fuel price reached its maximum for the period 1955-1991 in 1957. Therefore it does not make much sense to test for non-reversibility over the entire period 1955-91. It can be argued, that the hypothesis of non-reversibility is only relevant for the period beginning in the early 1970s, where the oil price turmoil might have marked a regime shift concerning expectations of the future oil price path.

Table 4.7.12 displays the results of testing for non-reversibility. Regression no. 4 is the same as table 4.7.11 no. 10 reestimated for the period 1973-91. The parameters do not change much, but the estimated variance for this shorter period is much lower and now the Chi^2 version of the Chow test indicates a break in 1983 reflecting that the test is tougher to pass, when the variance is lower. Although the variable I clearly explains part of the lacking expansion of gasoline consumption in the last part of the 1980s, non-reversibility might still provide an additional explanation. The fact that the linear trend is still significant on this shorter period, is an argument against regarding this trend as compensating for I assumed constant prior to 1970.

The first 4 regressions of table 4.7.12 include a linear trend. The variable $P_{Et}^{(3)}$ tracking price declines, cf. box 4.4.1, has a strong negative trend, and multicollinearity with the trend makes regression no. 1-3 useless. The last 4 regressions of table 12 is therefore performed without a trend. Regression no. 7 indicates, that the ratchet is a relevant model and the reversible special case is rejected at a 5 per cent level. The long run price elasticity is estimated to -.69 for price increases beyond earlier maximum and only -.26 for price movements below earlier maximum. However, in the ratchet regression there is first year overreaction to price movements below earlier maximum (short run price elasticity numerically larger than the long run elasticity), and the Chi^2 version of the Chow test still indicate a structural break in 1983. In sum, the ratchet specification is not fully convincing.

Table 4.7.13 finds no significant signs of asymmetric adjustment speeds. The long run price elasticity is estimated to -0.39 in line with the estimate of -0.43 from the ECM estimated directly in one step.

Figure 4.7.11 shows that the predictive performance of regression no. 10 of table 4.7.11 is poor judged by the preliminary figures for 1992 and 1993. The sudden increase of consumption in these years is at least partly connected with reversing cross-border trade. The Danish gasoline taxes fell relative to the German, which the estimated equation can not deal with. The recursive regressions reveal multicollinearity between the relative price and the trend in the observations prior to the second oil price hike, but the importance of this declines, as the relative price drop of the 1980s enter the recursive regression.

	Short run elasticities			Adj. speed	Long run elasticities			Annual trend, %			Regression statistics			Tests on residuals			Chow stability tests		
	Φ	β_K	β_Y	γ	Φ^*	β_K^*	β_Y^*	1960	1991	θ^*	s	R^2	L	DW	LM(1)	ARCH(1)	1974	1979	1983
1	-.47	.09^{*a}		.83	-.60	.85^{a}		-.39*		1.05*	.0595	.674	56.41	1.86	1.70	.04	.79 .51	.83 .58	.99 .95
2	-.28*	.05^{*a}		.74	-.43	1.03^{a}		-1.9			.0611	.644	54.80	1.96	.00	.29	.47 .21	.55 .28	.86 .69
3	-.52	.15^{*a}		.82	-.64	.80				1.31	.0587	.672	56.29	1.84	1.78	.02	.72 .48	.89 .74	.99 .98
4	-.37*	.95^{a}		.28	-.77*	.79^{*a}					.0720	.490	48.13	2.28	2.67	.14	.05 .01	.02 .00	.05 .01
5	-.29*	1.00		.62	-.43	1.00		-.47*	-2.1*		.0631	.419	53.01	2.08	.39	.09	.32 .14	.26 .10	.51 .30
6	-.38	1.00		.68	-.47	1.00		-.81		.76	.0611	.455	54.17	2.01	.03	.02	.65 .45	.89 .80	.99 .98
7[b]	-.20*	1.00		.64	-.41	1.00		-.60		.77	.0642	.398	52.35	2.11	.62	.08	.99 .99	.95 .90	.99 .99
8	-.27*	1.00		.57	-.53	1.00		-1.2			.0640	.384	51.90	2.12	1.49	.04	.19 .08	.39 .24	.54 .38
9	-.53	1.00		.38	-.34*	1.00				1.89	.0661	.343	50.71	2.13	.36	.23	.54 .38	.54 .38	.60 .44
10	-.34	1.00		.69	-.43	1.00		-.81		.57	.0606	.462	53.93	2.00	.02	.02	.49 .33	.92 .86	.98 .97
11	-.38	1.00		.67	-.40	1.00	.16*	-1.1		.60	.0612	.467	54.11	2.00	.01	.01	.59 .39	.97 .93	1.0 .99
12	-.80		.29*	.46	-.44*		3.39	-2.9*		1.92*	.0618	.648	54.98	2.36	3.61	1.24	.52 .20	.80 .52	.90 .71
13	-.59		.51*	.34	.02*		5.00	-7.3			.0632	.543	53.55	2.51	4.20	.82	.27 .08	.66 .41	.64 .38
14	-.92		.07*	.49	-.79		2.22			3.03	.0627	.625	53.84	2.12	.77	.91	.28 .08	.93 .82	.95 .88

Table 4.7.11 Consumption of transport fuels: Regression results for the simple ECM model, 1955-1991.

Note: a) Not significant different from 1.00 at a 5 per cent level.

b) The price of public transports replaces the general price index in relative price expression.

Regression no. 1-4 and no. 12-14: Dependent variable $Dlog(X_g)$. I and T does not enter the short run part of the ECM.

Regression no. 5-9: Dependent variable $Dlog(X_g/K_b)$ to fulfil the restriction $\beta_K=\beta_K^*=1$. I and T does not enter the short run part of the ECM.

Regression no. 10-11: Dependent variable $Dlog(X_g/(K_b{}^*I))$ to fulfil the restrictions $\beta_K=\beta_K^*=1$, $(1+\Phi)=\theta$ and $(1+\Phi^*)=\theta^*$.

See also note to table 4.7.3.

		Short run price elasticities			Adj. speed	Long run price elasticities			Annual trend	Regression statistics			Tests on residuals			Chow stability test 1983	Prob. value of H_0
		Φ_1	Φ_2	Φ_3	γ	Φ_1^*	Φ_2^*	Φ_3^*	%	s	R^2	L	DW	LM(1)	ARCH(1)		
1.	General	-.40*	-.40*	-.58*	.57*	-1.21	.19*	-.06*	1.1*	.0299	.751	45.80	1.96	.01	1.32	.07 .00	
	H_0: Jagged ratchet																.35
	H_0: Ratchet																.96
	H_0: Reversible																.59
2.	Jagged ratchet	-.22*	-.21*	-.50*	.65	-.49*	-.49*	-.28*	-.21*	.0303	.694	43.83	2.29	2.87	.12	.80 .04	
	H_0: Reversible																.73
2.	Ratchet	-.39*	-.51	-.51	.54	-1.27	-.01*	.01*	1.7*	.0274	.749	45.72	1.97	.59	.97	.78 .03	
	H_0: Reversible																.22
4.	Reversible (=table 4.7.11 no. 10 reest.)	-.30	-.30	-.30	.69	-.40	-.40	-.40	-.80	.0288	.678	43.34	2.10	.57	.93	.65 .05	
5.	General	-.37*	-.29*	-.60	.65	-.97	.28*	-.23*		.0287	.748	45.67	1.85	.09	1.82	.69 .00	
	H_0: Jagged ratchet																.34
	H_0: Ratchet																.75
	H_0: Reversible																.16
6.	Jagged ratchet	-.23*	-.23*	-.49*	.63	-.53	-.53	-.24*		.0291	.694	43.83	2.31	1.66	.06	.80 .09	
	H_0: Reversible																.09
7.	Ratchet	-.20*	-.48	-.48	.66	-.69	-.26	-.26		.0272	.632	45.17	1.88	.16	2.06	.72 .04	
	H_0: Reversible																.04
8.	Reversible	-.30	-.30	-.30	.22*	-.39*	-.39*	-.39*		.0325	.559	40.37	2.35	1.37	2.11	.35 .01	

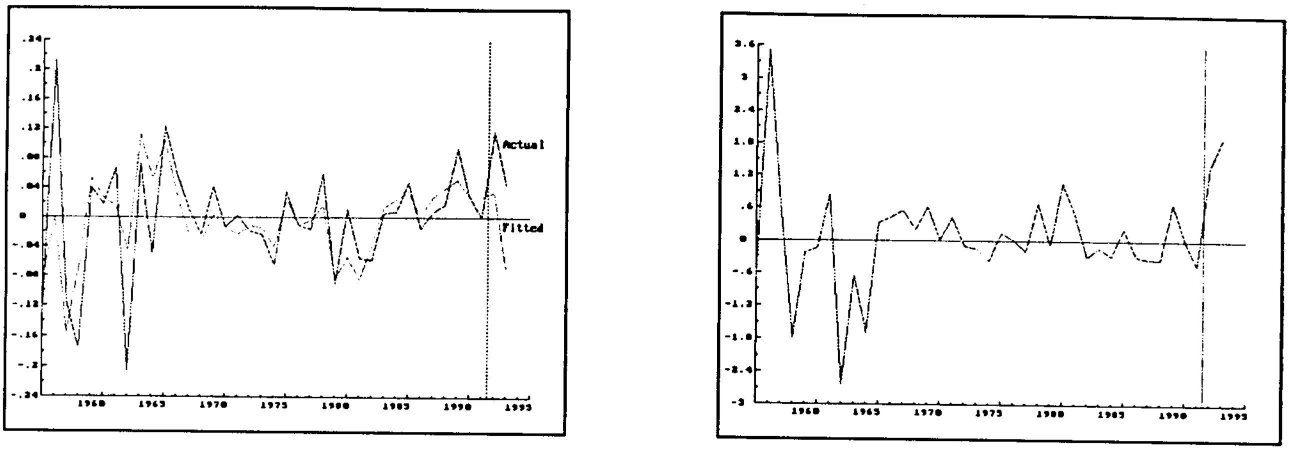
Table 4.7.12 Consumption of transport fuels per automobile: Testing non-reversibility, cf. box 4.4.1, in the ECM model, 1973-1991.

Note: The dependent variable $Dlog(X_k/(K_b{}^*I))$ and the price variables is P_kI to fulfil the restrictions $\beta_K=\beta_K{}^*=1$, $(1+\Phi)=\theta$ and $(1+\Phi^*)=\theta^*$. θ can be calculated from the restriction $\theta=(1+\Phi)$. Chow stability tests are forecasts tests due to the spare degrees of freedom. See also note to table 4.7.3.

		Adjustment speed					Annual trend, %	Regression statistics			Tests on residuals		
	Φ	γ^+	γ	γ^a	γ^d	Φ^*		s	R^2	L	DW	LM(1)	ARCH(1)
1. Step 1 regression						-.39	-.78	.0625	.501	51.64	1.30		
2. Step 2 EC regression *F*-test H_0: $\gamma^+=\gamma$, prob.val=.21	-.17*	.86	.45*			-	-	.0682	.446	52.85	1.58	.06	.12
3. Step 2 EC regression *F*-test H_0: $\gamma^a=\gamma^d$, prob.val=.44	-.17*			.55	.76	-	-	.0485	.518	57.80	1.74	.00	.08
4. Step 2 EC regression (Standard)	-.28	.68	.68	.68	.68	-	-	.0587	.420	52.03	1.50	1.16	.05

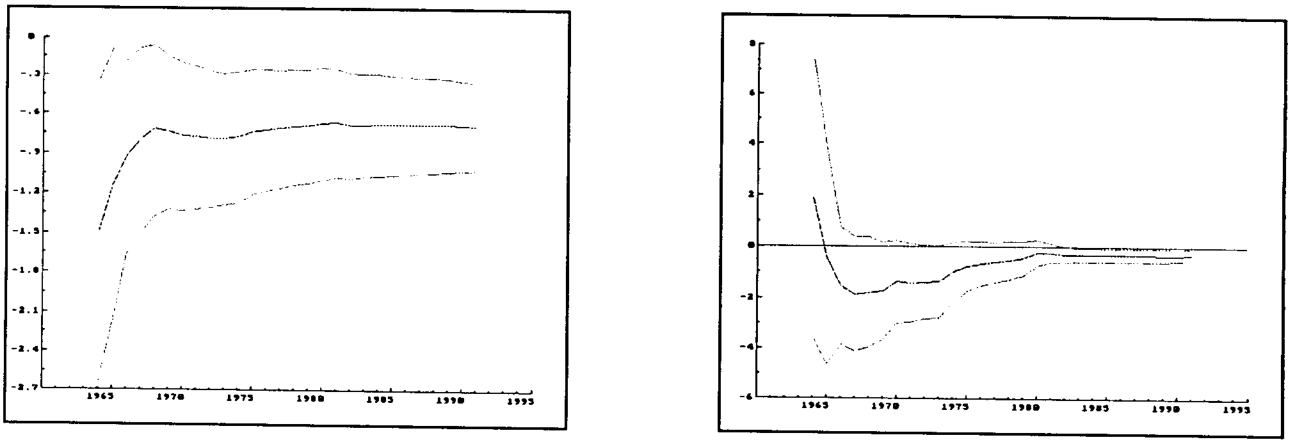
Table 4.7.13 Efficiency adjusted consumption of transport fuels per automobile: Testing asymmetry, cf. eq. 4.4.5 - 4.4.8, 1955-1991.[a]

Note: a) The time period is 1955-91 for no. 1, 1956-91 for no. 2 and 4 and 1957-91 for no. 3.
See also note to table 4.7.3.



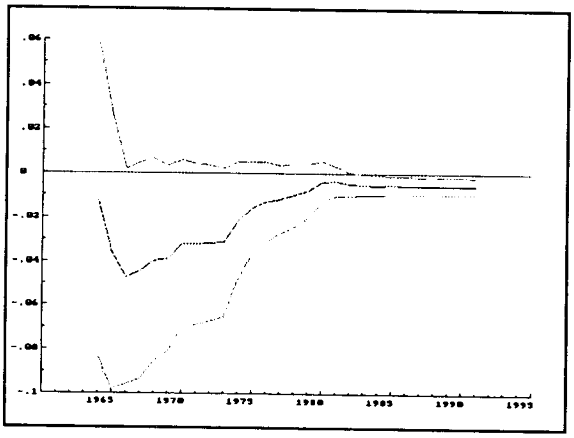
4.7.11.a. Log change of efficiency adjusted consumption per automobile

4.7.11.b. Standardized residuals



4.7.11.c. Recursive estimation: $-\gamma \pm 2 \cdot SE$

4.7.11.d. Recursive estimation: $\gamma\Phi^{*} \pm 2 \cdot SE$



4.7.11.e. Recursive estimation: $\gamma\pi^{*} \pm 2 \cdot SE$

Figure 4.7.11 Gasoline consumption: Regression plots for table 4.7.11 no. 10.

I.4.7.2.2 Purchased transport

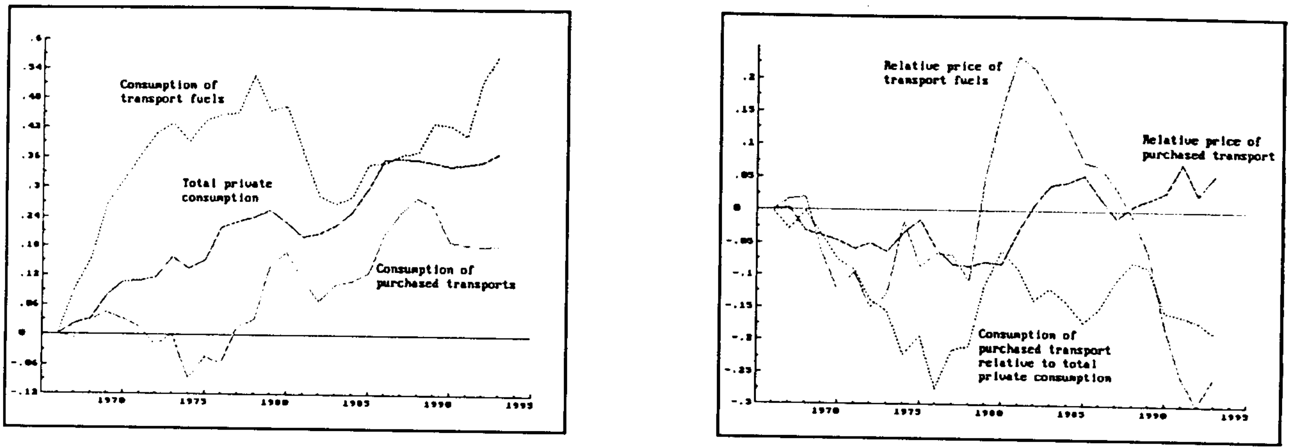
From 1966 to 1976, private consumption of purchased transport showed a clear negative trend relative to total private consumption cf. figure 4.7.12.a and b. It even declined in absolute terms. This development should be seen in light of the declining trend of the real price of transport fuels until the first oil price hike in 1973/74, although the real price of purchased transports also diminished a little. The budget elasticity of transport fuels might also be lower than unity. The decline of purchased transports relative to total consumption was partly reversed in the following period, especially around the second oil price hike in 1979. Hereafter the relationship continued to move in large cycles around a small negative trend, the relative price of purchased transports displaying a positive trend. However the relative price of transport fuels showed a steep decline.

Figure 4.7.12.c and d depicts the same variables where "purchased transport" includes communication as in the ADAM aggregate. This variable showed a much stronger growth during 1966-91 in 1980-prices, whereas its relative price had a weaker development. The share of communication in value terms of the ADAM aggregate rose steadily from 26 per cent in 1966 to 40 per cent in 1993. The expansion in real terms outpaced the declining relative price.

Table 4.7.14 and 4.7.10 reveal that consumption of purchased transports and its relative price are both I(1). Table 4.7.14 concerns the ADAM variable, but the outcome applies equally well for the narrow NA figures.

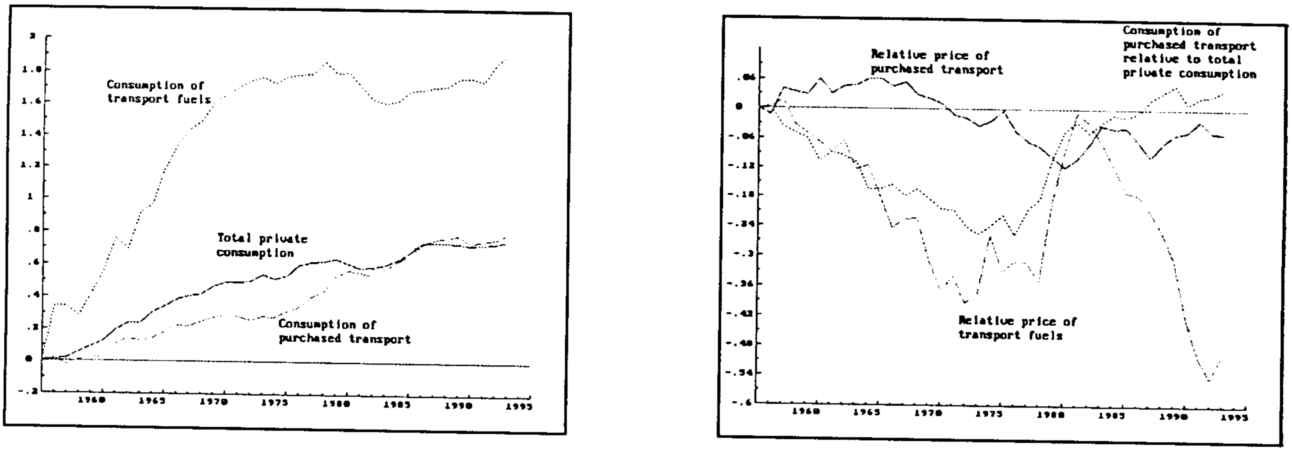
Table 4.7.15 shows regression results for the simple ECM for purchased transport. The price of transport fuels is measured in efficiency terms (P_gI). Regression no. 1-7 deals with the narrow NA definition of this variable. Regression no. 1 shows that the most general specification comes out with absurd estimates, which to some extent is due to multicollinearity. The trend variable counts from 1983 (i.e. equal to year minus 1981 but equal to one prior to 1982). A linear or quadratic trend through the entire period possess no explanatory power. Regression 2-4 investigate the multicollinearity problem either by eliminating the trend and/or the relative price of transport fuels, which is not significant when the trend is excluded. Regressions 5-7 are performed in absolute changes as origo regressions.

None of these regressions avoid the problem of insignificant coefficients to several vital variables. At least the regressions in changes (no. 5-7) avoid absurd estimates. Although the parameter estimates of these regressions are not significant different from zero, at least they supersede the standard deviations. A serious drawback is of course that the long run relation is unspecified.



4.7.12.a. Narrow measure 1966-1993, 1966=1

4.7.12.b. Narrow measure 1966-1993, 1966=1



4.7.12.c. ADAM definition 1955-1993, 1955=1

4.7.12.d. ADAM definition 1955-1993, 1955=1

Figure 4.7.12 Households' consumption of purchased transport and transport fuels in 1980 prices and relative prices, index 1955=1 and 1966=1, log scale.

Note: At figure c and d "purchased transport" includes communication as in ADAM. At figure a and b "purchased transport" includes only purchased transport according to national account definitions. There are no observations for this series prior to 1966.

	H_0:I(1)		H_0:I(2)		Conclusion
	C-term	Origo	C-term	Origo	
1. Consumption of purchased transports per capita	+.09		-5.39		I(1)
MacKinnon 5 percent crit. val.	-2.94	-1.95	-2.94	-1.95	

Table 4.7.14 (Augmented) Dickey Fuller statistics for regression variables, 1955-91
Note: See note to table 4.7.1.

	Short run elasticities			Adj. speed	Long run elasticities			Annual trend, %	Regression statistics			Tests on residuals			Chow stability tests		
	Φ	Φ_g	β_Y	γ	Φ^*	Φ_g^*	β_Y^*	From 1983	s	R^2	L	DW	LM(1)	ARCH(1)	1974	1979	1983
1	-1.07	.42	.84*	.74	-2.09	.84	-.12*	9.2	.0368	.587	52.63	2.02	.03	.99			
2	-.59*	.10*	.45*	.21*	.19*	.31*	1.41		.0420	.429	48.57	2.44	4.05	.37		.02 .00	.31 .01
3	-.57*		.39*	.19*	.49*		1.68	-2.4*	.0422	.390	47.75	2.33	2.41	.83			
4	-.57*		.43*	.23*	-.18*		1.19		.0415	.376	47.48	2.16	.42	1.07	.44 .13	.03 .00	.73 .41
5[a]	-.63*	.23*	.45*					2.8*	.0414		46.32	2.58					
6[a]	-.48*	.11*	.60*						.0425		45.08	2.24			.86 .80	.04 .01	.70 .61
7[a]	-.56*		.48*						.0422		44.68	2.17			.67 .62	.45 .38	.53 .47
								From 1982									
8	-.57	.23	.61	.46	-.59*	.54	.94	4.4	.0212	.635	95.19	1.98	.07	.08			.47 .11
9	-.49	.10*	.71	.01*	-13.4*	3.88*	4.79*		.0239	.521	90.15	2.29	1.37	1.09	.02 .00	.00 .00	.06 .00
10	-.56		.73	.06*	-5.23		.68*	1.3*	.0242	.490	89.00	2.12	.28	.00			.42 .17
11	-56		.73	.04*	-6.95		.74*		.0239	.490	88.97	2.15	.31	.00	.05 .01	.02 .00	.37 .17
12[a]	-.55	.18	.68					2.7	.0239		87.70	2.21					.13 .07
13[a]	-.44	.07*	.73						.0264		83.55	1.62			.46 .39	.23 .16	.03 .01
14[a]	-.49		.68						.0264		83.04	1.60			.58 .54	.51 .47	.03 .00

Table 4.7.15 Consumption of purchased transport: Regression results for the simple ECM model, 1967-1991 and 1955-91.

Note: a) Specified in changes and estimated by origo regression. The long run elasticities are then equal to the short run elasticities. R^2, LM and ARCH tests not reported as they are not subject to the usual interpretation.

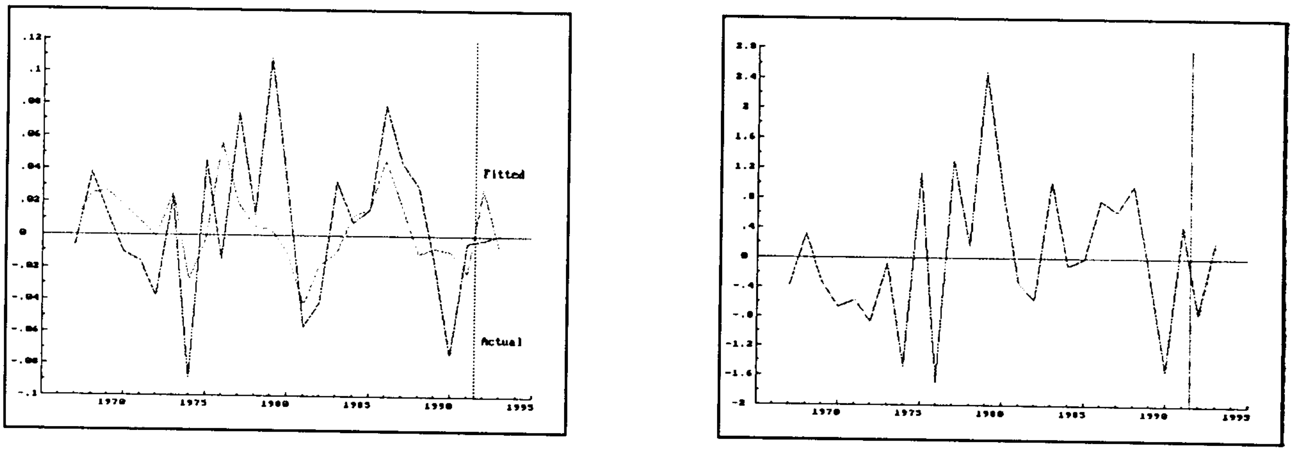
The price of transport fuels is measured in efficiency terms (P_gI) when present. See also note to table 4.7.3.

Regression no. 1-7 1967-91. Narrow NA definition of "purchased transport".

Regression no. 8-14: 1955-91. "Purchased transport" include communication as in ADAM.

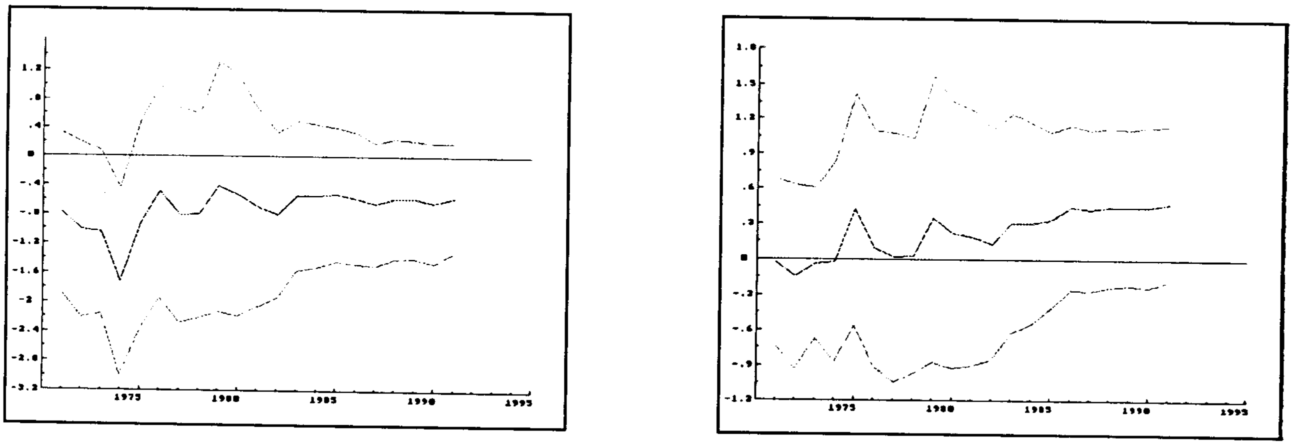
The regressions illustrate that in order it to obtain a well-defined underlying long run equation it is necessary to include both the relative price of gasoline and the trend starting in 1983 (T83). If they are not both included, the estimated adjustment speed becomes low (and insignificant). As figure 4.7.12.a and b indicate, the relative price of transport fuels can offer a contribution to the explanation of the development of consumption of purchased transport in 1966-72 and also 1979 and 1980, which are important observations. However, the sharp reduction of this price since 1981 did not derive a permanent increase in the purchase of transport. Therefore the dummy-trend T83 is called for in specifications including the relative price of gasoline.

Regression no. 8-14 of table 4.7.12 replicates no. 1-7 except that "purchased transport" is defined as the ADAM aggregate including communication. With this definition it is more suitable to start the trend in 1982. Comparing regression no. 13-14 with no. 6-7 the price elasticities are broadly in the same range, whereas the budget elasticity is larger when communication is included in the transport measure.



4.7.13.a. *Log change of purchased transport*

4.7.13.b. *Standardized residuals*



4.7.13.c. *Recursive estimation:* $\Phi \pm 2 \cdot SE$

4.7.13.d. *Recursive estimation:* $\gamma\beta_Y \pm 2 \cdot SE$

Figure 4.7.13 Purchased transport: Regression plots for table I.4.15 no. 7.

Figure 4.7.13 illustrates how regression no. 7 of table I.4.13 only catch the very broad features of purchased transport.

I.4.7.2.3 Joint modelling of transport fuels and purchased transport

In this section "purchased transport" is defined as in ADAM (including communication) because the purpose is to explore the room for an alternative and joint modelling in ADAM without further complications.

To deal with specific substitution effects, transport fuels and purchased transport should be modelled together in a demand system as AID, which allows for such effects. Table 4.7.16 displays the regression results for the static version and the partial adjustment version: the two dynamic parameters of the ECM (not reported) attain close to similar values, and the partial adjustment special case is clearly accepted.

The only extra explaining variable is the expression for inverse fuel efficiency. If the automobile stock is included (not reported), multicollinearity with the budget leads to an elasticity of gasoline consumption with respect to the stock considerably below unity. If this elasticity is restricted to unity on average (it varies with the budget share, i.e. considerably over the historical period), the budget is devoid of all explanatory power leading to atheoretical results.

The results of table 4.7.16 are useless. The elasticity of gasoline consumption with respect to the inverse fuel efficiency variable becomes excessive. Excluding the variable results in a large drop of the log likelihood value and serious deterioration of other statistics, cf. table 4.7.17, and in dynamic specifications the dynamic parameters attain atheoretical values (not reported).

	α_i^0	γ_{ii}	β_i	α_i^1	k_2	s	R^2	DW	L	e_i^*	e_{ii}^*	Elasticity wrt. fuel eff.
1. Static												
Transport fuels	.17 (.01)	.015 (.018)	.26 (.01)	.74 (.04)		.0144	.97	1.22	106.47	1.89	-1.21	2.5
Purchased transport	.83 (-)	.015 (-)	-.26 (-)	-.74 (-)						.62	-.71	-1.0
2. PA												
Transport fuels	.17 (.01)	.009 (.025)	.25 (.01)	.79 (.06)	.65 (.11)	.0126	.97	1.94	111.95	1.84	-1.22	2.6
Purchased transport	.83 (-)	.009 (-)	-.25 (-)	-.79 (-)						.63	-.73	-1.1

Table 4.7.16 Results for AID estimated for 1955-91 for transport. Inverse fuel efficiency is additional explaining variable

Note: Standard errors in brackets.
Elasticities are partial and shown for 1991.

	α_i^0	γ_{ii}	β_i	α_i^1	k_2	s	R^2	DW	L	e_i^*	e_{ii}^*
1. Static											
Transport fuels	.25 (.02)	.009 (.065)	.16 (.03)			.0513	.55	.12	58.95	1.38	-1.14
Purchased transport	.75 (-)	.009 (-)	-.16 (-)							.71	-.82

Table 4.7.17 Results for AID estimated for 1955-91 for transport. No extra explaining variables
Note: Standard errors in brackets.
Elasticities are partial and shown for 1991.

e_i	e_i^*	e_{ii}	e_{ii}^*	Adj. speed
.94	1.27	-.31	-1.16	.28

Table 4.7.18 ADAM elasticities and adjustment speed of transport in 1988
Note: The elasticities are relevant for DLES with total private consumption expenditure minus gross rents (per capita) as budget constraint.
Source: Danmarks Statistik (1993a).

ADAM's estimated long run elasticities for total transport are displayed in table 4.7.18. We abstain from calculating the total elasticities which result from substituting the AID regressions of table I.4.17 in ADAM. The treatment of automobile purchases in ADAM makes the calculation complicated and requires a model simulation. However, by glancing table 4.7.17 and 4.7.18 it is easily seen that for example the total long run price elasticity for gasoline would numerically far exceed the result from the ad hoc regressions.

I.4.7.2.4. Assessment

The results indicate that it is more fruitful to model households' aggregate demand for various fuels by "ad hoc" demand functions than by conditional demand functions in complete consumer demand systems. It should be emphasized that complete consumer demand systems might still be preferable in modelling the demand for all consumer goods. The focus of this paper has been the demand for fuels and purchased transport only.

For transport the special treatment of automobile purchases in ADAM adds to the problems. This special treatment is necessitated by the fact that the macro consumption function is only specified to deal with non-durables.

Fuel saving technological progress should be measured in the data a priori to the regressions when possible. This also creates a potential link to technical bottom up models like BRUS2 for heating and DEFU's electrical appliance model for electricity consumption.

Measuring technological progress seem to be a prerequisite for obtaining useful estimates of price and budget elasticities, i.e. technological progress variables do not take much explanatory power out of prices, probably because fuel saving technical progress is primarily exogenous supply determined to the households.

Non-reversibility and asymmetric adjustment do not seem to be of great significance, although there is some indication of non-reversibility in gasoline demand.

APPENDIX I.4.1

Conditional demand functions and total elasticities

Consider the demand functions generated by 2 step maximization in the broad sense

Stage 1 group demand functions in aggregate groups A,...,E,...,Z

$$X_E = F(P_A,\dots,P_E,\dots,P_Z,Y)$$

where the aggregate price index for example for group E, P_E, is defined as

$$P_E = g(P_{E_1},\dots P_{E_i},\dots P_{E_n})$$

i.e. independent of Y.

Stage 2 conditional demand functions for items $E_1,\dots,E_i,\dots E_n$ in group E

$$X_{E_i} = f(P_{E_1},\dots,P_{E_i},\dots,P_{E_n},Y_E)\ , \quad Y_E = P_E X_E$$

Partial differentiation of the conditional demand function for E_i with respect to Y gives

$$\frac{\partial X_{E_i}}{\partial Y} = \frac{\partial f}{\partial Y_E}\frac{\partial Y_E}{\partial Y} = \frac{\partial f}{\partial Y_E}\frac{\partial F}{\partial Y}P_E$$

i.e.

$$e_i^T = \frac{\partial X_{E_i}}{\partial Y}\frac{Y}{X_{E_i}} = \frac{\partial f}{\partial Y_E}\frac{1}{X_{E_i}}\frac{\partial F}{\partial Y}YP_E \quad \Rightarrow$$

$$e_i^T = \frac{\partial f}{\partial Y_E}\frac{Y_E}{X_{E_i}}\frac{\partial F}{\partial Y}\frac{Y}{Y_E}P_E = e_i e_{EY}$$

The total budget elasticity is the product of budget elasticities in each step.

Similarly, differentiation with respect to the price of *j* gives

$$\frac{\partial X_{E_i}}{\partial P_{E_j}} = \frac{\partial f}{\partial P_{E_j}} + \frac{\partial f}{\partial Y_E}\frac{\partial Y_E}{\partial P_E}\frac{\partial P_E}{\partial P_{E_j}}$$

therefore

$$e_{ij}^{T} = \frac{\partial X_{E_i}}{\partial P_{E_j}}\frac{P_{E_j}}{X_{E_i}} = \frac{\partial f}{\partial P_{E_j}}\frac{P_{E_j}}{X_{E_i}} + \frac{\partial f}{\partial Y_E}\frac{P_{E_j}}{X_{E_i}}\left(P_E\frac{\partial X_E}{\partial P_E}+X_E\right)\frac{\partial P_E}{\partial P_{E_j}} \Rightarrow$$

$$e_{ij}^{T} = e_{ij}+\frac{\partial f}{\partial Y_E}\frac{Y_E}{Y_E}\frac{P_{E_j}}{X_{E_i}}\frac{\partial P_E}{\partial P_{E_j}}X_E\left(\frac{P_E}{X_E}\frac{\partial X_E}{\partial P_E}+1\right) \Rightarrow$$

$$e_{ij}^{T} = e_{ij} + e_i\frac{P_{E_j}}{Y_E}\frac{\partial P_E}{\partial P_{E_j}}X_E(e_{EE}+1)$$

Assuming that P_E is defined as a geometric average of the P_{E_i}'s with weights equal to the budget shares of Y_E

$$\log P_E = \sum_{i=1}^{n} S_{E_i}\log P_{E_i}\,,\quad S_{E_i} = \frac{P_{E_i}X_{E_i}}{Y_E}$$

we find

$$\frac{\partial \log P_E}{\partial \log P_{E_j}} = S_{E_j} \quad \Rightarrow \quad \frac{\partial P_E}{\partial P_{E_j}} = S_{E_j}\frac{P_E}{P_{E_j}}$$

which inserted above gives

$$e_{ij}^{T} = e_{ij} + e_i\frac{P_{E_j}}{Y_E}S_{E_j}\frac{P_E}{P_{E_j}}X_E(e_{EE}+1) \Rightarrow$$

$$e_{ij}^{T} = e_{ij} + e_i S_{E_j}(e_{EE}+1)$$

The total cross price elasticity is equal to the partial price elasticity plus the effect that the price of *j* has on the budget of E times the partial budget elasticity of *i*. The price of *j* influences P_E according to the budget share of *j* in Y_E. The expression in the parenthesis determines the impact on Y_E hereof as the sum of the quantity reaction and the direct price effect.

It should be stressed that even if the conditions for two stage maximization are exactly fulfilled, the aggregate group price indices are generally not defined as geometric averages. The derived formula for the total price elasticity is therefore only approximative valid, but nevertheless a convenient analytical tool.

APPENDIX I.4.2

Data for private consumption

This appendix gives a short description of the data.

I.4.2.1. Heating: Utilization rates and climate adjustment

This section contains a short description of the data prepared for this study by Stephensen (1994). The primary data source is the 25 commodity energy balances of Danmarks Statistik (1994) aggregated to 6 fuels, cf. Appendix I.3.2. Compared with the aggregation of Appendix I.3.2, town gas (item 1) and LPG (item 19) is excluded from "liquid non-transport fuels" and therefore from total heating at figure 4.7.2 and table 4.7.1 - 4.7.4 as these two items are not primarily used for heating. The final regression of table 4.7.5 and the systems regressions of table 4.7.8 however include these fuels in "liquid non-transport fuels" and therefore in total heating. From table 4.7.5 it is concluded that using this standard aggregation does not affect the results much.

DEFU (1993) has estimated the share of electricity consumption devoted to heating. It rises from 1.9 per cent in 1966 to 21.2 per cent in 1993.

In the official energy balances purchasers prices exclude value added tax, but here the value added tax is included according to formula

$$P_{E_i} = P_{E_i}^{energy\ balances}(1 + btge * tg) \ , \quad i=1,....,5$$

where tg = general value added tax rate
$btge$ = VAT correction factor for heating etc. in ADAM

The VAT correction factor deviates from 1 due to exemptions, statistical errors etc.

The Energy Planning Agency has estimated the local utilization rates for the 5 aggregate heating fuels depicted at figure A4.2.1a. below. Local utilization rates less than 100 per cent reflect local conversion losses and local network losses for electricity and district heating.

If $E_{i,t}$ is direct consumption of fuel i in year t and $v_{i,t}$ is its local utilization rate, total efficiency adjusted consumption of heating, E_t°, and the corresponding price, $P_{E,t}^{\circ}$, are defined as

$$E_t^{\circ} = \sum_{i=1}^{n} v_{i,t} E_{i,t}\,, \quad P_{E,t}^{\circ} = \frac{P_{E,t} E_t}{E_t^{\circ}}$$

Climate adjustment is based on the two assumptions:

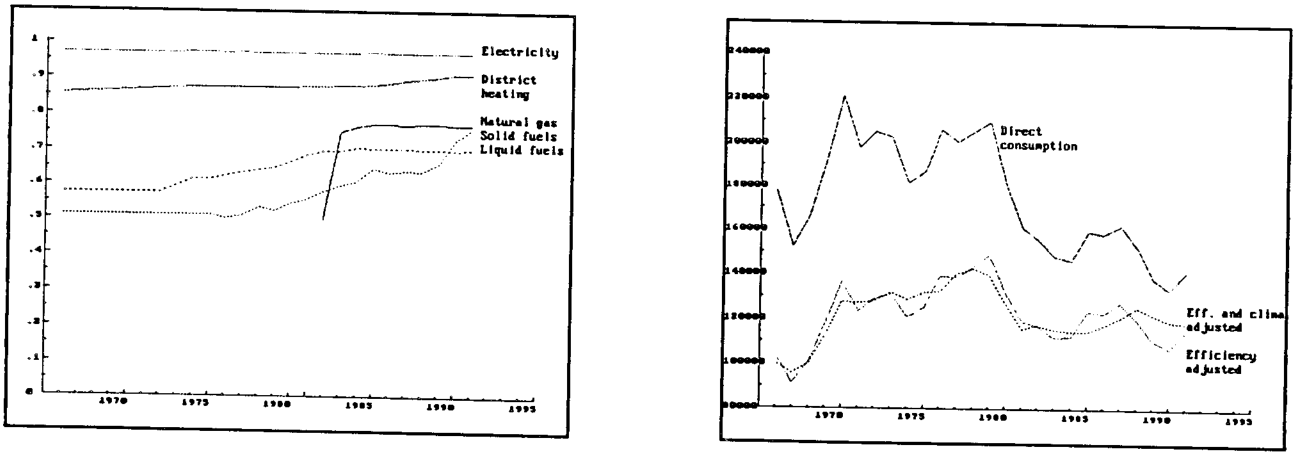
1. A constant share of climate adjusted consumption is independent of the climate.
2. The climate dependent share is directly proportional to the number of degree days.

This leads to the relation between the climate adjusted consumption, E_t^{ok}, and the unadjusted consumption, E_t°,

$$E_t^{\circ k} = G_t E_t^{\circ}\,, \quad G_t = \frac{\bar{g}}{(1-\alpha)g_t + \alpha\bar{g}}$$

where the climate adjustment factor, G_t, depends on the number of degree days, g_t, the average number of degree days, g bar, and the climate independent share, α. Stephensen argues that the climate independent share, α, was 37 per cent on average for the period 1966-91 but may have shown a declining trend. The Energy Planning Agency normally assumes α = 50 per cent. Table 4.7.5 also examines the impact on the regressions of alternative assumptions about α.

Figure A4.2.1.b illustrates that the weakly declining trend of total direct heating is mainly due to increased utilization rates (figure A4.2.1.a), substitution to relatively more efficient fuels as district heating and natural gas (see also figure 4.7.8 of the main text) and also an unusual period of mild winters at the end of the sample.



A4.2.1.a. Local utilization rates

A4.2.1.b. The impact of climate and efficiency adjustment, TJ

Figure A4.2.1 From direct consumption to climate adjusted and efficiency adjusted heating, 1966-1991.
Source: Stephensen (1994).

I.4.2.2 The residential stock in m^2

Stephensen (1994) has also compiled the data for the residential stock measured in m^2 and the number of dwellings for this study. From 1980 onwards the source is Danmarks Statistiks residential register. Before that Stephensen interpolated between occasionally countings.

I.4.2.3 The efficiency of household electrical appliances

DEFU (1993) has compiled figures for the total amount of electricity in GWH used by each of 24 different types of electrical non-heating household appliances, the number of private dwellings and the coverage of each appliance (the share of dwellings supplied with the appliance in question). The data are annual series starting in 1970.

Based on these series we calculate an index (1980=1) of the average annual electricity consumption by each appliance *i*, EFF_i, as

$$EFF_i = \left(\frac{GWH_i}{dwellings \cdot coverage_i} \right)_{1980=1}$$

where the denominator gives the number of appliance *i* with the households. Weighing each of these 24 individual indices by the share of total non-heating electricity consumption stemming from that appliance the year before and summing, one gets the inverse efficiency index depicted at figure 4.7.6 as

$$J_t = \sum_{i=1}^{24} EFF_{i,t} \cdot \left(\frac{GWH_i}{\sum_{i=1}^{24} GWH_i} \right)_{t-1}$$

The figures for J in 1966-1970 are calculated on the assumption that the average annual growth rate from 1966 to 1971 is equal to that of the period 1971-80.

I.4.2.4 A complete list of variables

Variable name	Description	Primary sources
Heating		
E°	Total efficiency adjusted consumption of heating, TJ	Stephensen (1994), cf. App. I.4.2.1
G	Climate adjustment factor	Stephensen (1994), cf. App. I.4.2.1
K	Residential stock medio, m^2 or 1980 prices	Stephensen (1994), cf. App. I.4.2.2 or ADAM (based on variable KH)
$P_E{}^\circ$	Price of E°, index 1980=1	As for E°
Non-heating Electricity		
E°	Total efficiency adjusted consumption of non-heating electricity, TJ	Energy matrices, DEFU and own calculations, cf. App. I.4.2.3
P_{E°	Price of E°, index 1980=1	As for E°
J	Electricity efficiency of household electrical appliances, index 1980=1	Appendix I.4.2.3 based on DEFU (1993)
Transport		
I	5 year moving average of inverse fuel efficiency, 1980=1	Bjørner (1994) (based on variable IEF)
K_b	Stock of automobiles with the households, primo, 1000 units	ADAM (variable KCB_{t-1})
P_g	Price of X_g, index 1980=1	ADAM (variable PCG)
P_k	Price of X_k, index 1980=1	NA price index of consumer item 630 or ADAM (variable PCK)
X_g	Consumption of gasoline in Denmark minus foreigners share, mill. 1980 D.kr.	ADAM (calculated as (CG-.06*ET)/PCG)
X_k	Consumption of purchased transport minus foreigners share, mill. 1980 D.kr	NA consumer item 630 adj.[a] or ADAM (CK-.07*ET)/PCK)
General		
P	Private consumption deflator, 1980=1	ADAM (variable PCP4V)
Y	Total private consumption, mill. D.kr.	ADAM (variable CP4)

Note: a) Adjusted for foreigners share using the same weigh as for the ADAM-variable.
All real variables are expressed per 1000 inhabitants (divided by ADAM variable U).

Appendix I.4.3

Climate adjustment in ADAM

Estimating the sub demand functions for heating and non-heating electricity by a consumer demand system, the climate adjustment of heating should be carried out consistent with the implicit climate adjustment of heating etc. in ADAM. ADAM's climate adjustment is assigned to heating alone as non-heating electricity is assumed to possess only negligible climate dependence. The adjustment is performed in current prices as ADAM's measure of real consumption (1980-prices) differs from the sub model's (TJ).

In ADAM, climate adjustment of consumption of heating etc. is performed by entering the number of frost days, FROS, as an extra explaining variable in DLES. Although ADAM utilizes another variant of DLES, eq. 4.3.12 is still valid expression for the first year impact of the number of frost days in ADAM. In ADAM the number of frost days is assumed to have no impact on habit formation, i.e. the second year impact is approximately zero (reflecting only negligible dynamic spill overs of the total system).

Eq. 4.3.12 can be restated as

$$\frac{\partial(FCE/U)}{\partial FROS} = \gamma_{FCE}^2\left(1-\frac{\beta_{FCE}}{\sum_j \beta_j}\right)$$

where FCE is real consumption of heating etc. in ADAM and U is the number of inhabitants. From this

$$\frac{\partial(PCE\cdot FCE)}{\partial FROS} = \gamma_{FCE}^2\left(1-\frac{\beta_{FCE}}{\sum_j \beta_j}\right)\cdot PCE\cdot U$$

where PCE is the price of FCE. Defining FROS bar as the average number of frost day, the additive climate adjustment factor, A_t, in current prices is

$$A_t = \gamma_{FCE}^2\left(1-\frac{\beta_{FCE}}{\sum_j \beta_j}\right)\cdot PCE_t\cdot U_t\cdot(FROS_t-\overline{FROS})$$

The climate adjusted consumption of heating etc. in current prices is then defined as

$$E^A_{HEATING,t}\cdot P_{HEATING,t} = E_{HEATING,t}P_{HEATING,t} - A_t$$

and the climate adjusted quantity is redefined accordingly.

The parameters are $\gamma_{FCE}^2 = .0038$
β_{FCE} normalized = .0475
FROS bar = 88.84.

It should be noted that this climate adjustment only posses a rough similarity with the climate adjustment described in Appendix I.4.2.

II Emission models

II.1 Introduction

This part of the report describes three emission models developed as satellite models to ADAM. The purpose of the models is to calculate emissions generated by alternative economic developments and to analyze effects on emissions of alternative environmental and economic policy instruments. The models described are pure satellite models, that is, given an economic projection with ADAM (incl. the sub-models described in part I) the models calculate emissions, however feed-backs from emissions to the economic development are not modelled. An example is, that an increase in the electricity consumption might imply increased purifying, changed electricity prices and thereby a changed electricity consumption. Such feed-back effects are not modelled and for most marginal environmental changes the effects are estimated to be minor, however for considerable changes the economic projections should be corrected for important feed-back effects.

The three models are based on the same data material and are as such consistent, however spill-over effects between the emission models are not modelled endogenous. An example is that certain technologies for sulphur purification emit CO_2, that is the emissions of CO_2 depend on the level of sulphur purification. This is not modelled endogenously, however in the CO_2 model the level of sulphur purification is considered an exogenous variable.

Therefore the three models considered are individual satellite models that use the same basic data, however consistency among the models is not secured automatically, and the user has to secure this by using the same assumptions in the individual models.

A further limitation of the models described is that they stop with emissions. The environmental consequences of the emissions and the economic effects of a changed environment is not described. Finally the models focus on emissions related to human/economic activities (anthropogenic emissions), while emissions from natural sources are not modelled. The distinction between anthropogenic and natural emissions is not always evident and often calculations of natural emissions are questionable. The models described are limited to emissions, that may be determined with relative reliability, and do not pretend to give a total estimate on all emissions of a given pollutant.

II.2 The method and the data

The starting point for modelling emissions is the identity:

emissions = activity level · emission coefficient

and for each pollutant total emissions are the sum of the different sources.

Except for exogenous variables the activity level is a variable in ADAM (incl. the satellite models described in part I). Emission coefficients are defined accordingly and attached to activities at this level of aggregation. The emission coefficients are technical determined and often calculated from more detailed or disaggregated data than an ADAM variable. For projections in general emission coefficients at the ADAM level of aggregation are assumed to be constant, however for model technical reasons they appear as exogenous variables. According to technical changes and changes in the environmental policy the coefficients may be changed exogenously. In a number of cases where it is known that the technology will change or that the relative size of activities within one ADAM variable will change, emission coefficients are projected accordingly.

Concerning energy consumption the data used are the direct energy consumption in TJ estimated by the energy balances of the Danish Statistical Office. These balances are part of the national accounting system and calculates the consumption of energy goods divided into 25 fuels and the 117 branches and private consumption of the national account. Concerning bio- and renewable fuels, which in the national accounting are not considered energy goods, the energy balances are supplemented with statistics from the Danish Energy Agency.

In general emission coefficients are based on the CORINAIR estimates, which are the official estimates reported to EU. In collaboration with the Danish Statistical Office and Research Centre Risø these coefficients are transformed to coefficients for the 25 fuels of the energy balances and the bio- and renewable fuels used. Concerning emissions from non-energy related economic activities the data sources are varying. In some cases data are available from the goods/industry statistics of the Danish Statistical Office, in other cases data are obtained directly from the producer. The non-energy related emissions modelled are those, that we are aware of at present; hopefully the largest and most important. A total listing of all sources of emissions does not exist and considerable sources may have been overlooked. As additional sources come to our attention these may be taken into account following the set-up used for the sources presently included.

II.3. CO_2 emissions

CO_2 is an important greenhouse gas and is in this section calculated as gross CO_2, that is, emissions of CO and other carbon containing gasses are converted to CO_2. For largely all flue gasses containing carbon, the carbon content is within a year converted to CO_2 and therefore contribute to the greenhouse gas emissions with the carbon content converted to CO_2.

II.3.0 CO_2 emission coefficients for fossil fuels

CO_2 emissions from combustion of fossil fuels depend of the characteristics of the fuel and is independent of the conditions under which, the fuel is combusted, that is, for a given fuel the emission coefficient is equal for all energy-uses and the coefficient is constant over time. Is the characteristics of a fuel changed, for instance changing the water content of coals, the fuel is considered as another fuel with another emission coefficient.

Assuming a complete combustion of the carbon content of fuels CO_2 emission coefficients measured in ton CO_2/TJ are calculated according to equation 3.0.1. From this it is seen that the emission coefficient depend of the ratio of the carbon content to the calorific value of the fuel.

$$eq.\ 3.0.1 \quad C_i = \frac{c_i \cdot M_{CO_2} \cdot 10}{B_i \cdot M_C} = \frac{c_i}{B_i} \cdot 36.6413\ tCO_2/TJ$$

where

C_i	is the CO_2 emission coefficient for fuel i
c_i	is the carbon percent of the fuel
M_{CO2}	is the mol weight for CO_2 = 44.0098 g/mol
M_C	is the mol weight for C = 12.0110 g/mol
and	
B_i	is the lower calorific value for fuel i in GJ/ton

As the ashes always contain some non-combusted carbon and the smoke contains carbon oxides and hydrocarbons, strictly speaking it is not correct to assume a complete combustion, however for all practical matters this is a reasonable assumption.

CO_2 emission coefficients for the individual fuels of the energy balances of the Danish Statistical Office are shown in table 3.0.1. A detailed description of the assumptions concerning the composition and characteristics of the individual fuels are given in (Andersen et. al. 1991)

Lb. nr.	Fuels	Carbon % c %	Calorific value B GJ/t	Emission coefficient tCO_2/TJ-gross
1	Coal gas	77	48.0	59.0
2	District heating	-	-	0.0[1]
3	Coal	68	26.2	95.0
4	Brown coal	48	18.2	97.0
5	Coal briquettes	48	18.2	97.0
6	Coke	85	28.8	108.0
7	Crude oil	-	-	-[2]
8	Jet kerosine	86	43.8	72.0
9	Jet gasoline	86	43.5	72.0
10	Gasoline (taxed)	87	43.5	73.0
11	Gasoline (tax free)	87	43.5	73.0
12	Naphtha	87	43.5	73.0
13	Kerosine (excl. jet kerosine)	86	43.8	72.0
14	Auto diesel	87	42.7	74.0
15	Gas oil	87	42.7	74.0
16	Marine diesel	87	42.7	74.0
17	Fuel oil	86	40.4	78.0
18	Manufacturing oil products	-	-	-[2]
19	LPG	82	46.2	65.0
20	Refinery gas	82	46.2	65.0
21	Natural gas from the NorthSea	-	-	56.9
22	Electricity	-	-	0.0[1]
23	Wood	-	-	0.0[3]
24	Petroleum coke	87	31.4	102.0
25	Natural gas to the consumers	75	48.5	56.9

Table 3.0.1 CO_2-emission coefficients for fuels in the energy balances of the Danish Statistical Office.

1) Converted fuels, emissions are related to the fuels used for generating the converted fuels.

2) Is not combusted.

3) Is a bio-fuel where the CO_2 is assumed to be recirculated. Is treated separately in section 3.3 "CO_2 emissions from bio-fuels.

II.3.1 CO_2 emissions from the converted fuels "electricity" and "district heating"

As the model operates on the direct energy consumption emission coefficients for using the converted fuels "electricity" and "district heating" are zero, and emissions from generating these fuels are assigned to the branches that produce the fuels. In addition emissions from imported electricity are zero, that is only emissions from Danish sources are included. For a number of analyses it is relevant to distribute the emissions from the conversion sector to the final consumers of the converted fuels and to consider emissions caused by the Danish energy consumption. To do so

1) emissions from the generation of electricity and district heating have to be distributed among the final users, and
2) a correction due to net import of electricity has to be introduced.

ad. 1) Emissions from the generation of converted fuels are distributed among the final users according to their use of the converted fuel, that is:

$$eq.\ 3.1.1 \qquad CO2^t_{g,j} = CO2^t_g \cdot \frac{E^t_{g,j}}{\sum_j E^t_{g,j}}$$

where	$CO2_{g,j}^t$	is emissions from the converting branch g ascribed to the final user j (branches, households and export)
	$CO2_g^t$	is emissions from the energy converting branches 'electricity- and district heating production'
and	$E_{g,j}^t$	is the consumption of electricity and district heating by the final users.

According to eq 3.1.1 emissions from Danish sources are distributed among final uses including export, that is aggregating over Danish uses (excluding export) gives emissions from Danish sources ascribed to the energy consumption in Denmark.

ad. 2) Including emissions from the net import of electricity eq. 3.1.1 is generalized to

$$eq.\ 3.1.2 \qquad CO2^t_{g,j} = (\ CO2^t_g + CO2imp^t_g\ ) \cdot \frac{E^t_{g,j}}{\sum_j E^t_{g,j}}$$

where $CO2imp_g^t$ is emissions ascribed to the net import of electricity.

The value of $CO2imp_g^t$ may be determined conditioned on different assumptions.

Assuming that the electricity imported to Denmark is produced on hydro- or nuclear power plants, which may be the case for quite a substantial part of the Danish electricity import, CO_2 emissions may be ascribed a of value zero.

Assuming that the alternative to import is a production on an average Danish power plant emissions may be calculated as:

$$eq.\ 3.1.3 \qquad CO2imp^t_g = \frac{CO2^t_g}{E^t_{DKprod\ g}} \cdot Eimp^t_g$$

where $E^t_{DKprod\ g}$ is the electricity production in Denmark, and
$Eimp^t_g$ is the net import of electricity

Inserting eq. 3.1.3 into eq. 3.1.2 gives:

$$eq.\ 3.1.4 \qquad CO2^t_{g,j} = CO2^t_g \cdot \left(1 + \frac{Eimp^t_g}{E^t_{DKprod\,g}} \right) \cdot \frac{E^t_{g,j}}{\sum_j E^t_{g,j}}$$

Aggregating over uses in Denmark, eq. 3.1.4 gives the emissions ascribed to the Danish electricity consumption, assuming it is all produced on an average Danish power plant.

II.3.2 Aggregated emission coefficients for ADAM branches and the household consumption

In the interfuel substitution model described in chapter I.3 the fuels in table 3.0.1 are aggregated to the 6 fuels shown in table 3.2.0.

Aggregated fuels	Fuels in the energy balances
Solid fuel	3,4,5,6,23,24
District heating	2
Other liquid fuels	1,12,13,15,17,18,19,20
Transport fuels	8,9,10,11,14,16
Natural gas	25
Electricity	22

Table 3.2.0. Aggregation of the fuels in the energy balances of the Danish Statistical Office.

Emission coefficients for the aggregated fuels are calculated as a weighted average of emission coefficients for the disaggregated fuels using the actual consumption of the disaggregated fuels as weights, that is:

$$eq.\ 3.2.1. \qquad C^t_{g,j} = \frac{\sum_{i \in g} E^t_{i,j} \cdot C_i}{\sum_{i \in g} E^t_{i,j}}$$

where	g	refers to the aggregated fuels of table 3.2.0
	i	refers to the disaggregated fuels of the energy balances
	j	refers to the users (branches and household consumption)
	C_i	is the CO_2 emission coefficients in table 3.0.1
and	$E^t_{i,j}$	is the direct energy consumption

For 1991 CO_2-emission coefficients for the aggregated fuels and branches of ADAM are shown in table 3.2.1. Looking at this table it is noticed that the coefficients for electricity and district heating are zero (emissions are assigned to the fuels used for the generation of these fuels), that the coefficients for natural gas are identical for all uses (natural gas is only one fuel in the disaggregated energy balances) and that the coefficients for solid-, transport- and other liquid fuels vary over branches (and time) according to the composition of the disaggregated fuels. Looking at the variation over uses, for solid fuel emission coefficients vary significantly. This is mainly due to a varying share of wood used (wood is ascribes an emission coefficient of zero). For a number of branches it should be noticed, that the use of solid fuel is minor, that is the variation is of minor importance in practical use. The major part of the solid fuel is used in branches using coal with an emission coefficient of 95 tCO_2/TJ. For other liquid fuels the coefficients vary mainly dependent on the weight of fuel oil and LPG. The coefficients for transport fuels are almost identical for all the uses.

Uses	Solid fuels	District heating	Other fluid fuels	Transport fuels	Natural gas	Electricity
Household consumption pc	28.54	0.0	73.37	73.02	56.90	0.0
Agriculture a	95.38	0.0	74.31	73.93	56.90	0.0
Oil and gas extraction e	-	0.0	76.92	73.02	56.90	0.0
Oil refineries ng	-	0.0	74.61	73.11	56.90	0.0
Energy conversion ne	95.00	0.0	77.94	73.57	56.90	0.0
of this: electricity prod b91	95.00	0.0	78.00	73.56	56.90	0.0
district heating b93	95.00	0.0	78.00	73.67	56.90	0.0
Food processing. nf	95.30	0.0	76.48	73.76	56.90	0.0
Man. of beverages etc. nn	95.00	0.0	76.99	73.85	56.90	0.0
Construct. sub suppliers nb	80.60	0.0	75.15	73.57	56.90	0.0
Iron and metal industry nm	78.13	0.0	73.70	73.42	56.90	0.0
Man. of transp. equipm. nt	84.42	0.0	74.39	73.40	56.90	0.0
Man. of chemicals nk	82.65	0.0	76.33	73.55	56.90	0.0
Other manufacturing nq	61.74	0.0	75.67	73.50	56.90	0.0
						0.0
Construction b	-	0.0	74.19	73.76	56.90	0.0
Trade qh	-	0.0	73.94	73.65	56.90	0.0
Sea transport qs	-	0.0	76.95	73.98	56.90	0.0
Other transport qt	-	0.0	76.04	73.31	56.90	0.0
of this: rail t11*	-	0.0	70.39	74.00	56.90	0.0
buses t12*	-	0.0	73.87	73.99	56.90	0.0
ferries t13*	-	0.0	77.87	74.00	56.90	0.0
tourist busses t21*	-	0.0	66.03	73.95	56.90	0.0
taxi t22*	-	0.0	65.34	73.76	56.90	0.0
road freight t23*	-	0.0	69.66	73.92	56.90	0.0
air transport t3	-	0.0	71.91	72.16	56.90	0.0
mail etc. t4	-	0.0	73.64	73.68	56.90	0.0
serv. rel. transp. t5	-	0.0	73.25	73.53	56.90	0.0
					56.90	0.0
Financial services qf	-	0.0	74.25	73.13	56.90	0.0
Other private services qq	-	0.0	73.96	73.63	56.90	0.0
Housing h	-	0.0	74.26	-	56.90	0.0
Public services o	-	0.0	74.08	72.70	56.90	0.0

Table 3.2.1. CO_2 emissions coefficients for the aggregated fuels in 1991, (tCO_2/TJ).

* Figures for 1990, disaggregated energy data for 1991 are not available at present.

Uses		Direct energy consumption TJ	CO_2 emissions 1000 tCO_2	Emission coefficients tCO_2/TJ
Household consumption	pc	225727	8932	39.57
Agriculture	a	42089	2597	61.70
Oil and gas extraction	e	2318	178	76.92
Oil refineries	ng	5878	370	62.95
Energy conversion	ne	356163	32701	91.81
of this: electricity prod.	b91	297288	27996	94.17
district heating	b93	58720	4697	79.98
Food processing.	nf	35041	2048	58.44
Man. of beverages etc.	nn	6469	413	63.92
Construct. sub suppliers	nb	32050	2228	69.53
Iron and metal industry	nm	17279	615	35.57
Man. of transp. equipm.	nt	2033	67	32.93
Man. of chemicals	nk	14853	605	40.76
Other manufacturing	nq	16573	767	46.26
Construction	b	13701	924	67.47
Trade	qh	30012	1351	45.00
Sea transport	qs	9222	696	75.42
Other transport	qt	80166	5533	69.02
of this: rail	t11			
buses	t12[1)]	16965	1189	70.10
ferries	t13			
tourist busses	t21			
taxi	t22[2)]	31045	2278	73.39
road freight	t23			
air transport	t3	25316	1800[4)]	71.09
mail etc.	t4	4193	153	36.51
serv. rel. transp.	t5	2648	113	42.72
Financial services	qf	6155	96	15.79
Other private services	qq	27640	649	23.49
Housing	h	1302	20	15.12
Public services	o	36038	1041	28.88
Total[3]		-	61833	-

Table 3.2.2. The direct energy consumption, CO_2 emissions and emission coefficients for 1991

1) Disaggregated data for 1991 are not available, aggregation of t11 - t13.

2) Disaggregated data for 1991 are not available, aggregation of t21 - t23.

3) Aggregating the energy consumption would include a double counting of the converted fuels.

4) According to international conventions only part of these emissions is the responsibility of Denmark.

For 1991 the direct energy consumption, total CO_2 emissions and the average emission coefficient for the individual uses are given in table 3.2.2.

Looking at the emissions given in table 3.2.2 about 50 percent comes from the energy converting branches. In 1991 about 6 percent of the electricity production was exported net, which corresponds to emissions of 1675 $ktCO_2$. Emissions generated by the Danish energy consumption were therefore 60158 $ktCO_2$. Looking at the emission coefficients they vary significantly between the uses, however the differences are mainly due to a varying share of electricity in the direct energy consumption. Distributing the emissions from the energy converting branches to the final uses gives almost identical aggregated emission coefficients for all the uses.

II.3.3 CO_2 emissions from bio-fuels

Assuming that CO_2 emissions from burning bio-fuels equal the amount of CO_2 absorbed from the air during the production of the bio-fuel, in calculations of net CO_2 emissions emission coefficients for bio-fuels are zero. In calculations of gross CO_2 emissions, emissions from and absorptions in bio-fuels are calculated separately. The purpose of this is to be able to evaluate effects of accumulating or reducing the stock of bio-mass, for instance increasing or decreasing the area of forests. Therefore in this section emissions from the use of bio-fuels shall be calculated, however the accumulation of CO_2 in bio-mass is outside this project.

For 1992 the use of bio-fuels, emission coefficients and total emissions are given in table 3.3.1, and the distribution among uses is shown in table 3.3.2.

Bio-fuels	Energy consumption[1] PJ	CO_2 emission coefficients[2] tCO_2/TJ	CO_2 emissions 1000 tCO_2
Fish oil	0.15	74	11.1
Waste	17.32	117	2026.4
Wood	10.19	102	1039.4
Wood waste	7.45	102	759.9
Straw	13.84	102	1411.7
Bio gas	1.54	57	87.8
Total	50.49	106	5336.3

Table 3.3.1. The consumption of bio-fuels, CO_2 emission coefficients and total CO_2 emissions for 1992.

1) Source: Energy statistics 1992 from the Danish Energy Agency. Consumption of renewable energy.

2) Source: Inventory of emissions to the air from Danish sources. J.Fenhann and N.A.Kilde, Research Centre Risø, January 1994.

Bio-fuels	Power plants PJ	District heating PJ	Heating PJ	Industry PJ	Agriculture PJ	Other uses PJ	Total PJ
Fish oil		0.15					0.15
Waste		17.32					17.32
Wood		1.78	8.40				10.19
Wood waste		2.37		3.30	0.03	1.75	7.45
Straw	1.45	3.92	6.36		2.12		13.84
Bio gas			0.02	0.78		0.74	1.54
Total PJ	1.45	25.54	14.78	4.08	2.15	2.49	50.49
CO_2-emiss. 1000 tCO_2	148	2861	1507	381	219	221	5336

Table 3.3.2. Consumption of bio-fuels distributed at uses in 1992.

Source: Energy statistics 1992 from the Danish Energy Agency.

From table 3.3.1 it is seen, that about 5000 $ktco_2$ is emitted from the use of bio-fuels. This is about 8 percent of the total energy related CO_2 emissions. The largest emissions come from the burning of waste, which is used in the production of district heating. Emissions from wood, wood waste and straw are considerable too. Looking at uses, emissions come mainly from the production of district heating and heating. Adding emissions from energy goods (table 3.2.2) and emissions from bio-fuels (table 3.3.1) gives the total energy related gross CO_2 emissions.

Finally it should be mentioned, that the use of bio-fuels creates problems in the forecasting of emissions. The energy model presented in part I forecasts the uses of energy goods only, and the introduction of bio-fuels is implicitly measured as fuel savings, that is using the model for forecasts implicitly assumes, that past trends in the introduction of bio-fuels are continued in the future. If this is not the case, the energy forecasts have to be corrected for the changes. Proposals for corrections are given in section II.3.5.2.

II.3.4 Process related CO_2 emissions

Beside emissions related to the use of energy, CO_2 is emitted from a few raw materials used in the production of different goods. Seen in relation to the energy related CO_2 emissions, in general process related emissions are relatively small, and a complete listing of the different sources is not available. The sources accounted for in this section hopefully are the most important, however considerable sources may have been overlooked. Therefore this section should be seen as a first attempt at accounting for process related CO_2 emissions, and may be expanded as information on additional sources becomes available.

The distinction between process related and natural emissions is not always very clear. When emissions from bio-fuels are accounted for, emissions from soil might be accounted for as well. The carbon content of soil changes due to cultivation and the lime contained in the soil emits CO_2 due to acid rain. In this section process related emissions are limited to emissions from raw materials used in the production process, while for instance soil improvements are not included.

II.3.4.1 Cement production

In the production of cement limestone is burned by which, CO_2 is emitted with the flue gases, and the burnt lime is part of the cement. The chemical reaction is:

	$CaCO_3$ -->	$CaO + CO_2$
mol weight	100	56 44

that is, per ton limestone used 440 kg CO_2 is emitted with the flue gasses. According to the cement producer "Ålborg Portland" 1.4 ton of limestone is used for the production of one ton cement, that is cement contains about 78 percent burnt lime and emits about 0.44*1.4 tCO_2 = 0.616 tCO_2/t cement. According to IPCC cement contains between 60 percent and 67 percent burnt lime and the average emission coefficient is 0.499 tCO_2/t cement, that is, the Danish figures are somewhat higher. Using the different emission coefficients the cement production and CO_2 emissions are shown in table 3.4.1. As may be seen from the table, the order of magnitude of the CO_2 emissions are 1000 to 1300 $ktCO_2$ per year corresponding to about 2 percent of the energy related emissions.

Year	Cement production[1] ton	CO_2 emissions 1000 tCO_2 coeff.=0.616 TCO_2/t cement	CO_2 emissions 1000 tCO_2 coeff.=0.499 tCO_2/t cement
1988	1681201	1035.62	754.86
1989	1999450	1231.66	897.75
1990	1655909	1020.04	826.30
1991	2019279	1243.88	1007.62
1992	2072081	1276.40	1033.97

Table 3.4.1 Cement production and CO_2 emissions from limestone

1) Source: DS. Industrial goods statistic series B. Production of cement.

II.3.4.2 Production of burnt lime.

As for the production of cement in the production of burnt lime limestone is burned and thereby emits CO_2. The chemical reaction is as for cement:

	$CaCO_3$ -->	CaO +	CO_2
mol weight	100	56	44

that is, for each ton burnt lime (CaO) produced 440 $kgCO_2$ is emitted, and the emission coefficient is 44/56 tCO_2/t burnt lime = 0.786 tCO_2/t lime burnt. The production of burnt lime and the related CO_2 emissions are shown in table 3.4.2.

Year	Production of burnt lime ton	CO_2 emissions 1000 ton
1988	134324	105.58
1989	122899	96.60
1990	150414	118.23
1991	110114	86.55
1992	126271	99.25

Table 3.4.2 Production of burnt lime and CO_2 emissions

Source: DS Industrial goods statistic series B. Production of burnt lime excl. wet.

Burnt lime is primarily used in the production of mortar which is part of the production in the branch "construction sub suppliers", and is assumed to develop parallel to the production in this branch. In addition considerable amounts of burnt lime is used for desulphurization by the power plants. In 1992 power plants used 60400 t burnt lime, however this was imported (primarily from Sweden and Belgium) and is not included in the Danish emissions.

II.3.4.3 Production of yellow bricks.

The clay used for the production of yellow bricks contains lime stone which emits CO_2 when burnt. According to the producer's organisation the clay used contain between 16 percent and 18 percent lime stone, that is, one brick that weights about 2 kg contains about 0.36 kg lime stone and emits about 0.158 kg CO_2. That is the emission coefficient is 0.158 kgCO_2 per yellow brick. The production of ceramic bricks is given in the "industrial goods statistic, series B", however how many of the bricks that are yellow is not calculated. The share of red and yellow bricks is determined by fashion and varies considerably over time. For the latest years the producers organisation estimates that about 60 percent of the bricks are yellow. According to these assumptions the CO_2 emissions from the production of yellow bricks are given in table 3.4.3.

Year	Production of ceramic bricks 1000 bricks	Production of yellow bricks (60%) 1000 bricks	CO_2 emissions 1000 ton
1988	345387	207232	32.74
1989	339188	203513	32.16
1990	291348	174809	27.62
1991	291497	174898	27.63
1992	302008	181205	28.63

Table 3.4.3 Production of yellow bricks and related CO_2 emissions
Source: DS. Industrial goods statistic series B. Production of ceramic bricks.

II.3.4.4 Desulphurization by power plants

In order to reduce sulphur emissions from power plants three different techniques are used: a wet process that produces gypsum, a dry process that produces a lime containing waste product called TASP and a catalytic process that produces sulphuric acid. In 1992 the power plants produced 94000 tons gypsum, 141000 ton TASP and 21000 tons sulphuric acid.

In the production of gypsum lime stone is burnt, and CO_2 is emitted. Per ton gypsum produced 44/136 tCO_2 is emitted and 64/136 tons SO_2 is removed, that is per ton SO_2 removed 44/64 ton CO_2 is emitted.[26] In 1992 the production of 94000 ton gyp-

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[26] Gypsum $CaSO_4$ mol weight 136 = 40 + 32 + 4*16;
CO_2 mol weight 44 = 12 + 2*16;
SO_2 mol weight 64 = 32 + 2*16

sum implied emissions of 30412 tCO_2 and the removal of 44235 tSO_2.

The dry process uses 1.16 kg burnt lime/$kgSO_2$ removed, and produces 2.8 kg TASP/kg SO_2 removed. The 1.16 kg burnt lime causes emissions of 44/56*1.16 $kgCO_2/kgSO_2$ removed. In 1992 the production of 141000 ton TASP therefore caused emissions of 45896 tCO_2 (141000/2.8 * 1.16 * 44/56) and the removal of 50357 ton SO_2 (141000/2.8). However as the power plants import the burnt lime the CO_2 emissions are not related to the Danish production. When included in table 3.4.4 the table shows the CO_2 emissions caused by the desulphurization by the power plants, independent of where the emissions are discharged.

The production of sulphuric acid does not cause CO_2 emissions, but the production of 21000 ton removed 13714 ton SO_2 (64/98 * 21000).

Technique	Production[1] 1000 t	CO_2 emissions 1000 tCO_2	SO_2 removed 1000 tSO_2	Emission coefficient tCO_2/tSO_2
Wet process (gypsum)	94	30	44	0.688
Dry process (TASP)	141	46	50	0.911
Sulphuric acid production	21	0	14	0.000
Total		76	108	0.705

Table 3.4.4 Desulphurization by power plants in 1992

1) Source : Danish Power Supply.

II.3.5 A forecast model for CO_2 emissions

II.3.5.1 CO_2 emissions from energy goods

ADAM and the fuel substitution model described in part I forecasts the energy consumption of the households, the individual ADAM branches and the fuels given in table 3.2.0. Based on these forecasts and the emission coefficients given in table 3.2.1, CO_2 emissions from the energy consumption are calculated according to eq. 3.5.1.

eq. 3.5.1. $$CO2_j^t = \sum_g E_{g,j}^t \cdot C_{g,j}$$

where

$CO2_j^t$ is the CO_2 emissions from branch j
$E_{g,j}^t$ is the direct energy consumption of branch j and fuel g
and $C_{g,j}$ is the emission coefficient for branch j and fuel g

It is noticed, that at this level the emission coefficients are assumed to be constant over time. The coefficients will vary due to changes in the fuel-mix in the aggregated fuels, however as the model only forecasts the energy consumption of the aggregated fuels, changes in the fuel-mix beneath this level require exogenous assumptions, that is the emission coefficients may be changed exogenously.

II.3.5.2 CO_2 emissions from bio-fuels

In the energy model the consumption of bio-fuels is considered as exogenous variables and is only introduced at the aggregated level shown in table 3.3.2, that is the consumption is not disaggregated between the individual ADAM branches. Parallel to eq 3.5.1 CO_2 emissions from bio-fuels are calculated as:

eq. 3.5.2. $$CO2_a^t = \sum_k E_{k,a}^t \cdot C_k$$

where

$CO2_a^t$ is emissions from use a in table 3.3.2.
$E_{k,a}^t$ is the direct energy consumption of fuel k in use a
and C_k is the emission coefficient of fuel k

As bio-fuels are exogenous, and changes in the use of bio-fuels influence the consumption of energy goods, the energy forecasts or CO_2 emissions from the energy goods have to be corrected for considerable changes in the use of bio-fuels. (As it is the consumption of energy goods that changes the corrections are independent of whether the CO_2 emissions are calculated gross or net). Taking 1992 as the base point and assuming, that a change in the use of bio-fuels corresponds to an equal but opposite change in the consumption of energy goods, the following corrections are introduced:

eq. 3.5.3. $$CO2_{a\,corr}^t = \left(\sum_k E_{k,a}^{92} - \sum_k E_{k,a}^t \right) \cdot C_{g,j}^t$$

where

$E_{k,a}^{92}$ is the consumption of bio-fuel k by use a in 1992
$E_{k,a}^t$ is the exogenous assumed consumption of bio-fuels in year t
and $C_{g,j}^t$ is the emission coefficient for the energy good that is substituted

Ideally $E^{92}_{k,a}$ should have been a baseline forecast for the consumption of bio-fuels assuming a continuation of past trends, however in lack of this the base year consumption is used. The 1992 consumption of bio-fuels and the emission coefficients for the energy goods, that the bio-fuels are assumed to substitute, are given in table 3.5.1. For the power plants and district heating the bio-fuels are assumed to substitute solid fuels. For the other uses bio-fuels are assumed to substitute liquid fuels.

Uses	Consumption of bio-fuel in 1992 $\Sigma E^{92}_{k,a}$ PJ	CO_2 coefficient for the substituted fuel $C_{g,i}$	CO_2 coefficient for the substituted fuel tCO_2/TJ
Power plants	1.45	$C1^{t}_{b91,solid}$	95.0
District heating	25.54	$C^{t}_{b93,solid}$	95.0
Heating	14.78	$C^{t}_{pc,fluid}$	73.4
Industry	4.08	$C^{t}_{nb,fluid}$	75.2
Agriculture	2.15	$C^{t}_{a,fluid}$	74.3
Other uses	2.49	$C^{t}_{total,fluid}$	74.9

Table 3.5.1. The consumption of bio-fuels in 1992 and CO_2-emission coefficients for the energy goods that are substituted.

II.3.5.3 Process related CO_2 emissions

As mentioned in section 3.4 the production of cement, burnt lime and yellow bricks use raw materials that cause emissions of CO_2. The production of these products are part of the production in the ADAM branch "construction sub suppliers", and therefore the CO_2 emissions from these raw materials are forecasted proportional to the production of this branch, that is although the production of cement, burnt lime and yellow bricks is only about 10 percent of the total production of the 'construction sub suppliers' for forecasts the shares are assumed to be constant, i.e. the emission coefficient is constant. From table 3.5.2 it is seen that this is a rather heroic assumption.

Year	Production in construct. sub suppliers Mill 1980-kr.[1]	CO_2 emissions from cement 1000 t.	CO_2 emissions from bricks 1000 t.	CO_2 emissions from burnt lime 1000 t.	CO_2 emissions total 1000 t.	CO_2 coeff. tCO_2/mill 1980-kr
1988	14109	755	33	106	894	63.36
1989	13868	898	33	97	1028	74.13
1990	13505	826	28	118	972	71.97
1991	14186	1008	28	87	1123	79.16
1992	14155	1034	29	99	1162	82.09

Table 3.5.2. Production in construction sub suppliers and process related CO_2 emissions.
After 1990 estimated figures.

CO_2 emissions from desulphurization by power plants are forecasted as ton SO_2 removed times the emission coefficient for the technology used (see table 3.4.4). For the dry process emissions are corrected for the share of burnt lime, that is imported, that is, assuming that the power plants continue to import all the burnt lime used by this process the emissions are zero. The ton of SO_2 removed by the different technologies are assumed exogenous.

The equation for the process related emissions is:

$$CO2^t_{process} = FX^t_{nb} \cdot C_{process} + \sum_p SO2^t_p \cdot C_{SO2,p} \cdot (1 - IMP^t_{SO2,p}) \qquad eq.\ 3.5.4.$$

where

FX^t_{nb}	is the production in the construction sub suppliers in 1980-prices
$C_{process}$	is the emission coefficient given in table 3.5.2
$SO2^t_p$	is ton SO_2 removed using technology p
$C_{SO2,p}$	is the emission coefficient for SO_2 removal by technology p given in table 3.4.4

and

$IMP^t_{SO2,p}$	is the import share for burnt lime used in the dry process and zero for the other technologies

II.3.4.5 The total CO_2 emissions

Adding emissions from the different sources total CO_2 emissions are given by:

$$CO2^t_{total} = \sum_j CO2^t_j + \sum_a CO2^t_a + \sum_a CO2^t_{a\ corr} + CO2^t_{process} \qquad eq.\ 3.5.5$$

where	$CO2^t_{total}$	is the total CO_2 emissions
	$CO2^t_j$	is CO_2 emissions from energy goods
	$CO2^t_a$	is CO_2 emissions from bio-fuels
	$CO2_{a,cor}$	is corrections to the use of bio-fuels
and	$CO2^t_{process}$	is process related emissions

Are CO_2 emissions calculated net, emissions from bio-fuels are defined to be zero, that is $CO2^t_a$ is zero, however the corrections $CO2^t_{a,cor}$ are always included.

II.4 SO_2 emissions

Sulphur dioxide (SO_2) is a major contributor to the acidification of forests and lakes and is transported in the air over several thousand kilometres.

II.4.0 SO_2 emission coefficients for fossil fuels

SO_2 emissions are calculated from the sulphur content of the individual fuels. For liquid and gaseous fuels the complete sulphur content is assumed to be converted to SO_2 and emitted with the flue gasses. For solid fuels part of the sulphur is contained in the ashes. Also for liquid and gaseous fuels part of the sulphur is contained in the ashes, however the share is minimal, and for all practical purposes it is reasonable to assume, that all the sulphur is emitted as SO_2 with the flue gasses. SO_2 emission coefficients for the individual fuels are calculated according to

$$\textit{eq. } 4.0.1 \quad S^t_{i,j} = \frac{s^t_{i,j} \cdot M_{SO_2} \cdot 10^4 \cdot f_i}{M_S \cdot B_i} = \frac{s^t_{i,j}}{B_i} \cdot f_i \cdot \frac{64}{32} \cdot 10^4$$

where	$S^t_{i,j}$	is the emission coefficient for fuel i branch j measured in $kgSO_2/TJ$
	$s^t_{i,j}$	is the sulphur content in fuel i branch j measured in percent of weight
	f_i	is the share of the sulphur content emitted with the flue gasses
	B_i	is the calorific value of fuel i
and	M_{SO_2} and M_S	are the mol weight of SO_2 and S respectively

As the sulphur content of the individual fuels vary over time and the allowed sulphur content of a fuel depend on the use, emission coefficients vary over both time and uses. A survey of the sulphur content and emission coefficients of the fuels in the energy balances of the Danish Statistical Office is given in table 4.0.1. (Fuels not included in the table are either converted fuels with a direct emission coefficient of zero, fuels used by the energy converting sectors only or energy goods used for other purposes than energy use. The figures listed in the column "uses" refer to the use categories of the energy balances.) As is seen from the table, it is mainly solid fuel and heavy oil products, that have a high sulphur content and high emission coefficients, and reductions carried through since the middle of the 1980s have concentrated on reducing the sulphur content of these fuels.

	Fuel	Calorific value GJ/t B	f	Uses	Sulphur % s[1]						Emission coefficient kgSO$_2$/TJ					
					66-77	78-85	86-88	89-91	92	93	66-77	78-85	86-88	89-91	92	93
1	Coal gas	48.0	1.00	1-122	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0	0
3	Coal	26.1	0.85	91[2] other	- 1.00	- 1.00	- 1.00	- 0.90	- 0.90	- 0.90	- 649	- 649	- 649	- 584	- 584	- 584
4-5	Brown Coal/briquettes	18.2	0.85	1-122	0.35	0.35	0.35	0.35	0.35	0.35	327	327	327	327	327	327
6	Coke	28.8	0.85	1-122	0.90	0.90	0.90	0.90	0.90	0.90	531	531	531	531	531	531
8	Jet kerosine	43.8	1.00	1-122	0.01	0.01	0.01	0.01	0.01	0.01	5	5	5	5	5	5
9	Jet gasoline	43.5	1.00	1-122	0.05	0.05	0.05	0.05	0.05	0.05	23	23	23	23	23	23
10-11	Gasoline	43.5	1.00	1-122	0.05	0.05	0.05	0.05	0.05	0.05	23	23	23	23	23	23
12	Naphtha	43.5	1.00	1-122	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0	0
13	Kerosine (excl. 8)	43.8	1.00	1-122	0.01	0.01	0.01	0.01	0.01	0.01	5	5	5	5	5	5
14	Auto diesel	42.7	1.00	6 other	1.00 0.50	1.00 0.50	1.00 0.30	1.00 0.20	1.00 0.20	1.00 0.05	468 234	468 234	468 141	468 94	468 94	468 23
15	Gas oil	42.7	1.00	1-122	0.50	0.50	0.30	0.20	0.20	0.20	234	234	141	94	94	94
16	Marine diesel	42.7	1.00	99 other	1.00 1.00	1.00 1.00	1.00 1.00	1.00 1.00	0.10 1.00	0.10 1.00	468 468	468 468	468 468	468 468	47 468	47 468
17	Fuel oil	40.4	1.00	6 57 91 93 101 other	3.00 2.50 2.50 2.35 3.50 2.35	3.00 2.50 2.30 2.35 3.50 2.35	3.00 1.50 2.30 1.45 3.50 1.45	3.00 1.00 0.92 1.00 3.50 1.00	1.50 1.00 0.92 0.50 3.00 0.64	1.50 1.00 0.92 0.50 3.00 0.50	1485 1238 1238 1163 1733 1163	1485 1238 1139 1163 1733 1163	1485 743 1139 718 1733 718	1485 495 455 495 1733 495	743 495 455 248 1485 316	743 495 455 248 1485 248
19-20	LPG-refinery gas	46.2	1.00	1-122	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0	0
23	Wood	14.5	0.94	1-122	0.10	0.10	0.10	0.10	0.10	0.10	130	130	130	130	130	130
24	Petroleum coke	31.4	0.89	1-122	1.20	1.20	1.20	1.20	1.20	1.20	680	680	680	680	680	680
21,25	Natural gas	48.5	1.00	1-122	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0	0
26	Straw	14.5	0.94	1-122	0.10	0.10	0.10	0.10	0.10	0.10	130	130	130	130	130	130
27	Waste	8.9	1.00	93	0.30	0.30	0.30	0.30	0.30	0.30	675	675	675	675	675	675

Table 4.0.1 SO$_2$ emissions coefficients for fossil fuels.

1) Source. Research Centre Risø, CORINAIR-database.

2) Sulphur content is not known, but SO$_2$ emissions are calculated residually from measurements of total SO$_2$ emissions from power plants.

II.4.1 SO_2 emissions from the converted fuels "electricity" and "district heating".

The sulphur content in coal used by the power plants is not known, however total emissions from power plants are measured. From information on the sulphur content of other fuels used by the power plants, emissions from coal are calculated residually. This implicitly assumes, that desulphurization are concentrated on coal fired plants. For recent years, where power plants have been mainly coal fired and desulphurization is introduced mainly on coal fired plants, this is a reasonable assumption, however in the future changes in the fuel mix may invalidate this assumption. This would imply a wrong distribution of emissions between fuels, however the total for power plants would be correct. Total SO_2 emissions from power plants, emissions ascribed to the use of coal and the calculated emission coefficients for coal are shown in table 4.1.1. As power plants produce both electricity and district heating the coefficient is used for both the electricity production and the share of coal ascribed to the production of district heating by power plants. The energy balances contain a distribution of the fuels used by the power plants on the production of electricity and district heating and the emissions are distributed according to this.

Distributing emissions from the converting sectors to the final consumers and considering emissions caused by the Danish energy consumption the methodology described in section II.3.1 may be used, that is, replacing CO_2 emissions by SO_2 emissions the equations 3.1.1 to 3.1.4 may be used. (In equation 3.1.1 total emissions from the converting branches may include emissions from bio-fuels, for instance from waste used for the production of district heating (see section II.4.3), however then these emissions should not also be included in the calculation of emissions from bio-fuels).

Year	Energy consump. of power plants PJ	SO_2 emissions[1] 1000 TSO_2	SO_2 quota 1000 TSO_2	Coal consump. PJ	SO_2 emissions from coal 1000 tSO_2	SO_2 emission coeff. for coal $kgSO_2/TJ$
1975	182.65	191.92		64.63	58.36	902.88
1976	202.70	200.63		95.73	80.76	843.64
1977	220.58	214.96		111.32	91.23	819.50
1978	210.70	187.68		123.49	97.23	787.38
1979	231.66	198.70		153.20	123.84	808.37
1980	274.27	215.91	212.00	229.78	157.30	684.57
1981	203.14	155.42	215.00	181.26	127.12	701.31
1982	240.28	179.02	215.00	221.39	158.53	716.06
1983	225.65	137.00	215.00	212.18	127.64	601.58
1984	228.08	120.00	200.00	219.35	112.26	511.78
1985	288.22	167.00	200.00	270.18	151.44	560.53
1986	297.11	167.00	195.00	276.05	151.94	550.41
1987	287.26	150.00	200.00	272.12	138.37	508.50
1988	274.09	157.00	205.00	255.57	145.28	568.46
1989	225.75	127.00	205.00	218.43	122.06	558.80
1990	246.71	119.00	195.00	227.93	115.32	505.94
1991	339.34	178.00	175.00	313.12	169.85	542.45
1992	286.01	130.00	163.00			
1993			129.00			
1994			123.00			
1995			116.00			
1996			108.00			
1997			90.00			
1998			82.00			
1999			77.00			
2000			73.00			

Table 4.1.1 Energy consumption and SO_2 emissions from power plants

1) Source: Inventory of emissions to the air from Danish sources. J.Fenhann and N.A.Kilde, Research Centre Risø, January 1994 and statistics from Danish power plants.

II.4.2 Aggregated emission coefficients for ADAM branches and the household consumption

Analogous to the CO_2 emission coefficients given in section II.3.2, SO_2 emission coefficients for the aggregated fuels are calculated as a weighted average of the underlying fuels, that is:

$$\text{eq. 4.2.1.} \quad S^t_{g,j} = \frac{\sum_{i\in g} E^t_{i,j} \cdot S^t_{i,j}}{\sum_{i\in g} E^t_{i,j}}$$

Where

g refers to the aggregated fuels given in table 3.2.0
i refers to the fuels of the energy balances given in table 4.0.1
j refers to the ADAM branches
$S^t_{i,j}$ are the emission coefficients calculated from eq 4.0.1
and
$E^t_{i,j}$ are the direct energy consumptions

As is seen from equation 4.2.1 and table 4.2.1 emission coefficients vary between branches and over time. Differences between branches mirror differences in the composition of fuels used, and variation over time are caused by changes in the fuel composition and in the sulphur content of the different fuels. (As wood is a bio-fuel and is accounted for separately in section II.4.3, emissions from wood are not included in table 4.2.1.)

Uses		Solid	District heating	Other fluid fuels	Transport fuels	Natural gas	Electricity
Household consumption	pc	163.1	0.0	86.7	24.1	0.3	0.0
Agriculture	a	599.9	0.0	267.7	252.8	0.3	0.0
Oil and gas extraction	e	-	0.0	386.2	24.1	0.3	0.0
Oil refineries	ng	-	0.0	159.5	30.5	0.3	0.0
Energy conversion	ne	543.4	0.0	435.9	63.0	0.3	0.0
of this: electricity prod.	b91	542.5	0.0	455.0	62.4	0.3	0.0
district heating	b93	550.9	0.0	398.3	70.1	0.3	0.0
Food processing.	nf	582.3	0.0	364.4	76.8	0.3	0.0
Man. of beverages etc.	nn	585.7	0.0	438.6	83.3	0.3	0.0
Construct. sub suppliers	nb	500.6	0.0	277.0	63.6	0.3	0.0
Iron and metal industry	nm	393.7	0.0	186.0	52.6	0.3	0.0
Man. of transp. equipm.	nt	518.1	0.0	185.6	51.1	0.3	0.0
Man. of chemicals	nk	509.5	0.0	348.7	61.5	0.3	0.0
Other manufacturing	nq	380.5	0.0	343.1	58.6	0.3	0.0
Construction	b	-	0.0	292.0	77.0	0.3	0.0
Trade	qh	-	0.0	115.2	69.0	0.3	0.0
Sea transport	qs	-	0.0	1301.6	437.9	0.3	0.0
Other transport	qt	-	0.0	357.7	72.4	0.3	0.0
of this: rail	t11*	-	0.0	74.6	93.6	0.3	0.0
buses	t12*	-	0.0	122.8	93.1	0.3	0.0
ferries	t13*	-	0.0	489.1	467.9	0.3	0.0
tourist busses	t21*	-	0.0	14.3	89.8	0.3	0.0
taxi	t22*	-	0.0	4.7	76.9	0.3	0.0
road freight	t23*	-	0.0	64.5	87.6	0.3	0.0
air transport	t3	-	0.0	89.0	7.6	0.3	0.0
mail etc.	t4	-	0.0	111.3	70.7	0.3	0.0
serv. rel. transp.	t5	-	0.0	106.3	60.3	0.3	0.0
Financial services	qf	-	0.0	119.2	32.4	0.3	0.0
Other private services	qq	-	0.0	116.3	67.4	0.3	0.0
Housing	h	-	0.0	119.3	-	0.3	0.0
Public services	o	-	0.0	117.6	85.2	0.3	0.0

Table 4.2.1. SO_2 emission coefficients for the aggregated fuels in 1991, ($kgso_2/TJ$)

* Figures for 1990, disaggregated energy data for 1991 are not available at present.

From table 4.2.1 it is noticed, that the coefficients for electricity and district heating are zero. Emissions from the consumption of the converted fuels are ascribed to the production of these. Natural gas has a very low sulphur content and correspondingly a low emission coefficient. For the other fuels, in general solid fuels have the highest emission coefficients, other liquid fuels have fairly large emission coefficients, while transport fuels are fairly clean, however with the exception of transport fuels used for sea transport.

From table 4.2.2 it is noticed that in general average emission coefficients for the industry are larger than for service branches and the household consumption. Part of this is due to the fact, that for households and the service branches the share of converted fuels (electricity and district heating) is larger than for the industry. However distributing the emissions from the converting sectors to the final users of the converted fuels, emission coefficients for the industry are still larger than for the service branches and the households. That is, fuels with a large sulphur content are mainly used within the industry, while households and service branches use cleaner fuels. Except for sea transport, especially the transport branches have low average emission coefficients. Looking at the development, from 1980 to 1991 total SO_2 emissions have been reduced with about 45 percent, and the average emission coefficient for most of the branches have been more than halved. A single important exception is the emission coefficient for sea transport, where the allowed sulphur content in fuel oil used have been unchanged over the period. In 1992 the sulphur content in fuel oil used for sea transport was reduced from 3.5 percent to 3.0 percent.

Uses		Energy consumption TJ	SO_2 emissions tSO_2	Emission coefficient $kgSO_2/TJ$ 1991	Emission coefficient $kgSO_2/TJ$ 1980
Household consumption	pc	225727	5897	26.12	118.77
Agriculture	a	42089	9473	225.08	461.39
Oil and gas extraction	e	2318	895	386.02	233.54
Oil refineries	ng	5878	790	134.45	743.89
Energy conversion	ne	356163	179801	421.22	809.51
of this: electricity prod.	b91	297288	159214	535.56	765.66
district heating	b93	58720	20561	350.16	1006.18
Food processing.	nf	35041	7788	222.24	728.85
Man. of beverages etc.	nn	6469	1909	295.05	930.00
Construct. sub suppliers	nb	32050	11150	347.91	620.20
Iron and metal industry	nm	17279	1027	59.46	402.50
Man. of transp. equipm.	nt	2033	138	67.80	458.13
Man. of chemicals	nk	14853	1960	131.96	556.43
Other manufacturing	nq	16573	2370	143.00	532.45
Construction	b	13701	1527	111.45	193.86
Trade	qh	30012	1353	45.10	240.03
Sea transport	qs	9222	9321	1010.66	1133.71
Other transport	qt	80166	6363	79.37	131.03
of this: rail	t11				
buses	t12[1]	16965	3223	189.97	224.06
ferries	t13				
tourist busses	t21				
taxi	t22[2]	31045	2681	86.35	199.16
road freight	t23				
air transport	t3	25316	198	7.82	8.68[4]
mail etc.	t4	4193	160	38.09	261.86
serv. rel. transp.	t5	2648	102	38.48	222.43
Financial services	qf	6155	125	20.23	326.21
Other private services	qq	27640	729	26.37	288.59
Housing	h	1302	26	20.09	329.61
Public services	o	36038	1291	35.81	309.05
Total[3]		-	243932	-	-

Table 4.2.2. Direct energy consumption, SO_2 emissions and emission coefficients for 1991, ($kgSO_2/TJ$)

1) Aggregation of t11-t13, disaggregated data for 1991 are not available.

2) Aggregation of t21-t23, disaggregated data for 1991 are not available.

3) Aggregating the energy consumption would include a double counting and the converted fuels.

4) According to international conventions only part of these emissions is the responsibility of Denmark.

II.4.3 SO_2 emissions from bio-fuels

As bio-fuels are not included in the energy balances of the Danish Statistical Office emissions from bio-fuels are calculated separately and added to the emissions from the energy goods. (The environmental effect of acid rain is independent of the sources of the SO_2 emissions).

For 1992 the consumption of bio-fuels, SO_2 emission coefficients and total emissions are shown in table 4.3.1, and the distribution among uses are given in table 4.3.2.

Bio-fuels	Energy consumption[1] PJ	SO_2 emission coefficients[2] $kgSO_2/TJ$	SO_2 emissions tSO_2
Fish oil	0.15	0	0
Waste	17.32	675	11691
Wood	10.19	130	1325
Wood waste	7.45	130	969
Straw	13.84	130	1799
Bio gas	1.54	0	0
Total	50.49	313	15784

Table 4.3.1. The consumption of bio-fuels, SO_2 emission coefficients and total SO_2 emissions for 1992
1) Source: Energy statistics 1992 from the Danish Energy Agency. Consumption of renewable energy.
2) Source: Inventory of emissions to the air from Danish sources. J.Fenhann and N.A.Kilde, Research Centre Risø, January 1994.

Bio-fuels	Power plants PJ	District heating PJ	Heating PJ	Industry PJ	Agriculture PJ	Other uses PJ	Total PJ
Fish oil		0.15					0.15
Waste		17.32					17.32
Wood		1.78	8.40				10.19
Wood Waste		2.37		3.30	0.03	1.75	7.45
Straw	1.45	3.92	6.36		2.12		13.84
Bio gas			0.02	0.78		0.74	1.54
Total PJ	1.45	25.54	14.78	4.08	2.15	2.49	50.49
SO_2 emiss. tSO_2	189	12740	1919	429	279	228	15784

Table 4.3.2. Consumption of bio-fuels and SO_2 emissions distributed on uses in 1992
Source: Energy statistics 1992 from the Danish Energy Agency.

As is seen from the tables, about 16 $ktSO_2$ is emitted from the use of bio-fuels, which is about 6.5 percent of the emissions coming from the use of energy goods. By far the largest part of the emissions from bio-fuels come from the burning of waste used for the production of district heating. Emissions from other uses of bio-fuels are limited, however not negligible (about 2 percent of the emissions coming from the use of energy goods).

Total energy related SO_2 emissions are calculated by adding emissions from energy goods (table 4.2.2 where bio-fuels are not included and emission coefficients for wood are zero) and emissions from bio-fuels (table 4.3.2). Concerning forecasts the energy model presented in part I forecasts the use of energy goods only. Past introductions of bio-fuels are implicitly measured as energy/fuel savings, that is, using the model for forecasts implicitly assumes a continuation of past trends in the introduction of bio-fuels. If this is not the case, the energy forecasts have to be corrected for the changes. Proposals for corrections are given in section 4.5.2.

II.4.4 Process related SO_2 emissions

Beside energy related emissions SO_2 is emitted from a few raw materials used in the production of different goods, and for some products part of the sulphur content of the fuels is contained in the product, that is, the SO_2 emitted with the flue gasses is reduced relatively to the emissions calculated from the sulphur content of the fuels. The containment of sulphur in products may be treated as reduced emission coefficients for fuels used in the production of these products, however here it is chosen to treat the containment of sulphur in certain products as process related corrections to the energy related emissions.

A complete list of process related sources of SO_2 emissions or products that contain part of the sulphur contained in the fuels is not available. The sources mentioned in this section hopefully are the most important, however the list is far from complete, and important sources may have been overlooked. In general process related emissions/containments are evaluated to be relatively minor seen in relation to the energy related SO_2 emissions.

II.4.4.1 Cement production

In Denmark the production of cement consists of both white and grey cement. Concerning the production of grey cement in 1988 the production process was changed from a wet to a semi-dry process, which implies that about 75 percent of the sulphur content of the fuels used is contained in the cement. For the production of white cement the wet process is still used, however in connection with the instalment of a heat recovery plant in 1991 the wet-process plants were equipped with desulphurization and present SO_2 emissions from these plants are minimal.

Assuming that 75 percent of the sulphur content of solid and liquid fuels used by the cement factories are contained in the cement or in the desulphurization equipment, emissions are reduced with about 5000 tSO_2 (see table 4.4.1). As the emissions from the cement factories are not modelled separately but are part of the emissions coming from the branch 'construction sub suppliers', emissions from this branch are reduced with 48.5 percent of emissions from the use of solid fuels and 37.2 percent of emissions from the use of liquid fuels.

	Cement factories tSO_2	Constr. sub suppl. tSO_2	Reduction tSO_2	Reduction % $SO_2{}^{rk,t}{}_{nb,j}$
Solid fuel	6057	9364	4543	48.5
Fluid fuel	1012	2041	759	37.2
Total	7069	11405	5302	46.5

Table 4.4.1 SO_2 emissions from the use of solid and liquid fuels by the cement factories and the branch 'construction sub suppliers' in 1990

Source: Calculated from the energy consumption in the NR. branch 'Cement factories etc.' and the emission coefficients in table 4.0.1.

II.4.4.2 Production of materials used for insulation

The stone material used in the production of Rockwool contains sulphur, however as the Rockwool contains an equal amount of sulphur, emissions from the production equals the amount of sulphur contained in the fuels used. The production of glass-wool does not cause separate process related SO_2 emissions.

II.4.4.3 Production of yellow bricks

In dry weight the clay used for the production of yellow bricks contain 0.023 percent sulphur. When burned this sulphur is emitted as SO_2 with the flue gasses. Per brick, that weights about 2 kg, emissions are 0.46 gram sulphur or 0.92 gram SO_2. Assuming that the production of yellow bricks are calculated as shown in section II.3.4.3, process related SO_2 emissions are given in table 4.4.2.

Year	Production of ceramic bricks 1000 bricks	Production of yellow bricks (60%) 1000 bricks	SO_2 emissions ton	Production in construction sub suppliers mill. 1980-kr.	Emission coefficient tSO_2/mill 1980-kr
1988	345387	207232	190.65	14109	0.0135
1989	339188	203513	187.23	13868	0.0135
1990	291348	174809	160.82	13505	0.0119
1991	291497	174898	160.91	13863	0.0116
1992	302008	181205	166.71	14608	0.0114

Table 4.4.3 Production of yellow bricks and related SO_2 emissions.

Source: DS. Industrial goods statistic series B. Production of ceramic bricks.

II.4.4.4 Production of sulphuric acid

In conventional production of sulphuric acid solid sulphur is burned to SO_2, and this is oxidized to SO_3. The heat from the burning of solid sulphur is used for process heat, but is not included in the energy balances. During the burning a minor part of the sulphur is lost and emitted as SO_2 with the flue gasses. The production of sulphuric acid and the related SO_2 emissions to the air are shown in table 4.4.4.

As the production of sulphuric acid varies and is a varying share of the production within the chemical industry both total emissions and the emission coefficient vary. For projections the latest observable coefficient will be used. Alternatively, if the future production of sulphuric acid is known, emissions may be calculated directly.

Year	Production of sulphuric acid ton[1]	SO_2 emissions ton[1,2]	Production in the chemical industry mill. 1980-prices	Emission coefficient tSO_2/mill 1980-kr.
1990	150000	327	26321	0.0124
1991	65500	109	26756	0.0041
1992	59000	43	28044	0.0015
1993	64000	76	27379	0.0028

Table 4.4.4 The production of sulphuric acid and the related SO_2 emissions

1. Source: KEMIRA DANMARK A/S (Excl. the production of sulphuric acid by desulphurization at power plants).

2. The emission coefficient is equal to a loss of sulphur between 0.11 percent and 0.33 percent and an emission coefficient between 0.001 and 0.002 tSO_2/tH_2SO_4.

II.4.5 A forecast model for SO_2 emissions

II.4.5.1 SO_2 emissions from energy goods

From forecasts of the energy consumption given by ADAM and the models described in part I, and the emission coefficients given in table 4.2.1 the energy related SO_2 emissions are calculated as:

eq. 4.5.1.
$$SO2_j^t = \sum_g E_{g,j}^t \cdot S_{g,j}^t$$

where $SO2^t_j$ is the energy related emissions from branch j
$E^t_{g,j}$ is the direct energy consumption of branch j and fuel g
and $S^t_{g,j}$ is the emission coefficient for branch j and fuel g

In standard projections the emission coefficients in equation 4.5.1 are (with the exception of solid fuel used by power plants) assumed to be constant, however they vary according to changes in the fuel-mix within the aggregated fuels and changes in the sulphur content of the individual fuels. (The emission coefficient for solid fuel used by the power plants is projected such, that emissions form power plants equals their emission quota).

As the energy consumption is projected only at the aggregated level changes in the fuel-mix within the aggregated fuels and changes in the sulphur content are not projected by the model, however such changes may be introduced exogenously. Changed emission coefficients may be calculated by changing the sulphur content of the individual fuels in equation 4.0.1 or by changing the fuel-mix in equation 4.2.1.

II.4.5.2 SO_2 emissions from bio-fuels

In the model the consumption of bio-fuels is assumed exogenous, and the emissions are calculated at the aggregated level given in table 4.3.2, that is, the consumption is not distributed among the different uses. In line with equation 4.5.1 the SO_2 emissions from bio-fuels are calculated as:

$$eq.\ 4.5.2. \qquad SO2^t_a = \sum_k E^t_{k,a} \cdot S_k$$

where	$SO2^t_a$	is the SO_2 emissions from use a in table 4.3.2
	E^t_a	is the direct energy consumption of fuel k by use a
and	S_k	is the emission coefficient for fuel k

As bio-fuels are not included in the energy model, and considerable changes in the use of bio-fuels affect the use of energy goods, the energy model forecasts and the SO_2 calculations have to be corrected for changes in the use of bio-fuels. Taking the 1992 consumption of bio-fuels as basis and assuming, that a change in the use of bio-fuels are accompanied by a corresponding change in the use of energy goods, the following corrections may be introduced:

$$eq.\ 4.5.3. \qquad SO2^t_{a\ korr} = \left(\sum_k E^{92}_{k,a} - \sum_k E^t_{k,a} \right) \cdot S^t_{g,j}$$

where

	$E^{92}_{k,a}$	is the consumption of bio-fuel k by use a in 1992
	$E^t_{k,a}$	is the consumption of bio-fuels given in table 4.3.2
and	$S^t_{g,j}$	is the SO_2 emission coefficient for the energy goods that are substituted

Ideally $E^{92}_{k,a}$ should have been a forecast for the consumption of bio-fuels assuming a continuation of past trends, however lacking this the base year consumption is used.

The consumption of bio-fuels in 1992 and the emission coefficients for the energy goods, that are substituted, are given in table 4.5.1. For power plants and district heating the bio-fuels are assumed to substitute solid fuels. For the other uses bio-fuels are assumed to substitute liquid fuels.

Uses	Consumption of bio-fuel in 1992 $\Sigma E^{92}_{k,a}$ PJ	SO_2 coefficient for the substituted fuel $S^t_{g,j}$	SO_2 coefficient for the substituted fuel $kgSO_2/TJ$
Power plants	1.45	$S1^t_{b91,solid}$	542.5
District heating	25.54	$S^t_{b93,solid}$	550.9
Heating	14.78	$S^t_{pc,fluid}$	86.7
Industry	4.08	$S^t_{nb,fluid}$	277.0
Agriculture	2.15	$S^t_{a,fluid}$	267.7
Other uses	2.49	$S^t_{total,fluid}$	268.0

Table 4.5.1. The consumption of bio-fuels in 1992 and the SO_2 emission coefficients for the energy goods that are substituted

II.4.5.3 Process related SO_2 emissions

As mentioned in section II.4.4, SO_2 is emitted from the raw materials used within the production of yellow bricks and sulphuric acid, and in the production of cement part of the sulphur content of the fuels is contained in the cement or in desulphurization equipment. The production of cement and yellow bricks is part of the production within the branch 'construction sub suppliers', and emissions from the production of yellow bricks are projected with the production in this branch. The containment and desulphurization of sulphur in the production of cement is projected with the consumption of solid and liquid fuels within the aggregated branch. Emissions from the production of sulphuric acid are projected proportional to the production within the branch 'chemical industry'. As the production of the relevant goods is only parts of the production within the aggregated branches, emission coefficients will vary with the share of the goods in the aggregated production. However as the production of the relevant goods is not projected separately, the emission coefficients are assumed to be constant. If the production of the relevant goods are changed significantly the emission coefficient should be changed exogenously. The equation for the process related emissions is:

eq. 4.5.4.
$$SO2^{t}_{process} = FX^{t}_{nb} \cdot S^{process}_{nb} - (SO^{t}_{2\ nb,solid} \cdot SO^{rk,t}_{2\ nb,solid} + SO^{t}_{2\ nb,fluid} \cdot SO^{rk,t}_{2\ nb,fluid}) + FX^{t}_{nk} \cdot S^{process}_{nk}$$

where

FX^{t}_{nb}	is the production by 'construction sub suppliers' in mill 1980-Dkr
FX^{t}_{nk}	is the production by the chemical industry in mill 1980-Dkr
$S^{process}_{nb}$	is the emission coefficient per mill 1980-Dkr given in table 4.4.3
$S^{process}_{nk}$	is the emission coefficient per mill 1980-Dkr given in table 4.4.4
$SO^{t}_{2\ nb,solid}$	is the SO_2 emissions from the use of solid fuels by branch "construction sub suppliers"
$SO^{t}_{2\ nb,fluid}$	is the SO_2 emissions from the use of liquid fuels by branch "construction sub suppliers"
$SO^{rk,t}_{2\ nb,solid}$	is the reduction coefficient for solid fuels given in table 4.4.1

and

$SO^{rk,t}_{2\ nb,fluid}$	is the reduction coefficient for liquid fuels given in table 4.4.1

II.4.5.4 The total SO_2 emissions

Adding the different sources total SO_2 emissions are given by:

eq. 4.5.5
$$SO2^{t}_{total} = \sum_{j} SO2^{t}_{j} + \sum_{a} SO2^{t}_{a} + \sum_{a} SO2^{t}_{a\ korr} + SO2^{t}_{process}$$

where

$SO2^{t}_{total}$	is the total SO_2 emissions
$SO2^{t}_{j}$	is SO_2 emissions from energy goods
$SO2^{t}_{a}$	is emissions from bio-fuels
$SO2^{t}_{a,cor}$	is corrections due to the use of bio-fuels

and

$SO2^{t}_{process}$	is process related emissions

II.5 NO_x emissions

Like SO_2, emissions of NO_x are a major contributor to the acidification of forests and lakes and may be transported in the air over thousands of kilometres. In addition the nitrogen content in NO_x contributes to the eutrophication that leads to increased production and dominance of certain species at the expense of others.

II.5.0 NO_x emission coefficients for fossil fuels

During the combustion of fuels NO_x is formed mainly from the nitrogen content of the air (for solid fuels the nitrogen content of the fuel contribute to the emissions, however this is a minor part of the emissions). The amount of NO_x that is formed depend of the combustion conditions; the higher the temperature and the more air that is induced, the more NO_x will be formed and emitted with the flue gasses. Therefore when calculating NO_x emissions, beside the amount of fuels used one has to know, for what purpose the fuels are used, and how they are combusted? As a detailed knowledge, on how the different fuels are used, is not available, emission coefficients for the individual branches are based on evaluations of typical uses within the individual branch. Concerning transport fuels, that account for about 50 percent of the total NO_x emissions, some information, on how the fuels are used within the individual branches, is available. This information is used to calculate branch specific emission coefficients, however the distribution of the energy consumption between the different uses is somewhat uncertain.

The NO_x coefficients used for the individual fuels and uses are given in table 5.0.1. The calculation of branch specific emission coefficients for the transport fuels are shown in section 5.0.1. Emission coefficients for the other fuels vary between branches, but the coefficient is assumed to be valid for the total consumption of the fuel within the branch. In general it has to be said, that NO_x emissions and - coefficients are somewhat uncertain, typically the overall uncertainty is about 10 percent.

	Fuel	Branch/use	NO$_x$ emission coefficient kg NO$_x$/GJ
1	Coal gas	1-95 96-122	0.100 0.050
3	Coal	91 other	calculated 0.200
4-5	Brown coal/briquettes	1-122	0.050
6	Coke	1-122	0.200
8	Jet kerosine	1-122	0.196
9	Jet gasoline	1-122	0.196
10	Gasoline	with catalysts without catalysts jet fuel used in 103	0.088 0.884 0.196
11	Gasoline (tax free)	1-122	0.884
12	Naphtha	1-122	0
13	Kerosine (excl.8)	1-95 96-122	0.100 0.050
14	Auto diesel	person cars delivery vans small lorries large lorries off roader ships rail roads	0.250 0.373 0.908 1.058 1.171 1.382 1.033
15	Gas oil	1-95 96-122	0.100 0.050
16	Marine diesel	1-122	1.382
17	Fuel oil	6 91 93 101 other	1.460 0.240 0.150 1.770 0.150
19	LPG	transport process	0.898 0.100
20	Refinery gas	1-122	0.000
24	Petroleum coke	1-122	0.200
25	Natural gas	91 93 other 1-95 96-122	0.240 0.150 0.100 0.050
23 26	Wood/straw	1-95 96-122	0.130 0.050
27	Waste	93	0.150

Table 5.0.1 NO$_x$ emission coefficients for fossil fuels
Source: Research Centre Risø, CORINAIR-database.

II.5.0.1 NO_x mission coefficients for transport fuels

Gasoline

The emission coefficient for gasoline vary according to the construction of the car, the engine and drive conditions such as speed, whether the engine is cold or warm and how cold the weather is. The emission coefficients used here are calculated using the COBERT-model and express an average for cars and drive conditions in Denmark. For forecasts it is assumed, that the cars and drive conditions are unchanged except for the introduction of catalysts on all new gasoline driven cars. Catalysts reduce NO_x emissions to 1/10'th and became statutory on all new cars october 1990. In 1990 about 2 percent of all cars had catalysts, and the average emission coefficient for gasoline was 0.868 kgNO_x/GJ. For the branches we assume that cars are replaced with 1/4'th per year, and the average emission coefficient is 0.786 i 1991, 0.570 in 1992, 0.353 in 1993, 0.172 in 1994 and 0.088 in 1995 and following years. For the households car purchases are determined in the ADAM-model, and new cars bought in 1991 and following years will have catalysts. Changes in the car size and drive conditions may be analyzed in the COBERT-model and introduced exogenously as changes in the emission coefficients.

Looking at table 5.0.1 there is a specific emission coefficient for branch 103 'air transport and airports'. This is because part of the gasoline consumption is jetfuel with an emission coefficient of 0.196 kgNO_x/GJ. In 1990 jetfuel was 85.75 percent of the gasoline consumption of the branch and this share is assumed to be constant, that is, in 1990 the average emission coefficient is 0.292, and this is reduced to 0.181 in 1995, where all cars are assumed to have catalysts.

Auto diesel and LPG

The emission coefficients for auto diesel and LPG vary with the uses and the uses vary between branches, that is, the emission coefficients vary between branches. Emission coefficients for the individual branches are calculated as a weighted average of the coefficients for the different uses. The weights are the 1990 share of the fuel used for the individual uses. As the uses are not modelled the share of the individual use is assumed to be constant, and assuming that the emission coefficients for the individual uses are constant, the emission coefficients for the branches will be constant. Emission coefficients and weights for the individual uses may be changed exogenously, and changed emission coefficients for the branches may be calculated.

For auto diesel the emission coefficients for uses, the weights of uses and the emission coefficients for branches are shown in table 5.0.3, and equal information for LPG is given in table 5.0.4.

	Emission coefficient kg NO_x/GJ	Person cars 0.250	Delivery vans 0.373	Small lorries 0.908	Large lorries 1.058	Off roaders 1.171	Ships 1.382	Rail roads 1.033	Total
	Branch:	Shares							kg NO_x/GJ
1	Agriculture	0.001	0.002	-	-	0.997	-	-	1.1685
2	Horticulture	0.003	0.091	0.467	-	0.439	-	-	0.9728
3	Fur farming, etc.	0.006	0.037	0.957	-	-	-	-	0.8843
4	Agricultural services	0.001	0.005	0.087	-	0.907	-	-	1.1432
5	Forestry and logging	0.002	0.037	0.961	-	-	-	-	0.8869
6	Fishing	0.000	0.000	0.004	-	-	0.996	-	1.3801
7	Extraction of coal, oil and gas	1.000	-	-	-	-	-	-	0.2500
8	Other mining	0.001	0.008	0.848	0.143	-	-	-	0.9245
9	Slaughtering of pigs, cattle	0.001	0.008	0.991	-	-	-	-	0.9031
10	Poultry killing, dressin, pack.	0.001	0.010	0.989	-	-	-	-	0.9020
11	Dairies	-	-	0.270	0.730	-	-	-	1.0175
12	Processed cheese, cond. milk	0.071	0.266	0.663	-	-	-	-	0.7190
13	Ice cream manufacturing	0.004	0.015	0.981	-	-	-	-	0.8973
14	Processing of fruits and veg.	0.000	0.002	0.997	-	-	-	-	0.9060
15	Processing of fish	0.004	0.049	0.947	-	-	-	-	0.8792
16	Oil mills	0.001	0.015	0.984	-	-	-	-	0.8993
17	Margarine manufacturing	0.001	0.006	0.992	-	-	-	-	0.9041
18	Fish meal manufacturing	0.001	0.001	0.998	-	-	-	-	0.9068
19	Grain mill products	0.044	0.086	0.870	-	-	-	-	0.8330
20	Bread factories	0.000	0.001	0.999	-	-	-	-	0.9075
21	Cake factories	-	0.006	0.994	-	-	-	-	0.9048
22	Bakeries	0.008	0.992	-	-	-	-	-	0.3720
23	Sugar factories and refineries	0.002	0.025	0.973	-	-	-	-	0.8933
24	Chocolate and sugar confect.	0.001	0.005	0.994	-	-	-	-	0.9047
25	Manufacture of food products	0.002	0.004	0.994	-	-	-	-	0.9045
26	Manuf. of prep. animal feeds	0.001	0.001	0.998	-	-	-	-	0.9068
27	Distilling and blending spirits	0.011	0.009	0.980	-	-	-	-	0.8960
28	Breweries	0.000	0.002	0.264	0.733	-	-	-	1.0160
29	Tobacco manufactures	0.012	0.049	0.939	-	-	-	-	0.8739
30	Spinning, weaving etc. textiles	0.004	0.065	0.931	-	-	-	-	0.8706
31	Manuf. of made-up text. goods	0.029	0.038	0.932	-	-	-	-	0.8677
32	Knitting mills	0.011	0.057	0.932	-	-	-	-	0.8703
33	Cordage, rope and twine indu.	0.012	0.080	0.907	-	-	-	-	0.8564
34	Manufact. of wearing apparel	0.014	0.038	0.948	-	-	-	-	0.8785
35	Manufact. of leather products	0.024	0.038	0.938	-	-	-	-	0.8719
36	Manufacture of footwear	0.163	0.837	-	-	-	-	-	0.3530
37	Ma. of wood prod. excl. furnit.	0.003	0.014	0.983	-	-	-	-	0.8985
38	Manuf. of wooden furnit., etc.	0.004	0.012	0.985	-	-	-	-	0.8999
39	Manuf. of pulp, paperboard	0.001	0.003	0.996	-	-	-	-	0.9057
40	Paper containers, wallpaper	0.014	0.029	0.957	-	-	-	-	0.8833
41	Reprod. and composing serv.	0.005	0.013	0.982	-	-	-	-	0.8978
42	Book printing	0.048	0.952	-	-	-	-	-	0.3671
43	Offset printing	0.005	0.013	0.982	-	-	-	-	0.8978
44	Other printing	0.013	0.040	0.947	-	-	-	-	0.8781
45	Bookbinding	0.013	0.042	0.945	-	-	-	-	0.8770
46	Newspaper print. and publ.	0.006	0.072	0.922	-	-	-	-	0.8655
47	Book and art publishing	0.006	0.072	0.922	-	-	-	-	0.8655
48	Magazine publishing	0.006	0.093	0.902	-	-	-	-	0.8552
49	Other publishing	0.006	0.072	0.922	-	-	-	-	0.8655
50	Manuf. of basic industr. chem.	0.237	0.763	-	-	-	-	-	0.3439
51	Man. of fertilizers and pesticid.	0.001	0.021	0.968	-	-	-	-	0.8870
52	Manuf. of basic plastic mat.	0.005	0.011	0.985	-	-	-	-	0.8997
53	Manuf. of paints and varnishes	0.003	0.014	0.983	-	-	-	-	0.8985
54	Manuf. of drugs and medicines	0.019	0.025	0.956	-	-	-	-	0.8821
55	Manuf. of soap and cosmetics	0.021	0.007	0.972	-	-	-	-	0.8904
56	Manuf. of chemical products	0.009	0.051	0.940	-	-	-	-	0.8748
57	Petroleum refineries	0.034	0.966	-	-	-	-	-	0.3688
58	Ma. of asphalt and roof. mater.	0.009	0.116	0.875	-	-	-	-	0.8400
59	Tyre and tube industries	0.003	0.015	0.981	-	-	-	-	0.8971
60	Manuf. of rubber products	0.003	0.016	0.981	-	-	-	-	0.8975
61	Manuf. of plastic products	0.003	0.003	0.994	-	-	-	-	0.9044
62	Manuf. of earthenw. and pot.	0.011	0.025	0.964	-	-	-	-	0.8874
63	Manuf. of glass and glass prod.	0.004	0.006	0.990	-	-	-	-	0.9022
64	Manuf. of structural clay prod.	0.006	0.049	0.945	-	-	-	-	0.8778
65	Man. of cement, lime and plast	0.004	0.061	0.935	-	-	-	-	0.8727
66	Concrete prod. and stone cut.	0.004	0.027	0.969	-	-	-	-	0.8909
67	Non-metallic mineral prod.	0.002	0.016	0.982	-	-	-	-	0.8981
68	Iron and steel works	0.002	0.015	0.983	-	-	-	-	0.8987
69	Iron and steel casting	0.003	0.013	0.984	-	-	-	-	0.8991

	Emission coefficient kg NO_x/GJ	Person cars 0.250	Delivery vans 0.373	Small lorries 0.908	Large lorries 1.058	Off roaders 1.171	Ships 1.382	Rail roads 1.033	Total
70	Non-ferrous metal works	0.004	0.012	0.984	-	-	-	-	0.8990
71	Non-ferrous metal casting	0.004	0.012	0.984	-	-	-	-	0.8990
72	Manuf. of metal furniture	0.083	0.917	-	-	-	-	-	0.3628
73	Manuf. of struct. metal prod.	0.011	0.100	0.889	-	-	-	-	0.8473
74	Man. of metal cans and cont.	0.002	-	0.998	-	-	-	-	0.9067
75	Man. of other fabr. metal prod.	0.020	0.149	0.830	-	-	-	-	0.8142
76	Manuf. of agricult. machinery	0.007	0.052	0.941	-	-	-	-	0.8756
77	Manuf. of industrial machinery	0.006	0.140	0.854	-	-	-	-	0.8292
78	Repair of machinery	0.005	0.227	0.768	-	-	-	-	0.7833
79	Manuf. of househ. machinery	0.001	0.054	0.945	-	-	-	-	0.8785
80	Man. of refrigerat., accessories	0.006	0.093	0.901	-	-	-	-	0.8543
81	Manuf. of telecom. equipment	0.005	0.074	0.921	-	-	-	-	0.8651
82	Man. of electr. home appl.	0.009	0.130	0.861	-	-	-	-	0.8325
83	Man. of accumulat. and bat.	0.003	0.066	0.931	-	-	-	-	0.8707
84	Man. of other electr. supplies	0.002	0.021	0.977	-	-	-	-	0.8955
85	Ship building and repairing	0.005	0.026	0.969	-	-	-	-	0.8908
86	Railr. and automob. equipment	0.019	0.098	0.883	-	-	-	-	0.8431
87	Manuf. of cycles, mopeds, etc.	0.041	0.163	0.796	-	-	-	-	0.7938
88	Prof. and measur. equipment	0.020	0.312	0.668	-	-	-	-	0.7279
89	Manuf. of jewellery, etc.	0.058	0.942	-	-	-	-	-	0.3659
90	Manuf.of toys, sporting goods	0.261	0.739	-	-	-	-		0.3409
91	Electric light and power	0.004	0.047	0.949	-	-	-	-	0.8802
92	Gas manuf. and distribution	0.001	0.089	0.910	-	-	-	-	0.8597
93	Stream and hot water supply	0.002	0.020	0.978	-	-	-	-	0.8960
94	Water works and supply 1)	0.002	0.014	-	-	-	-	-	0.1042
95	Construction	0.001	0.035	0.172	0.388	0.404	-	-	1.0531
96	Wholesale trade	0.000	0.025	0.296	0.679	-	-	-	0.9965
97	Retail trade	0.011	0.761	0.228	-	-	-	-	0.4936
98	Restaurants and hotels	0.023	0.086	0.891	-	-	-	-	0.8469
99	Railway and bus transport, etc.	-	0.000	0.012	0.632	-	-	0.356	1.0473
	of this:								
	Rail roads 35.6%	-	-	-	-	-	-	1.000	1.0330
	Bus transport, etc 64.4%	-	0.000	0.019	0.981	-	-	-	1.0552
100	Other land transport	0.064	0.003	0.182	0.751	-	-	-	0.9769
	of this:								
	Tourist coaches 12.0%	-	-	-	1.000	-	-	-	1.0580
	Taxies 6.4%	1.000	-	-	-	-	-	-	0.2500
	Road freight 81.6%	0.000	0.004	0.223	0.773	-	-	-	1.0218
101	Ocean and coast. wat. transp.	0.003	0.012	0.315	-	-	0.670	-	1.2172
102	Supp. serv. to water transport	0.002	0.006	0.992	-	-	-	-	0.9035
103	Air transport	0.005	0.021	0.974	-	-	-	-	0.8935
104	Services allied to transport, etc.	0.172	0.001	0.306	0.521	-	-	-	0.8724
105	Communication	0.001	0.028	0.971	-	-	-	-	0.8924
106	Financial institutions	-	1.000	-	-	-	-	-	0.3730
107	Insurance	-	1.000	-	-	-	-	-	0.3730
108	Dwellings	-	-	-	-	-	-	-	-
109	Business services	0.039	0.606	0.355	-	-	-	-	0.5400
110	Education, market services	0.064	-	0.936	-	-	-	-	0.8659
111	Health, market services	-	1.000	-	-	-	-	-	0.3730
112	Recreat. and cultural services	0.004	0.088	0.908	-	-	-	-	0.8583
113	Repair of motor vehicles	0.028	0.972	-	-	-	-	-	0.3696
114	Household services	0.001	0.027	0.195	0.778	-	-	-	1.0105
115	Domestic services	-	-	-	-	-	-	-	-
116	Private non-profit institutions	-	1.000	-	-	-	-	-	0.3730
117	Produc. of government serices	0.072	0.072	0.771	0.085	-	-	-	0.8349
118	Household	1.000	-	-	-	-	-	-	0.2500
119	Total	0.032	0.015	0.170	0.453	0.165	0.120	0.045	1.0528

Table 5.0.3. The distribution of auto diesel on uses and the average NO_x emission coefficient for the individual branches in 1990.

1) The rest 0.985 is used for electricity production and ascribed an emission coefficient of 0.100 kgNO_x/GJ

	Emission coefficient kg NO_x/GJ	Transport 0.898	Process 0.100	Total
	Branch:	Shares		kg NO_x/GJ
1	Agriculture	0.007	0.993	0.1056
2	Horticulture	0.036	0.964	0.1287
3	Fur farming, etc.	-	-	-
4	Agricultural services	0.522	0.478	0.5166
5	Forestry and logging	-	-	-
6	Fishing	0.010	0.990	0.1080
7	Extraction of coal, oil and gas	-	-	-
8	Other mining	0.037	0.963	0.1295
9	Slaught. etc. of pigs and cattle	0.063	0.937	0.1503
10	Poult. killing, dress., packing	0.041	0.959	0.1327
11	Dairies	0.205	0.795	0.2636
12	Proces. cheese, condens. milk	0.022	0.978	0.1176
13	Ice cream manufacturing	0.097	0.903	0.1774
14	Proc. of fruits and vegetables	0.317	0.683	0.3530
15	Processing of fish	0.007	0.993	0.1056
16	Oil mills	0.040	0.960	0.1319
17	Margarine manufacturing	0.537	0.463	0.5285
18	Fish meal manufacturing	0.064	0.936	0.1511
19	Grain mill products	0.007	0.993	0.1056
20	Bread factories	0.061	0.939	0.1487
21	Cake factories	0.001	0.999	0.1008
22	Bakeries	0.909	0.091	0.8254
23	Sugar factories and refineries	0.060	0.940	0.1479
24	Chocolate and sugar confec.	0.068	0.932	0.1543
25	Manuf. of food products	0.114	0.886	0.1910
26	Manuf. of prep. animal feeds	0.466	0.534	0.4719
27	Distilling and blending spirits	0.000	1.000	0.1000
28	Breweries	0.011	0.989	0.1088
29	Tobacco manufactures	0.022	0.978	0.1176
30	Spinning, weaving etc. textiles	0.001	0.999	0.1008
31	Manuf.of made-up text. goods	0.047	0.953	0.1375
32	Knitting mills	-	-	-
33	Cordage, rope and twine ind.	0.010	0.990	0.1080
34	Manuf. of wearing apparel	-	-	-
35	Manuf. of leather products	-	-	-
36	Manuf. of footwear	-	-	-
37	Manuf.of wood prod excl furn	0.011	0.989	0.1088
38	Manuf. of wooden furniture	0.080	0.920	0.1638
39	Manuf. of pulp, paper, paperboard	0.002	0.998	0.1016
40	Manuf.of paper contai., wallp.	0.006	0.994	0.1048
41	Reprod.and compos. services	-	-	-
42	Book printing	0.042	0.958	0.1335
43	Offset printing	0.015	0.985	0.1120
44	Other printing	0.032	0.978	0.1255
45	Bookbinding	-	-	-
46	Newsp. printing and publish.	-	-	-
47	Book and art publishing	-	-	-
48	Magazine publishing	-	-	-
49	Other publishing	-	-	-
50	Manuf. of basic indust. chemi.	0.001	0.999	0.1008
51	Manuf.of fertilizers and pestic.	0.022	0.978	0.1176
52	Manuf. of basic plastic mater.	0.040	0.960	0.1319
53	Manuf.of paints and varnishes	0.065	0.935	0.1519
54	Manuf.of druge and medicines	0.013	0.987	0.1103
55	Manuf. of soap and cosmetica	0.003	0.997	0.1023
56	Manuf. of chemical produc.	0.047	0.953	0.1375
57	Petroleum refineries	-	-	-
58	Manuf. of asph. and roof. mat.	0.001	0.999	0.1008
59	Tyre and tube industries	0.035	0.965	0.1279
60	Manuf. of rubber products	0.005	0.995	0.1040
61	Manuf. of plastic products	0.033	0.967	0.1263
62	Man.of earthenw. and pot.	0.011	0.989	0.1088
63	Manuf.of glass, glass prod.	0.003	0.997	0.1024
64	Manuf. of struct. clay prod.	0.001	0.999	0.1008
65	Man.of cem., lime, plaster	0.025	0.975	0.1200
66	Concr. prod. and stone cut.	0.000	1.000	0.1000
67	Non-metallic mineral prod.	0.021	0.979	0.1168
68	Iron and steel works	0.001	0.999	0.1008
69	Iron and steel casting	0.001	0.999	0.1008
70	Non-ferrous metal works	0.002	0.998	0.1016
71	Non-ferrous metal casting	0.001	0.999	0.1008
72	Manuf. of metal furniture	0.002	0.998	0.1016
73	Man. of struct. metal prod.	0.006	0.994	0.1048
74	Man.of met. cans and conta.	0.002	0.998	0.1016
75	Manuf.of fabrica. met. prod.	0.005	0.995	0.1040
76	Man. of agricul. machinery	0.002	0.998	0.1016
77	Man. of industr. machinery	0.031	0.969	0.1247
78	Repair of machinery	1.000	0.000	0.8980
79	Man. of househ. machinery	0.006	0.994	0.1048
80	Manuf. of refrig., accessories	0.018	0.982	0.1144
81	Man. of telecom. equipment	-	-	-
82	Manuf. of electr. home appl.	0.001	0.999	0.1008
83	Man. of accumul. and batt.	0.027	0.973	0.1216
84	Man. of other electr. suppl.	0.091	0.909	0.1726
85	Ship building and repairing	0.004	0.996	0.1032
86	Railroad and autom. equip.	0.003	0.997	0.1024
87	Manuf. of cycles, mopeds	0.002	0.998	0.1016
88	Prof. and measur. equipm.	0.096	0.904	0.1766
89	Manuf. of fewellery, etc.	0.021	0.979	0.1168
90	Man.of toys, sporting goods	-	-	-
91	Electric light and power	-	-	-
92	Gas manuf. and distribution	0.002	0.998	0.1016
93	Stream and hot water supp.	-	-	-
94	Water works and supply	-	-	-
95	Construction	0.050	0.950	0.1399
96	Wholesale trade	0.445	0.555	0.4551
97	Retail trade	0.404	0.596	0.4224
98	Restaurants and hotels	0.036	0.964	0.1287
99	Railway and bus transport of this:	0.017	0.983	0.1136
	Rail roads 1.7%	0.000	1.000	0.1000
	Bus Transport, etc. 98.3%	1.000	0.000	0.8980
100	Other land transport of this:	1.000	0.000	0.8980
	Tourist coaches 16.3%	1.000	0.000	0.8980
	Taxies 62.5%	1.000	0.000	0.8980
	Road freight, etc. 21.2%	1.000	0.000	0.8980
101	Ocean and coast. wat.transp	-	-	-
102	Supp.servic.to water transp.	0.008	0.992	0.1064
103	Air transport	0.007	0.993	0.1056
104	Serices allied to transport	1.000	0.000	0.8980
105	Communication	0.154	0.846	0.2229
106	Financial institutions	-	-	-
107	Insurance	-	-	-
108	Dwelling	-	-	-
109	Business serices	1.000	0.000	0.8980
110	Education,market services	1.000	0.000	0.8980
111	Health, market serices	0.721	0.279	0.6754
112	Recreat. and cultural serv.	0.629	0.371	0.6019
113	Repair of motor vehicles	0.935	0.065	0.8461
114	Household services	0.951	0.049	0.8589
115	Domestic services	-	-	-
116	Priv. non-profit institutions	-	-	-
117	Producers of governm. serv.	0.073	0.927	0.1583
118	Household	0.167	0.833	0.2333
119	Total	0.103	0.897	0.1822

Table 5.0.4. The distribution of LPG on uses and the average NO_x emission coefficient for the individual branches in 1990

II.5.1 NO$_x$ emissions from the converted fuels "electricity" and district heating

Like SO$_2$, NO$_x$ emissions from power plants are measured, and emissions from coal used by power plants are calculated residually as the difference between total emissions and emissions from other fuels than coal. Total NO$_x$ emissions from power plants and emissions ascribed to the use of coal are given in table 5.1.1. The emission coefficient for coal, which is calculated in table 5.1.1, is used both for the coal used to produce electricity and the share of coal used by power plants for the production of district heating.

Distributing emissions from the converting sectors to the final consumers and considering emissions caused by the Danish energy consumption the methodology described in section II.3.1 may be used, that is, replacing CO$_2$-emissions by NO$_x$-emissions, the equations 3.1.1 to 3.1.4 may be used.

Year	Energy consump. on power plants PJ	NO$_x$-emissions[1] 1000 tNO$_x$	NO$_x$ quota 1000 tNO$_x$	Coal consump. PJ	NO$_x$-emissions from coal 1000 tNO$_x$	NO$_x$ emission coeff. for coal kgNO$_x$/TJ
1975	182.65	51.15		64.63	25.23	390
1976	202.70	63.96		95.73	40.69	425
1977	220.58	70.55		111.32	46.53	418
1978	210.70	70.10		123.49	51.02	413
1979	231.66	79.98		153.20	64.19	419
1980	274.27	101.99	115.00	229.78	90.62	394
1981	203.14	77.17	120.00	181.26	71.12	393
1982	240.28	93.14	125.00	221.39	88.82	401
1983	225.65	87.00	130.00	212.18	85.10	401
1984	228.08	89.00	130.00	219.35	87.40	398
1985	288.22	110.00	135.00	270.18	106.57	394
1986	297.11	122.00	140.00	276.05	118.64	430
1987	287.26	118.00	145.00	272.12	115.25	424
1988	274.09	110.00	140.00	255.57	107.29	420
1989	225.75	89.00	135.00	218.43	85.57	392
1990	246.71	83.00	130.00	227.93	80.60	354
1991	339.34	124.00	125.00	313.12	121.29	387
1992	286.01	82.00	106.00			
1993			92.00			
1994			89.00			
1995			85.00			
1996			84.00			
1997			77.00			
1998			71.00			
1999			61.00			
2000			61.00			

Table 5.1.1 Energy consumption and NO$_x$ emissions from power plants

1) Source: Inventory of emissions to the air from Danish sources. J.Fenhann and N.A.Kilde, Research Centre Risø, January 1994 and statistics from Danish power plants.

II.5.2 Aggregated emission coefficients for ADAM branches and the household consumption

Analogous to the CO_2 emission coefficients given in section II.3.2, NO_x emission coefficients for the aggregated fuels are calculated as a weighted average of the underlying fuels, that is:

$$\text{eq. 5.2.1.} \qquad N^t_{g,j} = \frac{\sum_{i\in g} E^t_{i,j} \cdot N^t_{i,j}}{\sum_{i\in g} E^t_{i,j}}$$

Where	g	refers to the aggregated fuels given in table 3.2.0
	i	refers to the fuels of the energy balances given in table 5.0.1
	j	refers to the ADAM branches
	$N^t_{i,j}$	are the NO_x-emission coefficients for the individual fuels and branches
and	$E^t_{i,j}$	are the direct energy consumptions

Uses		Solid	District heating	Other fluid fuels	Transport fuels	Natural gas	Electricity
Household consumption	pc	48.1	0.0	52.3	795.8	50.0	0.0
Agriculture	a	197.4	0.0	161.6	1232.2	100.0	0.0
Oil and gas extraction	e	-	0.0	136.5	760.6	-	0.0
Oil refineries	ng	-	0.0	48.6	726.2	-	0.0
Energy conversion	ne	383.4	0.0	221.1	829.7	159.0	0.0
of this: electricity prod.	b91	387.3	0.0	240.0	830.8	240.0	0.0
district heating	b93	350.7	0.0	179.0	853.6	150.0	0.0
Food processing.	nf	199.6	0.0	134.9	907.4	100.0	0.0
Man. of beverages etc.	nn	200.0	0.0	143.8	974.1	100.0	0.0
Construct. sub suppliers	nb	165.2	0.0	123.3	858.2	100.0	0.0
Iron and metal industry	nm	146.6	0.0	114.1	802.0	100.0	0.0
Man. of transp. equipm.	nt	178.1	0.0	112.4	833.2	100.0	0.0
Man. of chemicals	nk	174.0	0.0	126.7	838.0	100.0	0.0
Other manufacturing	nq	130.0	0.0	132.5	828.1	100.0	0.0
Construction	b	-	0.0	124.7	986.0	50.0	0.0
Trade	qh	-	0.0	69.4	900.7	50.0	0.0
Sea transport	qs	-	0.0	1319.0	1362.1	50.0	0.0
Other transport	qt	-	0.0	151.8	723.4	50.0	0.0
of this: rail	t11*	-	0.0	76.4	1033.0	50.0	0.0
buses	t12*	-	0.0	102.4	1054.0	50.0	0.0
ferries	t13*	-	0.0	156.2	1382.0	50.0	0.0
tourist busses	t21*	-	0.0	805.7	1041.2	50.0	0.0
taxi	t22*	-	0.0	867.6	396.1	50.0	0.0
road freight	t23*	-	0.0	480.1	1008.9	50.0	0.0
air transport	t3	-	0.0	68.9	209.9	50.0	0.0
mail etc.	t4	-	0.0	67.4	852.2	50.0	0.0
serv. rel. transp.	t5	-	0.0	66.3	824.7	50.0	0.0
Financial services	qf	-	0.0	56.4	715.8	50.0	0.0
Other private services	qq	-	0.0	65.1	906.3	50.0	0.0
Housing	h	-	0.0	56.4	-	50.0	0.0
Public services	o	-	0.0	56.9	514.5	50.0	0.0

Table 5.2.1. NO_x emission coefficients for the aggregated fuels in 1991, (kgNO_x/TJ)

* Figures for 1990, disaggregated energy data for 1991 are not available at present.

The emission coefficients for the individual fuels and uses (given in table 5.0.1) and for auto diesel and LPG (given in table 5.0.2 and 5.0.3) are simply aggregated to coefficients for the ADAM branches. The aggregated emission coefficients calculated from equation 5.2.1 are given in table 5.2.1, and total emissions are given in table 5.2.2.

	Total NO_x emissions tNO_x	Transp. fuels tNO_x	Other fuels tNO_x
Total	323156	166370	156786
Household consumption	49156	45435	3721
Transport branches	64747	56131	8616
Fuel conversion	129239	125	129114
Other branches	80014	64679	15335

Table 5.2.2. Total NOx emissions for aggregated sources and fuels in 1991

From table 5.2.1 it is noticed, that the emission coefficients for the transport fuels are considerably larger than for the other fuels, and from table 5.2.2 that about 50 percent of the total NO_x emissions come from the use of transport fuels. About 40 percent come from the production of electricity and district heating, which leaves only about 10 percent to come from all other uses.

Looking at the individual coefficients in table 5.2.1, the coefficients for transport fuels used by the branches 'agriculture', 'construction' and 'sea transport' are very large. This is due to the large coefficients for ships and off-readers given in table 5.0.1. For 'sea transport' the coefficient for other liquid fuels is very large. This is due to fuel oil being used for transport purposes in this branch. For the branch 'other transport', that accounts for about 20 percent of the total emissions, it is noticed, that the coefficients for the sub-branches are very different. The low coefficients for transport fuels in the branches 'taxi' and 'air transport' mirror the use of small diesel cars and jet fuel for airplanes respectively. The relatively high coefficients for other liquid fuels for 'tourist busses' and 'taxi' is due to LPG being used for transport purposes, however the use of LPG is minor, and emissions from this is less than 10 percent of emissions coming from these sub-branches.

In general the emission coefficients in table 5.2.1 change with changes in the fuel composition and the technical use of the fuels. For the transport fuels emission coefficients will be reduced due to the introduction of catalysts on all new gasoline driven cars and improved standards for diesel driven vehicles. As an example table 5.2.3 show the emission coefficients for the transport fuels assuming that all gasoline cars were equipped with catalysts in 1991, and table 5.2.4 show the effect of this assumption on total NO_x emissions. The conclusions from these tables are, that the introduction of catalysts imply a reduction of total emissions with about 20 percent and, that about 80 percent of this reduction is ascribed to the reduced emission coefficient for the household consumption. Total NO_x emissions from households are reduced with about 80 percent. (Improved standards for diesel driven cars mainly reduce emissions form the branches.)

Uses		Transport emission coefficients in 1991 kgNO_x/TJ	Transport emission coefficients with catalyses
Household consumption	pc	795.8	90.5
Agriculture	a	1232.2	1194.9
Oil and gas extraction	e	760.6	90.5
Oil refineries	ng	726.2	117.8
Energy conversion	ne	829.7	535.2
of this: electricity prod.	b91	830.8	529.8
district heating	b93	853.6	627.0
Food processing.	nf	907.4	750.1
Man. of beverages etc.	nn	974.1	877.0
Construct. sub suppliers	nb	858.2	652.4
Iron and metal industry	nm	802.0	420.4
Man. of transp. equipm.	nt	833.2	545.7
Man. of chemicals	nk	838.0	534.8
Other manufacturing	nq	828.1	497.6
Construction	b	986.0	825.7
Trade	qh	900.7	663.5
Sea transport	qs	1362.1	1351.2
Other transport	qt	723.4	681.5
of this: rail	t11*	1033.0	1033.0
buses	t12*	1054.0	1049.1
ferries	t13*	1382.0	1382.0
tourist busses	t21*	1041.2	1006.3
taxi	t22*	396.1	211.7
road freight	t23*	1008.9	943.2
air transport	t3	209.9	194.7
mail etc.	t4	852.2	631.5
serv. rel. transp.	t5	824.7	503.4
Financial services	qf	715.8	126.0
Other private services	qq	906.3	654.2
Housing	h	-	-
Public services	o	514.5	427.8

Table 5.2.3. NO_x emission coefficients for transport fuels in 1991 if all gasoline driven cars were equipped with catalysts, (kgNO_x/TJ)

* Figures for 1990, disaggregated energy data for 1991 are not available at present.

	Total NO_x emissions in 1991 tNO_x	Transport fuel emissions in 1991 tNO_x	Total NO_x emissions with catalysts tNO_x	Transport fuel emissions with catalysts tNO_x
Total	323156	166370	270891	114105
Househ. consumption	49156	45435	8888	5167
Transport branches	64747	56131	61703	53087
Fuel conversion	129239	125	129195	80
Other branches	80014	64679	71105	55771

Table 5.2.4. Total NO_x emissions in 1991 and assuming catalysts on all gasoline driven cars

II.5.3 NO_x emissions from bio-fuels

As bio-fuels are not included in the energy balances of the Danish Statistical Office, emissions from bio-fuels are calculated separately and added to the emissions from the energy goods. (The environmental effect of acid rain and eutrophication is independent of the sources of the NO_x emissions). For 1992 the consumption of bio-fuels, NO_x emission coefficients and total emissions are shown in table 5.3.1 and the distribution among uses are given in table 5.3.2.

Bio-fuels	Energy consumption[1] PJ	NO_x emission coefficients[2] $kgNO_x/TJ$	NO_x emissions tNO_x
Fish oil	0.15	100	15
Waste	17.32	150	2598
Wood	10.19	130	1325
Wood waste	7.45	130	969
Straw	13.84	130	1799
Bio gas	1.54	150	231
Total	50.49	137	6937

Table 5.3.1. The consumption of bio-fuels, NO_x emission coefficients and total NO_x emissions for 1992

1) Source: Energy statistics 1992 from the Danish Energy Agency. Consumption of renewable energy.

2) Source: Inventory of emissions to the air from Danish sources. J.Fenhann and N.A.Kilde, Research Centre Risø, January 1994.

Bio-fuels	Power plants PJ	District heating PJ	Heating PJ	Industry PJ	Agriculture PJ	Other uses PJ	Total PJ
Fish oil		0.15					0.15
Waste		17.32					17.32
Wood		1.78	8.40				10.19
Wood waste		2.37		3.30	0.03	1.75	7.45
Straw	1.45	3.92	6.36		2.12		13.84
Bio gas			0.02	0.78		0.74	1.54
Total PJ	1.45	25.54	14.78	4.08	2.15	2.49	50.49
NO_x-emiss. tNO_x	189	3662	1922	546	279	339	6937

Table 5.3.2. Consumption of bio-fuels and NO_x emissions distributed on uses in 1992
Source: Energy statistics 1992 from the Danish Energy Agency.

As is seen from the tables, about 7 $ktNO_x$ is emitted from the use of bio-fuels, which is about 2 percent of emissions coming from the use of energy goods. That is, the use of bio-fuels contribute with a relatively minor part of total NO_x emissions.

II.5.4 Process related NO_x emissions

Beside energy related emissions, NO_x is emitted from raw materials used in the production of certain products, and in some productions fuels are combusted using a low-NO_x combustion technique. A complete list of NO_x emitting productions and the use of low-NO_x combustion techniques is not available. The sources mentioned in this section hopefully are the most important, however important sources may have been overlooked. In general process related emissions and the use of low NO_x combustion is evaluated to be of minor importance seen in relation to the energy related emissions.

II.5.4.1 The production of nitric acid

In the production of nitric acid, ammonia (NH_3) is combusted, and by this NO_x is emitted.

The production of nitric acid and the related NO_x emissions are given in table 5.4.1.

The production of nitric acid is part of the production within the branch 'chemical industry', and for forecasts emissions will be projected assuming a constant emission coefficient (tNO_x/mill 1980-Dkr) for this branch. As the production of nitric acid is only a minor and a varying part of the production within the chemical industry, this very rough method is used due to the lack of more specific information. If specific information on the development of the production of nitric acid is available, this should be used for the projections.

Year	Production of nitric acid ton[1]	NO_x emissions ton[1,2]	Production in the chemical industry mill. 1980-Dkr.	Emission coefficient tNO_x/mill 1980 Dkr.
1990	450000	806	26321	0.0306
1991	412000	752	26756	0.0281
1992	354000	564	28044	0.0201
1993	338000	548	27379	0.0200

Table 5.4.1 The production of nitric acid, related NO_x emissions end the production within the chemical industry

1. Source: KEMIRA DANMARK A/S.

2. The emission coefficient is equal to a loss of nitrogen (N) between 0.22 percent and 0.25 percent and an emission coefficient between 0.0016 and 0.0018 tNO_x/t nitric acid.

II.5.4.2. The production of cement and materials for insulation

The technique of low-NO_x combustion is used in the production of cement, and this reduces the emissions from the consumption of solid and liquid fuels with about 25 percent.

In the production of materials for insulation the consumption of solid fuel is combusted in a cupola-furnace burned with an oxygen deficit. This implies a reduction of the NO_x emissions with about 50 percent. In addition the natural gas used by the branch for the fibrillation of the stone material is combusted at a temperature of about 300^{0}C, which is evaluated to reduce emissions with about 50 percent.

Total NO_x emissions from the two productions and the reductions mentioned are given in table 5.4.2.

Year 1991.	Cement prod.	Insulation material	Reductions tNO_x			Construc. sub-suppl.	Reduction %
	tNO_x	tNO_x	Cement 25% of 1 and 2	Insulation 50% of 1 and 3	Total	tNO_x	$NO_x{}^{rk,t}{}_{nb,j}$
1 Solid fuel	1968	439	492	220	512	3071	16.7
2 Fluid fuel	275	41	69	0	69	804	8.6
3 Natural gas	16	76	0	38	38	346	11.0
Total[1]	3049	669	561	258	819	4720	17.4

Table 5.4.2 NO_x emissions from the production of cement and materials for insulation and reductions seen in relation to the emissions from the branch 'construction sub-suppliers

1: Includes emissions from the use of transport fuels.

Source: Calculated from the energy consumption in the branches 'Manuf. of cement, lime and plaster' and 'Non-metallic mineral products' and the emission coefficients in table 5.0.1.

II.5.5 A forecast model for NO_x emissions

II.5.5.1 NO_x emissions from energy goods

From forecasts of the energy consumption given by ADAM and the models described in part I, and the emission coefficients given in table 5.2.1, the energy related NO_x emissions are calculated as:

eq. 5.5.1.
$$NOx_j^t = \sum_g E_{g,j}^t \cdot N_{g,j}^t$$

where NOx_j^t is the energy related emissions from branch j
$E_{g,j}^t$ is the direct energy consumption of branch j and fuel g
and $N_{g,j}^t$ is the emission coefficient for branch j and fuel g

In general the emission coefficients $N_{g,j}^t$ vary with the fuel-mix within the aggregated fuels, the use of the individual fuels and technical changes. As a starting point for projections the fuel-mix within the aggregated fuels and the uses are assumed to be unchanged, that is the coefficients for solid-, other liquid fuels and natural gas are with one exception assumed to be constant. The exception is the coefficient for solid fuels used by power plants, which is projected such that the total NO_x emissions from the power plants equals their quota.

The emission coefficients for transport fuels are projected conditioned on the introduction of catalysts on all new gasoline drive cars and changed standards for diesel driven vehicles. That is, the fuel-mix within transport fuels (gasoline, diesel etc.) is assumed constant, and the distribution of the diesel consumption on different vehicles is assumed constant (shares given in table 5.0.3), however the emission coefficient for gasoline is projected according to the introduction of catalysts, and the emission coefficients for diesel driven vehicles (at the top of table 5.0.3) are changed due to changed standards for diesel driven vehicles.

II.5.5.2 NO_x emissions from bio-fuels

In the model the consumption of bio-fuels is assumed exogenous, and emissions are calculated at the aggregated level given in table 5.3.2, that is, the consumption is not distributed among the different uses. In line with equation 5.5.1 NO_x emissions from bio-fuels are calculated as:

eq. 5.5.2.
$$NOx_a^t = \sum_k E_{k,a}^t \cdot N_k$$

where NOx_a^t is the NO_x emissions from use a in table 5.3.2
E_a^t is the direct energy consumption of fuel k by use a
and N_k is the emission coefficient for fuel k

As bio-fuels are not included in the energy model, and considerable changes in the use of bio-fuels affect the use of energy goods, the energy model forecasts and the NO_x calculations have to be corrected for changes in the use of bio-fuels. Taking the 1992 consumption of bio-fuels as basis and assuming, that a change in the use of bio-fuels is accompanied by a corresponding change in the use of energy goods, the following corrections are introduced:

$$\textit{eq. } 5.5.3. \qquad NOx^{t}_{a\ korr} = \left(\sum_{k} E^{92}_{k,a} - \sum_{k} E^{t}_{k,a} \right) \cdot N^{t}_{g,j}$$

where $E^{92}_{k,a}$ is the consumption of bio-fuel k by use a in 1992
$E^{t}_{k,a}$ is the consumption of bio-fuels given in table 5.3.2
and $N^{t}_{g,j}$ is the NO_x emission coefficient for the energy goods that are substituted

Ideally $E^{92}_{k,a}$ should have been a forecast for the consumption of bio-fuels assuming a continuation of past trends, however lacking this the base year consumption is used.

The consumption of bio-fuels in 1992 and the emission coefficients for the energy goods that are substituted are given in table 5.5.1. For power plants and district heating the bio-fuels are assumed to substitute solid fuels. For the other uses bio-fuels are assumed to substitute liquid fuels.

Uses	Consumption of bio-fuel in 1992 $\Sigma E^{92}_{k,a}$ PJ	NO_x-coefficient for the substituted fuel $N^{t}_{g,j}$	NO_x coefficient for the substituted fuel $kgNO_x/TJ$
Power plants	1.45	$N1^{t}_{b91,solid}$	387.3
District heating	25.54	$N^{t}_{b93,solid}$	350.7
Heating	14.78	$N^{t}_{pc,fluid}$	52.3
Industry	4.08	$N^{t}_{nb,fluid}$	123.3
Agriculture	2.15	$N^{t}_{a,fluid}$	161.6
Other uses	2.49	$N^{t}_{total,fluid}$	157.9

Table 5.5.1. The consumption of bio-fuels in 1992 and the NO_x emission coefficients for the energy goods that are substituted

II.5.5.3 Process related NO_x emissions.

As mentioned in section II.5.4, NO_x is emitted from raw materials used within the production of nitric acid, and the technique of low-NO_x combustion is used within the production of cement and materials for insulation.

Emissions from the production of nitric acid is projected proportional to production of the chemical industry, and the reductions in the production of cement and materials of insulation is projected as the reduction percent calculated in table 5.4.2 multiplied by the relevant emissions from the construction sub-suppliers.

The equation for the process related emissions is:

$$eq.\ 5.5.4.\qquad NOx^{t}_{process} = FX^{t}_{nk} \cdot N^{process}_{nk}$$

$$- (NO^{t}_{x\ nb,solid} \cdot NO^{rk,t}_{x\ nb,solid} + NO^{t}_{x\ nb,fluid} \cdot NO^{rk,t}_{x\ nb,fluid} + NO^{t}_{x\ nb,gas} \cdot NO^{rk,t}_{x\ nb,gas})$$

where	FX^{t}_{nb}	is the production by 'construction sub suppliers' in mill 1980-Dkr.
	FX^{t}_{nk}	is the production by the chemical industry in mill 1980-Dkr.
	$N^{process}_{nk}$	is the emission coefficient per mill 1980-Dkr. given in table 5.4.1
	$NO^{t}_{x\ nb,solid}$	is the NO_x emissions from the use of solid fuels by branch "construction sub suppliers"
	$NO^{t}_{x\ nb,fluid}$	is the NO_x emissions from the use of liquid fuels by branch "construction sub suppliers"
	$NO^{t}_{x\ nb,gas}$	is the NO_x emissions from the use of natural gas by branch "construction sub suppliers"
	$NO^{rk,t}_{x\ nb,solid}$	is the reduction coefficient for solid fuels given in table 5.4.2
	$NO^{rk,t}_{x\ nb,fluid}$	is the reduction coefficient for liquid fuels given in table 5.4.2
and	$NO^{rk,t}_{x\ nb,gas}$	is the reduction coefficient for natural gas given in table 5.4.2

II.5.5.4 The total NO_x emissions

Adding the difference sources total NO_x emissions are given by:

$$eq.\ 5.5.5\qquad NOx^{t}_{total} = \sum_{j} NOx^{t}_{j} + \sum_{a} NOx^{t}_{a} + \sum_{a} NOx^{t}_{a\ korr} + NOx^{t}_{process}$$

where	NOx^{t}_{total}	is the total NO_x emissions
	NOx^{t}_{j}	is NO_x emissions from energy goods
	NOx^{t}_{a}	is emissions from bio-fuels
	$NOx^{t}_{a,cor}$	is corrections due to the use of bio-fuels
and	$NOx^{t}_{process}$	is process related emissions

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