

**AKF**

**Industrial Energy Demand and the  
Effect of Taxes, Agreements and Subsidies**

by

Thomas Bue Bjørner  
Henrik Holm Jensen

AKF Forlaget  
September 2000



# Preface

This report contains empirical analyses based on AKF's large micro panel database containing information on energy consumption and value added of industrial companies. The database has been constructed in association with Peter Sandager and Jan Foghmar, Statistics Denmark.

The project has been supported by the Danish Energy Research Programme. An advisory group with representatives from Risø, Statistics Denmark, the Federation of Danish Industries, the Danish Energy Agency, Ministry of Economic Affairs, and Elkraft System has followed the project. The authors are also grateful for valuable discussions and/or comments from Martin Browning, Mikael Togeby, Alan D. Woodland, Almas Heshmati, Lars Gårn Hansen, and Anders Holm at different stages of the research.

Thomas Bue Bjørner

September 2000



# Contents

<b>Summary</b> .....	7
<b>1 Introduction</b> .....	11
<b>2 Energy Tax, Agreements and Subsidies to Industrial Companies in Denmark</b> .....	14
2.1 Period from 1993 to 1995 .....	14
2.2 The Multi-level Tax Scheme Introduced in 1996 .....	16
2.3 The Agreement Scheme .....	18
2.4 Subsidies to Investments in Energy Efficiency .....	20
<b>3 Previous Econometric Studies about Industrial Energy Demand</b> .....	23
<b>4 Model</b> .....	28
<b>5 Description of the Database</b> .....	33
5.1 Construction of the Database .....	33
5.2 Number of Companies and Match Rate in the Database .....	37
5.3 Energy Agreements and Subsidies in the Database .....	40
5.4 Other Information .....	43
5.5 Summary .....	49
<b>6 Estimation Results in Models with Common Elasticities</b> .....	52
6.1 Cross-section Versus Fixed Effects Model .....	52
6.2 Functional Form .....	55
6.3 Estimating the Effect of the Energy Agreements .....	58

6.4	Effect of Agreements in a Sub-sample and with Alternative Time Effects .....	61
6.5	On the Effect of Subsidies in Alternative Specifications .....	64
<b>7</b>	<b>Model with Differences in Demand Parameters Between Sectors</b>	<b>68</b>
<b>8</b>	<b>On the Effect of Taxes, Subsidies and Agreements</b> .....	<b>75</b>
<b>9</b>	<b>Discussion and Some Issues for Future Research</b> .....	<b>88</b>
	<b>Appendix 5.1</b> .....	<b>92</b>
	<b>Appendix 6.1</b> .....	<b>93</b>
	<b>Appendix 7.1</b> .....	<b>95</b>
	<b>References</b> .....	<b>96</b>

# Summary

This report presents an econometric analysis of industrial companies' demand for energy. The effect of energy taxes, energy agreements and subsidies to investments in energy efficiency, which have been applied as policy instruments in Denmark since 1993, is also quantified.

The econometric analysis is based on an extensive database, which contains information on industrial companies' consumption of energy and their value added in a number of years covering the period 1983 to 1997 (information from the years 1983, 1985, 1988, 1990, 1993, 1995, 1996 and 1997 is included). The database has been constructed by combining information from different registers in Statistics Denmark. The database contains information on the majority of all existing industrial companies with more than 20 employees (from 1995 to 1997 primary data on energy consumption were only collected for half the industrial companies with 20-50 employees).

The database has a panel (longitudinal) nature, where each industrial company can be followed over time. This makes it possible to compare energy consumption in companies before and after they have been given a subsidy to invest in energy efficiency or entered an energy agreement with the Danish Energy Agency. The econometric analysis utilises the panel nature of the data by relying on so-called fixed effect estimators.

## **Impact of Prices and Taxes**

An energy-demand elasticity with respect to energy price at -0.44 for the whole industry is obtained. There are variations in the price elasticity between the different industrial companies, which relate to type of production (i.e. industrial sub-sector) and level of energy intensity. With respect to energy intensity it appears that the most energy-intensive industrial com-

pany responds less to changes in the energy price. The estimated price - elasticities for different industrial sub-sectors can be seen in table 1. They range from -0.21 to -0.69.

Table 1 Own price elasticities for energy demand

<b>Industrial sub-sector</b>	<b>Price elasticity</b>
Extraction of gravel, clay, stone, salt	-0.43
Food, beverages and tobacco	-0.45
Textiles, wearing and leather	-0.35
Wood and wood products	-0.39
Paper, printing and publishing	-0.35
Chemicals	-0.51
Rubber and plastic products	-0.52
(Other) Non-metallic mineral products	-0.21
Basic metals (manufac. and process.)	-0.51
Machinery and equipment	-0.48
Electrical and optical instruments	-0.69
Transport equipment	-0.56
Furniture and manufacturing n.e.c.	-0.56
<b>Total industry</b>	<b>-0.44</b>

Note: Mean price elasticities weighted with share of energy consumption.

The estimated price elasticities are within the same range as found in international studies, but they are higher (numerical) than previously found in Danish studies based on aggregated time series. The higher price elasticities therefore imply that the taxes on energy demand have larger effect on energy demand than previously assumed. Based on the estimated model it is found that the whole industrial sector's consumption of energy in 1997 would have been 10% higher if there had been no taxes on energy used in the industrial sector.

### **The Impact of Voluntary Agreement**

Since 1993 the most energy-intensive industrial companies have had the option of paying a reduced energy tax if they entered a (voluntary) energy agreement, which committed them to carry out certain activities in order to reduce energy consumption. From 1993 to 1995 these arrangements were officially described as energy »audits«, but from 1996 the term »agreements« was used (for short we just use the term »agreements« for both generations of these arrangements).

It is found that the energy agreements have had a significant impact on the energy consumption in the affected companies (after controlling for the effect of the reduced energy tax). The estimated reduction in energy consumption associated with an agreement is around 9%. This effect can be interpreted as relating to the activities carried out by the companies with agreements as their part of the bargain. It should be noted that only a relatively small share of the industrial companies in the database has had an agreement, and (perhaps therefore) the estimated effect of agreements is not determined as precisely as the effect of energy prices and taxes. In addition, some bottom-up evaluations suggest that the effect of agreements is smaller. However, overall it appears that the agreements have had the intended effect on energy consumption in the industrial companies.

The estimated effects of agreements at 9% can be labelled as a »gross« effect, which relates to the effect of the activities the companies commit to (energy audit and energy management etc). The gross effect can be compared with the reduction in energy demand, if the companies had not entered (or been offered) the agreement, but instead paid the full tax on energy. Calculations on the estimated model suggest that the companies with an agreement would have reduced their energy demand by only 1% in 1997 if they had paid the full tax instead of obtaining the tax reduction. Altogether this suggests that companies with an agreement would have used more energy if they had not been offered the agreement, but just had paid the full tax. Thus, it appears that the agreements have been successful in reducing energy consumption in the most energy-intensive companies.

The finding that companies with an agreement use less energy than without an agreement (and full energy tax) is in accordance with findings in the theoretical literature on voluntary agreements in situations, where the »voluntary« agreement is backed by a credible threat of alternative regulation.

### **Investment Subsidies for Improved Energy Efficiency**

The empirical analysis also suggests that the subsidies given to improve energy efficiency in industrial companies have had relatively little impact on energy consumption in the affected companies. I.e. the estimated effect of the subsidies is small and the parameter is not significantly different from zero. Based on the estimated effect it is calculated that one DKK paid in

subsidy had led to a 0.22 kg reduction in CO<sub>2</sub>. This is lower than found in a recent evaluation, which obtained a reduction at 0.51 kg CO<sub>2</sub> per DKK payed in subsidy. Thus, the study suggests that the effect of subsidies is lower than previously found, but it should be emphasised that the effect of subsidies is not very precisely determined and the result should be interpreted with care.

If it is assumed that the projects associated with the subsidies have an effect on energy use and CO<sub>2</sub> lasting eight years, and if future reductions in CO<sub>2</sub> are discounted at a 6% rate the amount of subsidies paid to obtain a one ton reduction in CO<sub>2</sub> (including the discounted future CO<sub>2</sub> effects) is 701 DKK.

There may be different interpretations of the (apparently) lower effect of the subsidies. One potential explanation is that the subsidies have not been successful in inducing additional investments in energy efficiency, but have rather been given to projects that would have been carried out anyway (free riding).

It should be noted that industrial companies with local production of electricity and district heating (industrial CHP) have not been included in the empirical analysis described above. Subsidies given to support and/or improve the efficiency of local production of district heating or electricity in industrial companies are therefore not covered by the above conclusions (agreements in such industrial companies are not included either).

# 1 Introduction

Since 1993 a complex mix of instruments like energy agreements, energy taxes and investment subsidies has been used in order to reduce energy consumption in the Danish industrial sector. The energy agreements have only been offered to the most energy-intensive companies in the industrial sector. These companies have been given the option to pay a reduced CO<sub>2</sub> tax if they enter an agreement that commits them to carry out certain actions to increase energy efficiency.

This report presents an econometric analysis, aiming at quantifying the effect on energy consumption of the energy agreements and the other more traditional instruments (taxes and subsidies). The empirical analysis is based on an extensive micro panel database, which contains information about »individual« industrial companies' production and consumption of energy in the period from 1983 to 1997. The majority of all Danish industrial companies (with more than 20 employees) is included in this database.

The Danish energy agreements belong to a type of arrangement which has been described as »voluntary agreements«. Such agreements have achieved increasing attention worldwide from policymakers and academics, and the use of different types of voluntary agreements has repeatedly been put forward as an appealing alternative to more traditional types of regulation like Pigouvian taxation or command and control as a way to improve environmental performance. However, the voluntary approaches have also been looked upon with scepticism. Thus, it has been argued that voluntary approaches are merely »cheap talk«, which polluting companies have used as a way to avoid or postpone harder (and presumably more effective) types of regulation.

A number of theoretical contributions in environmental economics have recently emerged on the topic of voluntary approaches. They have dealt with

issues like the motives of the private firms to participate in such agreements, characteristics and classification of different types of voluntary approaches, and finally a discussion of the pros and cons – and ultimately the efficiency – of voluntary agreements as compared with other instruments. This includes a comparison of the effect on environmental quality and general welfare from the use of different instruments (subject to different regulation constraints and assumptions on the functioning of the economy). Examples are contributions like Stranlund (1995), Carraro and Siniscalco (1996), Segerson and Miceli (1998), and Segerson and Li (1998). A recent and comprehensive survey of this literature can be found in Krarup (1999).

In contrast to the increasing number of theoretical contributions, only few econometric analyses have apparently been carried out on the effects of voluntary agreements. One exception is the study of Arora and Cason (1995), who look at American companies' participation in a programme for reductions in the release of toxic chemicals, i.e. the American Environmental Protection Agency's (EPA) so-called »33/50 Program«. Also, a number of case studies or ad-hoc evaluations have been performed on voluntary approaches both in Denmark and in other countries.

Voluntary agreements cover a large variety of different arrangements. For some types of these agreements it is difficult to carry out quantitative evaluations of the effects. In Holland, Germany and France agreements on energy efficiency are made for all industrial companies within a certain industrial sub-sector (e.g. dairy or cement industry). In these situations, where all companies with the same production technology collectively enter the same agreement, it is difficult to separate the effect of the agreement on energy efficiency from general technological changes, because changes in technology may take place at different speeds in different industrial sectors. Thus, with these types of agreements no natural control group is available.

The primary focus of the study is on the *effect* of the different instruments leaving the (important) issue of efficiency aside. However, an empirical verification of effects of voluntary agreements seems to be a necessary prerequisite for statements on the efficiency of voluntary approaches. With a (large) micro panel two control dimensions become available. First, it is possible to compare the energy intensity of companies before and after they have signed an agreement. Second, it is possible to compare the energy efficiency of companies with agreements/subsidies with companies not

affected by these instruments. With panel data it also becomes possible to control for certain kinds of unobserved heterogeneity between the different industrial companies.

With respect to the effect of the agreements and the subsidies it should be noted that only companies in the industrial sector according to the definition used by Statistics Denmark are included in the analysis (this follows from the available primary data). As a result the effect of the agreements made for e.g. greenhouses is not included in the analysis. Furthermore, in the analysis presented here it has been chosen to exclude all industrial companies with local production of electricity and/or district heating (industrial CHP). Some of the investment subsidies have been given in order to make industrial companies build local power and/or heat plants. The effect of subsidies given for that purpose is not included in the analysis. Only relatively few companies have obtained such subsidies, but the granted amounts are considerably larger than the average subsidy, so that type of subsidies accounts for a large share of the total subsidies in the period in question.

In the following section a (background) description of the Danish voluntary energy agreements and other policies towards industrial energy consumption is presented. Section 3 contains a short survey of previous empirical models on industrial energy demand. Sections 4 and 5 describe the applied model and the data. Estimation results are presented in sections 6 and 7. In section 8 different simulations on the estimated model are carried out in order to illustrate the effect of the taxes on energy, the energy agreements and the subsidies given to increase investment in energy efficiency. This section also contains some broader discussions of the different instruments and relates the empirical findings to some of the theoretical discussions in the literature on voluntary agreements. In section 9 some issues for further research that may be carried out using the micro database are discussed.

## 2 **Energy Tax, Agreements and Subsidies to Industrial Companies in Denmark**

This section contains a description of the policy instruments that have been adopted in order to reduce the consumption of energy from the Danish industrial sector. The purpose of the section is to provide background information for the following sections, which are devoted to a quantitative assessment of the effect of the different instruments. More extensive descriptions of the design and development of these instruments can be found in various official publications, e.g. Ministry of Finance (1994 and 1995), Ministry of Finance et al. (1999) and Ministry of Taxation (1998). A description of previous efforts to evaluate the Danish energy agreements can be found in Johannsen and Tøgeby (1999).

### 2.1 **Period from 1993 to 1995**

Before 1993, Danish companies in the private trade (service) and industry sectors did not pay any tax on energy consumption (a general energy tax was in effect, but companies in these sectors could get the energy tax refunded). In 1993, a general CO<sub>2</sub> tax was introduced in Denmark. The effective tax on trade and industry was 50 DKK per ton CO<sub>2</sub> for most companies (while households paid 100 DKK per ton CO<sub>2</sub>). This tax was in effect in 1993, 1994 and 1995. The CO<sub>2</sub> tax varied between different types of fuels according to the associated CO<sub>2</sub> emissions (see table 2.1).

Table CO<sub>2</sub> tax on different types of fuels from 1993-95

2.1 (According to an effective CO<sub>2</sub> tax at 50 DKK per ton CO<sub>2</sub>)

	DKK/GJ	CO <sub>2</sub> tax as % of 1995 price
Gas oil	3.76	9
Fuel oil	3.96	23
Coal	4.80	34
LPG	3.26	3
Natural gas	0.00	0
Electricity	13.89	16
District heating	0.00	0

Note: CO<sub>2</sub> tax as % of 1995 price is based on the list price for typical use. The actual price may vary between companies. Energy input to produce district heating is taxed (i.e. district heating is taxed indirectly, while no CO<sub>2</sub> tax was paid on natural gas in this period).

However, the energy-intensive companies were offered a lower effective tax (motivated by considerations for their international competitiveness and their high tax burden). The effective tax was lowered according to a measure of the energy intensity of the company. For companies where the tax at 50 DKK per ton CO<sub>2</sub> would account for more than 1% of value added the marginal tax was to be reduced.<sup>1</sup> The marginal effective CO<sub>2</sub> tax rates at different levels of energy intensity appear in table 2.2.

Table Marginal CO<sub>2</sub> tax per ton CO<sub>2</sub> from 1993 to 1995 (effective tax after refund)

2.2

CO <sub>2</sub> tax/value added	Less than 1%	1 to 2%	2 to 3%	Above 3%
DKK per ton CO <sub>2</sub>	50	25	12.5	5

Note: The marginal CO<sub>2</sub> tax for different types of fuels can be calculated by combining table 2.1 and 2.2.

A special arrangement was set up for the most energy-intensive companies (i.e. CO<sub>2</sub> tax/value added above 3%) to give them an additional opportunity to reduce the CO<sub>2</sub> tax burden. These companies could enter a (voluntary) energy agreement with the Danish Energy Agency (DEA) instead of paying the CO<sub>2</sub> tax.<sup>2</sup> In addition to the CO<sub>2</sub> tax and energy agreements as policy instruments, the industrial companies could also apply for subsidies to investments that could increase energy efficiency (see later).

## 2.2 The Multi-level Tax Scheme Introduced in 1996

In 1995, the Danish Parliament adopted a package of new measures in order to conform to the environmental targets concerning reduction of CO<sub>2</sub> and SO<sub>2</sub> emissions. Between 1996 and 2000 the CO<sub>2</sub> tax was to increase considerably. A new SO<sub>2</sub> tax was also introduced.

The level of taxation of energy in the industrial sector became dependent on the purpose of the energy consumption. Three types of energy use are defined: space heating, light processes and heavy processes. Heavy processes comprise several energy-intensive processes (e.g. melting, concentration and drying in relation to production of cement, mineral wool, condensed milk etc.). In 1996, the heavy processes accounted for 61% of the total energy consumption in industry, while the remainder is divided between light processes (27%) and space heating (12%). The total tax levels on different types of energy use in industry appear in table 2.3. The table shows the level of tax on energy from 1996 to 2000, where the taxes are fully phased in.

Processes (and especially the heavy processes) are taxed considerably lower than space heating (space heating is taxed in the same way as private households).

The arrangement with voluntary energy agreements introduced in the period 1993-1995 was continued from 1996, but in a modified form. Now two types of agreements could be carried out, one for companies with heavy processes and one for companies with light processes (described later). The reduced taxes subject to energy agreements can also be seen in table 2.3. In 1996 there is only a tax discount for companies with heavy processes (but a small discount for companies with a light process agreement was introduced in 1997).

Table 2.3 Taxes (DKK/GJ) on energy on different types of fuels (effective energy, CO<sub>2</sub> and SO<sub>2</sub> tax for industrial companies)

		1996	1997	1998	1999	2000
<b>Coal</b>	Space heating	22.53	36.25	56.57	60.39	62.30
	Light process	8.06	8.98	9.91	10.83	11.76
	– with agreement	8.06	8.06	8.06	8.80	9.72
	Heavy process	3.90	4.36	4.83	5.29	5.75
	– with agreement	3.72	3.72	3.72	3.72	3.72
<b>Gas oil</b>	Space heating	22.00	40.79	59.08	59.56	59.98
	Light process	3.99	4.74	5.49	6.25	7.00
	– with agreement	3.99	3.99	3.99	4.59	5.34
	Heavy process	0.61	0.98	1.36	1.73	2.11
	– with agreement	0.46	0.46	0.46	0.46	0.46
<b>Fuel oil</b>	Space heating	22.20	36.40	53.66	56.72	56.72
	Light process	6.11	6.89	7.67	8.46	9.24
	– with agreement	6.11	6.11	6.11	6.74	7.52
	Heavy process	2.59	2.98	3.37	3.76	4.16
	– with agreement	2.43	2.43	2.43	2.43	2.43
<b>LPG</b>	Space heating	19.56	34.78	58.37	58.37	58.80
	Light process	3.26	3.91	4.56	5.22	5.87
	– with agreement	3.26	3.26	3.26	3.78	4.43
	Heavy process	0.33	0.65	0.98	1.30	1.63
	– with agreement	0.20	0.20	0.20	0.20	0.20
<b>Natural gas</b>	Space heating	5.81	36.62	36.62	42.68	43.44
	Light process	2.78	3.34	3.89	4.45	5.00
	– with agreement	2.78	2.78	2.78	3.22	3.78
	Heavy process	0.28	0.56	0.83	1.11	1.39
	– with agreement	0.17	0.17	0.17	0.17	0.17
<b>Electricity</b>	Space heating	60.28	102.50	159.72	165.00	169.17
	Light process	16.39	19.17	21.94	25.83	28.61
	– with agreement	16.39	16.39	16.39	19.72	22.50
	Heavy process	3.89	5.28	6.67	9.17	10.56
	– with agreement	3.33	3.33	3.33	4.44	4.44
<b>District heating</b>	Space heating	7.79	11.92	16.61	16.61	16.61
	Light process	2.54	2.97	3.41	3.84	4.28
	– with agreement	2.54	2.54	2.54	2.88	3.32
	Heavy process	0.58	0.80	1.01	1.23	1.45
	– with agreement	0.49	0.49	0.49	0.49	0.49

Source: The Ministry of Economic Affairs, 1999 («Erhvervsmodellen») and own calculations.

Note: The »tax« on district heating has an indirect nature (i.e. reflects the tax on the primary fuels in the production of district heating). The indirect »tax« on district heating is based on average primary fuels. In reality the indirect tax will vary between different suppliers.

The revenue from the trade and industry sector of the taxes on energy was to be recycled back to the companies. This was mainly carried out by lowering the non-wage labour costs, but also through subsidies to invest-

ment in projects improving energy efficiency.

## 2.3 The Agreement Scheme

In the Danish (voluntary) energy agreements a number of companies have the choice between paying the »usual« tax or paying a reduced tax if they commit to carrying out activities in order to increase energy efficiency.<sup>3</sup> These agreements may be included in the (fairly broad) concept of voluntary agreements, which achieve increasing attention worldwide from policy-makers and academics. However, the Danish energy agreement scheme is probably characterised better as a »menu voluntary agreement« following Chidiak (1999). This label emphasises that the agreement it is not really a voluntary action initiated by industries, but rather an offer made to individual companies to choose (voluntarily) between two different types of regulation.

The choice to sign an agreement has only been offered to energy-intensive companies. The agreement is made between the Danish Energy Agency (representing the government) and the individual company. These agreements run for three years.<sup>4</sup>

An agreement specifies several activities which the individual company must undertake to qualify for the reduced tax rate. The company's commitments must be enumerated in an individual action programme. The basis for the action programme is energy audit reports made by energy consultants. The audit report identifies energy-saving projects, and subject to specific criteria certain of these energy-saving projects must be carried out in order for the company to get the tax discount. If no saving projects meeting these criteria can be identified at the energy audit, the company is considered energy efficient and as a consequence may obtain the tax discount without carrying out further investments in energy efficiency. However, all companies with energy agreements commit to improve energy management activities (e.g. energy accounting systems etc.).

The definition of energy intensiveness – i.e. the criteria for entering an agreement – has not been the same in the period from 1993 to 1995 and the period starting in 1996. From 1993 to 1995 all companies where the ratio of the CO<sub>2</sub> tax (at 50 DKK per ton CO<sub>2</sub>) over value added exceeded 3%

could enter an agreement.<sup>5 + 6</sup>

From 1996 all companies with heavy processes according to the detailed description of processes in a »process list« always had the right to enter an agreement. In total, about 35 processes have been defined as heavy processes. Companies that only use energy for light processes are defined as energy intensive if the calculated tax of the energy consumption exceeds 3% of value added.<sup>7</sup> Furthermore, the calculated tax should exceed a minimum of 10,000 DKK (raising to 20,000 DKK in the year 2000).

The benefit of the tax discount was reduced in 1996, so that the gross benefit of entering an agreement was reduced from 1995 to 1996. Also the obligations of the companies entering agreements were tightened in various ways from 1996. Consequently, the number of companies entering into an agreement in 1996 was low compared with the number of agreements being in effect in 1995 (see section 5 for a quantitative description of the number of agreements in industry). However, as it can be seen in table 2.3 the tax discount for companies with agreements increases gradually, so that the gross benefit for companies of entering an agreement also increases.

The criteria for whether a project identified in the energy audit should be carried out have been changed so that more projects now must be carried out for companies with an agreement. From 1993 to 1995 only certain types of projects with a payback period of two years had to be carried out. From 1996 all projects with a payback period of four and six years (for heavy and light agreements respectively) were to be carried out (the energy cost at tax levels without agreement should be used in the calculation of the payback period). From 1997 all energy audit reports were to be verified by a second energy consultant (the company pays for the verification as well as the energy audit<sup>8</sup>). It has also been put forward that the energy consultants carrying out energy audits from 1993 to 1995 mainly focussed on standard solutions and service equipment, because documentation requirements were more strict for this part of the audit. After 1996 it has been specified that energy audits should comprise all energy consumption (minimum 90%) in the companies, and emphasis is put on heavy processes, which account for the main part of energy consumption in the companies. Also, the monitoring and sanctioning efforts were increased in 1996/1997 as compared with the first period (see e.g. Johannsen and Larsen (2000), Johannsen and Togeby (1999) or Krarup and Larsen (1998)). Thus, it appears that the require-

ments/commitments of companies entering an agreement have increased from the period 1993-1995 to the period in the last part of the 1990s.

Finally, it should be noted that modifications in the agreements have continued outside the »range« of the database used in this study. Starting from 2000 companies with agreements no longer need to obtain an external energy audit, but instead the energy management within the companies has received increased attention, see Danish Energy Agency (2000a).

## 2.4 **Subsidies to Investments in Energy Efficiency**

From 1993, individual companies have been able to apply for support for carrying out investments in energy-saving projects. Projects may be supported with up to 30% of investment costs. Projects may be individually designed by the companies, but a number of standard energy-saving solutions have been identified (partly in order to reduce the administrative cost for smaller companies).<sup>9</sup> It is the intention only to support projects that would not have been carried out without a subsidy. In practice this means that only projects with a payback period exceeding two years (including the subsidy) are supported.

As part of the package passed by the Danish Parliament in 1995 1.8 billion DKK was earmarked for these investment subsidies in the period 1996 to 1999 (also to companies outside the industrial sector). The subsidies were (together with a reduction in non-wage labour cost) one way to recycle green tax revenue back to the private companies. It has been agreed to continue with subsidies to industrial companies and from the year 2000 a yearly amount of 175 million DKK has been earmarked to subsidies only in the industrial sector.

The subsidies paid to companies in the industrial sector in the period 1993 to 1998 can be seen in table 2.4.

Table 2.4 Subsidies (million DKK) paid to industrial companies

1993	1994	1995	1996	1997	1998
62.6	26.3	18.3	91.6	155.0	184.3

Source: DEA and own calculations.

Note: The table does not include subsidies given to companies in the trade and service sector.

## Notes

1. The actual measure used was the so-called »Proms-criteria«, which in many respects is similar to value added.
2. Though, companies that entered an agreement had to pay a (small) fixed amount (10,000 DKK).
3. This section also builds on Johannsen and Larsen (2000).
4. However, a) some agreements signed in 1994 and 1995 did not run for three years, because of the new rules introduced in 1996, b) group agreements were available for companies in an industrial sub-sector with similar production processes (e.g. greenhouses). For these group agreements the identification of energy efficiency projects is a bit different than for the »individual« agreements, but each company in the group agreements has to sign the agreement and is committed to an action programme in order to improve energy efficiency.
5. Companies that entered an energy agreement also had to pay a small fixed amount (10,000 DKK). However, the cost of an energy audit is normally considerably higher than this cost.
6. It is a widely held view that the majority of the companies that could enter an »agreement« in 1993 to 1995 choose to do so and thus totally avoided the CO<sub>2</sub> tax. We have tried to investigate if this view also corresponds with the information in our panel database. However, it appears difficult to confirm because we only have value added in the database, which is a bit different from the Proms. Furthermore, information about value added is not available for the individual production sites within an industrial firm (see also section 5 for a more detailed description of data).
7. In the calculation the value of the tax of space heating should be calculated using the (considerably lower) rate for light processes.

8. However, from 1997 the companies have been able to apply for a reimbursement of up to 50% of the expenditures for the audit and the verification as part of the subsidy scheme (see section 2.4).
9. Other activities (energy audits, demonstration projects etc.) may also be supported through this programme, but they only account for a few per cent of total subsidies given.

### 3 Previous Econometric Studies about Industrial Energy Demand

A very large number of studies on energy demand of the production sector have been published. A discussion of methodological aspects of (aggregate) energy models can be found in e.g. Griffin (1993) and Atkinson and Manning (1995). The latter also summarises the results of a number of studies published in the period from the mid-1970s to the early 1990s. All of the studies in the survey seem to rely on aggregate data.

Most of the previous studies belong to the following two categories. One category focusses on the demand for various types of energy, which yields information about substitution possibilities between say electricity and coal. Early examples are Griffin (1977), Halvorsen (1977) and Pindyck (1979). The other category focusses on substitution between energy (as an aggregate) and other factors like labour, capital and materials. For this category early examples include Griffin and Gregory (1976) and Berndt and Wood (1975). Both categories of models are typically estimated by a system of factor demand equations derived from cost minimisation firms (or of an average firm) using one of the so-called flexible functional forms that can be regarded as second order approximations to an unknown cost function. The translog form appears to be the most favoured among the family of flexible functional forms.

Table 3.1 summarises the own price energy-demand elasticities of relevant studies in the survey of Atkinson and Manning. It appears that a price elasticity around -0.5 is »typical« in all the studies. It also seems that time series studies have resulted in lower price elasticities as compared with studies based on aggregated cross-section data (included pooled time series) from different countries/regions. This supports the often stated view that time series studies produce short-run or medium-run elasticities, while the cross-section studies yield elasticities with a long-run nature.<sup>1</sup>

Table 3.1 Energy price elasticities from international studies

Type of study	All studies	Time series studies	(Pooled) cross-section studies
Median	-0.47	-0.38	-0.84
Mean	-0.66	-0.44	-1.06
Minimum	-0.06	-0.06	-0.27
Maximum	-2.05	-1.06	-2.05
Number of studies	25	16	9

Note: Calculated from studies surveyed in Atkinson and Manning (1995), including studies published between 1975-1993. In the table we have excluded studies from the survey that focus primarily on the private sectors energy demand (e.g. the residential sector). When both a »short-run« and a »long-run« elasticity are reported, we have only included the long-run elasticity. Finally, sometimes the survey of Atkinson and Manning (1995) reports a range for the elasticity (or two elasticities) of a single study. In these cases we have used the simple average, so that each study in the survey is only represented by a single elasticity.

With respect to individual fuels Atkinson and Manning conclude that the elasticity of electricity is lower than the elasticities of coal, oil and gas. With respect to other types of factors in the production function they note that labour and materials in general are substitutes for energy, while there is conflicting evidence regarding the substitutability/complementarity between energy and capital (which has also been pointed out by several others, see e.g. Solow (1987) and Apostolakis (1990).

Demand studies based on aggregate time series have also been carried out in Denmark. For instance Andersen et al. (1998) obtain a price elasticity at -0.26 for the manufacturing sectors' energy demand. The aggregate elasticity for various industrial sub-sectors ranges between -0.10 and -0.35 (the latter is reported in Statistics Denmark, 1997). Thomsen (1995) obtains a price elasticity at -0.14. Both results are obtained by estimation of a system of factor demand equations using the generalised Leontief functional form. Bentzen and Engsted (1993) also use Danish time series data, but rely on information on the aggregate Danish primary energy consumption (also including energy used for consumption). They use a single equation VAR-model and obtain a long-run price elasticity at -0.47.

Compared with the large number of studies based on aggregate data we are aware of only a few econometric studies of industrial companies' energy

demand that use information at the micro level, and most of these rely on cross-section data.

Woodland (1993) uses repeated cross-section data for about 10,000 companies in the years 1977-85 from the Australian state of New South Wales. He uses a translog system with coal, gas, electricity, oil, labour and capital included as production factors. Woodland observes that only a minor share of the companies have an energy »pattern« (i.e. combination of different types of energy), where they use all four types of energy.<sup>2</sup> Woodland estimates separate translog functions for each observed energy pattern assuming that these patterns are exogenous due to technological constraints. Own-price elasticities from his study in general result in an elastic energy demand, e.g. the price elasticity for electricity is between -1.2 and -1.5 for different industrial sub-sectors, while the own-price elasticities of oil and gas range between -1.2 and -2.5. The own price elasticity of coal is a bit lower ranging from -0.8 and -1.1 in different industrial sub-sectors.

Kleijweg et al. (1989) look at a panel of Dutch firms from 1978-86 also using the translog functional form focussing on aggregate energy demand. The long-run price elasticity of energy for the whole manufacturing sector in their study is -0.56, while the long-run output elasticity is 0.61. Kleijweg et al. subsequently analyse subsets of data divided by firm size, energy intensity and investment level. They find that the own price elasticity of energy increases with firm size, and – to a lesser extent – that the price elasticity decreases with energy intensity and increases with the level of investments. However, these findings are derived from separate estimations and therefore do not take into account correlation between firm size, level of investment and energy intensity.

Doms and Dunne (1993) estimate demand for energy and electricity using cross-section data. They find a negative cross-price elasticity between energy consumption and the wage rate implying that energy and labour are complementary inputs (Woodland obtained the opposite result). Doms and Dunne do not estimate own price elasticities of energy, but they argue that the effect of energy prices is controlled for by regional dummy variables. Doms and Dunne also find that plants that use advanced technologies are less energy intensive and that they rely relatively more on secondary forms of energy like electricity, while old plants are more energy intensive and rely more on primary energy forms like fossil fuels.

In an important article Lee and Pitt (1987) provide a general theoretical analysis of the estimation of demand (including factor demand) relationships, when there are binding non-negativity constraint, which results in »corner« solutions where one or several types of input are not used in the production process. The focus of their article is the presentation of the general theoretical analysis, but as an application they apply a translog cost function to estimate the demand for three energy inputs from a cross section of Indonesian firms in the Weaving and spinning sector and in the Metal product sector (including respectively 362 and 379 companies). They analyse substitution between the three fuels and therefore (»only«) obtain partial own- and cross-price elasticities. Lee and Pitt conclude that their partial own-price elasticities are slightly higher than typically found aggregate studies of the same nature.

More recently, Bousquet and Ivaldi (1998) apply the methodology from Lee and Pitt (1987) to estimate substitution between different fuels in the French dairy industry using a cross section of 244 dairy firms.<sup>3</sup>

Finally, Bjørner, Togeby and Jensen (2000) have carried out a study based on the same database as used here, but with focus on industrial companies' demand for electricity instead of total energy. This study investigated how various company characteristics like size, type of production and electricity intensity influenced demand parameters.

In the study presented in this report the focus is on the demand for total energy in the individual companies. The model is described in the following section, but in short we rely on a simple single equation factor demand model. This model is more restricted than in most of the other micro-economic studies described above, but it has the advantage that it is easy to include information about (voluntary) energy agreements and investment subsidies and estimate parameters, which relate to the effect of these instruments. Inclusion of a description about use of labour and capital as well as different types of energy, which even takes into account corner solutions, is rather involved and raises a number of methodological issues outside the scope of this study.

## Notes

1. Some arguments against this view can be found in Atkinson and Manning (1995).
2. Thus, only few companies choose to use all the different available types of energy even though all different types (presumably) are available to them. As discussed by Woodland (1993) this suggests that there are »corner« solutions to the cost minimizing problem, which can either be attributed exogenous technological constraints (e.g. if certain types of energy are not available to all companies due to technological supply constraints or if a certain type of production process can only be produced with one type of fuel input) or can be derived from the cost minimizing of the companies (e.g. if a production process can be carried out by combinations of different types of fuels, but where the company finds that one type of fuel is simply cheaper to use for the process). Estimation of the joint choice of fuel pattern and the choice of how much to use of the different types of fuel in the chosen pattern is rather involved (i.e. a joint model for continuous choices and multiple discrete choices as described in Lee and Pitt (1987)). Woodland therefore estimates his demand systems subject to the assumption that the energy patterns are exogenously given, which leaves »only« the continuous choices to be estimated.
3. Bousquet and Ivaldy (1998) also devote methodological attention to a problem of missing data in their information set.

## 4 Model

This section contains a short description of the model framework used to estimate industrial companies' consumption of total energy and the effect of (voluntary) energy agreements and subsidies. The panel data set is presented in the following sections. By *total energy* we refer to companies' consumption of eight major types of energy:

- Coal
- Fuel oil
- Heating oil
- LPG (Liquid Pressurised Gas)
- Natural gas
- City gas
- Electricity
- District heating.

Together these account for most of the energy used for processes and heating in the industrial sector. A few minor types of energy like straw, biogas, wood and wood waste have not been included in the analysis.<sup>1</sup> Furthermore, we have excluded transport fuels, because the nature of demand for these types of fuel is different than for energy used more directly in the production process.

Energy can be regarded as input in production in the same way as labour, capital etc. Assuming that all companies treat the price of energy and other factors as exogenous and that each company minimises the production cost, the demand for energy can be expressed as a function of factor price and level of production. As a starting point we choose the following functional form as »baseline model« to estimate firms' demand for energy.

$$LE8_{it} = \hat{\alpha}_i + \hat{\alpha}_1 LFVA_{it} + \hat{\alpha}_2 LPE8_{it} + \hat{\alpha}_3 DCO2AG_{it} + \hat{\alpha}_4 SUBVA + \ddot{\epsilon}_t + v_{it}$$

$$v_{it} \sim \text{i.i.d } N(0, \sigma_v^2 I) \quad (4.1)$$

where  $LFVA_{it} = \text{Log}(VA_{it}/PVA_{Bt})$   
 $LPE8_{it} = \text{Log}(PE8_{it}/PVA_{Bt})$

and  $t = \text{time } (83, 85, 88, 90, 93, 95, 96, 97)$   
 $i = \text{industrial company } (1..3762)$   
 $B = 1..56 \text{ industrial sub-sector from the Danish National Accounts}$

The aggregate of energy consumption (measured in log of the sum of the energy content of the different types of energy) is given as a function of value added in fixed prices (LFVA), which is calculated as value added in yearly prices (VA) and a price deflator for value added (PVA), and the relative prices of input which are measured as price of energy (PE8) and the price deflator for value added (cost of labour and capital). The price of energy is an average price calculated as total cost of energy (including taxes) divided by total energy content (in Joule). This implies that the »price« of energy varies between companies in a given year, because this price is dependent on the composition of companies' energy consumption (because the price of say one Joule of coal is different from one Joule of natural gas etc.).<sup>2</sup>

Subscript *it* denotes company *i* at time *t*. Company-specific deflators for PVA do not exist, so we have to rely on more aggregate deflators. Subscript *B* denotes one of 56 different industrial branches that were the most disaggregated levels for which we could obtain deflators.

The variable DCO2AG is a dummy variable denoting if the company has signed an energy agreement. The variables take the value 1 both in years when a company has an agreement and also in the years after the agreement is terminated, even though the company has not signed a new agreement. This reflects that the activities the company commits to (investments in energy reduction and energy management) can be expected to have an effect on energy consumption, which lasts longer than the agreement period (this expectation will be investigated more formally in section 6).

The variable SUBVA denotes the subsidies to investments in energy

efficiency given to the company as the per cent of value added of the company. The subsidies in year  $t$  are measured as the accumulated subsidies paid to the companies from 1993 to year  $t$ . This also reflects that the effect of investments in energy efficiency can be expected to last longer than just one year.<sup>3</sup>

The parameter  $\hat{\alpha}_1$  denotes the elasticity of energy demand with respect to value added. The elasticity of energy demand with respect to price corresponds to  $\hat{\alpha}_2$ , which will also capture the effect of taxes on energy. The parameter  $\hat{\alpha}_3$  will denote the per cent reduction in energy consumption associated with the presence of an energy agreement (derived from the energy audit or the commitment to energy management). Finally,  $\hat{\alpha}_4$  denotes the per cent reduction in energy consumption from a subsidy corresponding to one per cent of value added in the company.

The parameter  $\hat{\alpha}_i$  denotes an individual intercept (or fixed effect). The fixed effect will capture all unobserved time invariant company specific variables that have an influence on energy demand, e.g. like management ability (or attention devoted) to minimise the energy cost. It could also be the level of energy consumption that is embedded in the capital (production equipment). Thus, the inclusion of the individual constant term controls for (time invariant) unobserved heterogeneity of the companies. The parameters  $\ddot{\epsilon}_t$  denote time dummies that are included to capture the effect of changes in unobserved variables that influence the companies equally, e.g. temperature and exogenous technological change.

In the baseline model it is assumed that all the  $\ddot{\epsilon}_t$  and the  $\hat{\alpha}$  parameters are equal among companies. It is, however, quite likely that different types of companies respond differently to changes in say electricity prices or changes in production. After having estimated our simple model we will later investigate whether company characteristics like size, energy intensity and industrial sub-sector influence the demand parameters.

The model represents a rather restricted production function with just two inputs, namely energy and »other input«. However, the equation can be seen as an approximation to the factor demand equation that represents a CES function with only two inputs (energy and a composite input of capital and labour).<sup>4</sup> This implies that the price of energy does not affect the elasticity of substitution between capital and labour (i.e. separability between energy and the use of capital and labour). It may be argued that one should

start by estimating more flexible or general input demand equations and then test whether simplifying assumptions like separability etc. can be imposed. However, this would raise a number of methodological issues which are beyond the scope of this report (e.g. measuring cost of labour and stock of capital at the micro level etc.).<sup>5</sup>

With respect to the choice of aggregation of energy (and the price index for energy) a simple aggregation according to energy content has been applied. In the Anglophone literature this has been denoted as a Btu aggregator (British Thermal Units). However, this intuitive appealing aggregator can be criticised, because it implicitly assumes that one Joule of say electricity is as good as one Joule of say coal, i.e. coal and electricity are perfect substitutes. If this was the case then the price of one energy unit of coal and one energy unit of electricity should be identical, but the prices per energy unit of different types of fuels are very different. Other aggregates or index functions have been proposed (like the Divisia-Tornqvist or the Fisher indices), which in different ways incorporate information on the prices of the different fuels. A discussion of these issues can be found in Nguyen (1987) (or in a Danish context in Statistics Denmark, 1997). In an *unbalanced* panel – like the one used here – the calculation of the alternative types of aggregation becomes a little involved, because the index calculation relies on lagged values of price and/or energy consumption. However, a comparison of the model results using respectively the Btu aggregation and a Fisher chain index (based on a sub-sample of the data) suggests that we obtain similar results in our case (see appendix 6.1).

## Notes

1. They were excluded because they account for a small share of energy consumption and/or because it is difficult to obtain relevant measures of price. For instance, the industrial sector producing wood products also uses wood waste as an energy source. However, it is difficult to obtain a good measure of the cost of wood waste for the companies in this sector, because it is a by-product. Finally, we have not included refineries (and therefore refinery oil) in our definition of *industry*.
2. In most cases, the price of the fuels is (assumed to be) common for all companies. Two important exceptions are the prices of electricity and district heating, which vary between companies because they have been supplied by different utilities. For these two fuels we use

individual average prices. In Bjørner, Togeby and Jensen (2000) we explore the potential endogeneity problems associated with the use of such average prices. It is found that the use of average electricity prices does not seriously bias the price elasticity of electricity in a fixed effects model (but they will probably be a serious cause for bias in the price elasticity in cross-section models (i.e. models without fixed effects)).

3. Say for instance that a company has a value added at 100 million DKK in both 1995 and 1996. Also, the company receives a subsidy in 1995 at 1 million DKK and a subsidy in 1996 at 1.5 million DKK. In this case the value of the SUBVA variable in 1993, 1995 and 1996 will be respectively 0, 1, and 2.5. Thus,  $\hat{\alpha}_4$  measures the per cent reduction in energy consumption associated with a subsidy corresponding to 1% of value added.
4. If the BFI deflator PVA were replaced by the composite price of the other input (representing capital and labour) and energy (and if materials other than energy are assumed to be strongly separable from capital, labour and energy) then equation 4.1 would correspond to the factor demand equation of a CES function (where materials other than energy are assumed to be strongly separable from the other input, i.e. materials enter the production function in a Leontief fashion). However, since energy only accounts for a small share of cost in industrial companies, then PVA is presumably a fairly good approximation to the composite input price. With respect to materials, studies based on aggregate time series do suggest that materials can be considered strongly separable in Denmark (see Statistics Denmark, 1997).
5. Like how to account for different qualities of labour and how to calculate »economic« capital stock from accounting measures of stock (see for example Griliches and Mairesse (1995) for further discussion of these issues). Woodland (1993) also discusses problems involved in the estimation of substitution between different types of energy when »corner solutions« are observed (see note 2 in section 3).

# 5 Description of the Database

This section contains a general description of the construction of a micro panel database for industrial companies' energy consumption. It is the intention that the section may also serve as a general introduction to the database (and serve as a condensed documentation). Therefore, this section also includes a description of a number of variables that have not directly been used in the empirical analyses presented in this report.

## 5.1 Construction of the Database

The database contains information about energy consumption at production site divided among different types of energy (electricity, coal, fuel oil, natural gas etc.). Information about energy consumption has been combined with information about value added, production, value of capital, company surplus, employment and wages.

The database is constructed in the following way:

- S** The starting point is a sample containing all information from the last eight *energy surveys* carried out by Statistics Denmark. The energy surveys have been carried out in 1983, 1985, 1988, 1990, 1993, 1995, 1996 and 1997. All industrial companies with 20 or more employees are included in these surveys, except in 1995, where only 50% of the companies with 20-50 employees were included in the surveys. This yields information about use of energy divided between 19 different types of energy. Furthermore, there is also information about production and sale of electricity and district heating of industrial companies. It is compulsory for the companies to return the survey.

- S The above sample has been matched with data from *accounts statistics*, where we have obtained information about value added, production, value of capital and investments (divided between financial assets, land and buildings, plant and machinery, etc.). The account statistics generally include all companies with more than 20 employees; however, starting from 1996 only 50% of the companies with 20-50 employees were included.
- S Various information about number of *employees* of the production sites and the paid salaries is obtained partly from the sources noted above and partly other registers from Statistics Denmark (information on employment and labour costs is not utilised in the current report, but can be use in the estimation of more flexible production functions).
- S Information from the Danish Energy Agency (DEA) about *subsidies for investment* in energy efficiency as well as the so-called *energy agreement* (including energy audits) between the company and the DEA has been added to the database (see section 2 for a description of these two policy instruments).
- S *Various more general information* like general energy prices, taxes, deflators for value added, production etc. have been obtained from varies sources (e.g. like Statistics Denmark and the IEA).

Information related to the industrial companies exists at different levels: At firm or company level, which is defined as the legal unit (covering all production sites of the same company), the individual production site within the companies, and an intermediary one: *all production sites within the same industrial sub-sector for each company* [in Danish: Faglige enheder]. Energy surveys are collected for each production site, while information concerning activity, e.g. value added, exists at the intermediary level, which therefore also will be our level of analysis. In general, we denote this intermediate unit as a »*company*« (disregarding that the real company may cover several such units).

Finally, we reserve the notion of a »*firm*« for the legal unit, which may consist of a number of different »*companies*« (defined as above). However,

in most cases a »firm« consists of only one production site and there will by our definition also only be one »company« belonging to this firm.

The sub-sectors used to identify the companies are determined according to a sector code, which is the Danish DB93 nomenclature conforming with the EU classification NACE. The definition of the sector code is rather disaggregated with about 300 industrial sub-sector codes represented in the Danish industry. Statistics Denmark continuously revises the DB93 sector code for the different industrial companies, which leads to many changes, especially in the last two digits in the DB93 codes. Since the DB93 sector code is used to identify the individual »companies« over time, these small reclassifications reduce the number of companies that can be identified over time. In order to reduce this problem it has been chosen only to rely on the first four digits of the DB93 nomenclatures (which is still fairly detailed).<sup>1</sup>

The process of matching different official registers has led to a dropout of observations because of missing observations or other match problems between the different data sources. However, these match problems appeared to be fairly small (see later). Observations with a successful match between the energy surveys and the accounts statistics are labelled as our *gross database*.

From this gross database we have created a *net database* used in the estimations in this particular report. In the net database a number of observations from the gross database have not been included. The motivation for exclusion of some observations is to remove observations with potential errors and observations that are difficult to apply to the type of empirical analysis carried out in this report. If the following conditions have not been met, the observations in the gross database have not been included in the net database:

- Companies must have been in the database for at least two years.  
[In a fixed effects panel model companies only appearing in one year will simply be »dummied out«. This restriction accounts for most of the reduction in the number of companies when going from the gross database to the net database.]
- Companies must have positive value added.
- Only eight types of energy are included in the analysis. A company must

only get up to one third of its total energy consumption from other energy sources (e.g. wood, straw, biogas etc.) than these eight (not including transport fuels).

[Main implication of this rule is that some of the companies in the wood product and furniture industries are excluded.]

- Companies with extremely large fluctuations over time in energy intensity have been excluded. The motivation was to exclude companies with potentially erroneous observations.<sup>2</sup>
- The price of district heating must be between DKK 20 and DKK 250 per GJ (also in order to exclude potentially erroneous observations).
- Companies which locally produce electricity and/or district heating have not been included in the net database.  
[Only a limited number of companies have local production of electricity/district heating, but these generally have high energy consumption.]

The exclusion of industrial companies with local production of district heating and/or electricity implies that a fairly limited number of companies are excluded, but these companies have generally (very) high energy consumption, and the exclusion therefore implies that there is a large reduction share of total energy use by the industrial sector. However, the *net* energy consumption in these companies is more complex to model for a number of reasons. First of all the conversion loss associated with the local energy production is now taken place inside the company instead of in the public utility (as in the other industrial companies), and it is not possible from the data to calculate the conversion loss of the individual companies.<sup>3</sup>

For companies, which during the period start up local production of energy, the comparison of net energy use before and after the local energy production has started becomes very sensitive to the calculation of the conversion loss. A number of industrial companies have obtained large subsidies to make them start local energy production. Systematic measurement/calculation errors on the net energy consumption after the start of local energy production may therefore lead to biases in the estimated effect of the subsidies on energy demand.

## 5.2 Number of Companies and Match Rate in the Database

Table 5.1 shows in detail the distribution of companies in each year in the gross and net database and the number of years the company can be followed during the period 1983-1997. The table also shows the total size of the population of companies in the Danish industries.

It appears from table 5.1 that the match between energy surveys and accounts statistics has been successful for most of the industrial companies. The number of matched companies in the gross database is lower in 1995 and especially in 1996 and 1997 compared with the other years. One explanation for this is that primary data have only been collected for 50% of the companies with 20-50 employees in 1995, 1996 and 1997. However, the extraordinary low number of matched companies in 1996 and 1997 may also be related to changes in the way Statistics Denmark has organised the collection of primary data.

Table 5.2 shows how much of the total energy consumption, consumption of electricity, production and value added in the Danish industry that is included in the database. It appears that about 90% of total energy, electricity, production and value added in the whole industrial sector is included in the gross database (in the period before 1996). Thus, table 5.2 confirms that the match between different primary databases has been successful for most of the industrial companies.

It also appears from table 5.2 that there is a relatively large reduction in energy consumption when going from the gross to the net database. The main explanation for this is that the industrial companies with local production of district heating and/or electricity also belong to the most energy-consuming companies (these companies are excluded in the net database). The reduction in production and value added in the net database is considerably smaller.

Table 5.1 Number of companies in each year and number of years in the net database (gross database in brackets)

Number of years	1983	1985	1988	1990	1993	1995	1996	1997
1	(209)	(134)	(152)	(119)	(215)	(576)	(40)	(87)
2	295 (323)	346 (374)	218 (222)	219 (214)	188 (205)	172 (190)	160 (154)	128 (122)
3	254 (284)	327 (344)	416 (429)	262 (242)	211 (219)	243 (242)	202 (201)	173 (175)
4	272 (299)	321 (357)	388 (429)	412 (447)	276 (329)	182 (217)	165 (188)	156 (174)
5	251 (255)	295 (310)	346 (362)	395 (418)	374 (414)	188 (186)	144 (142)	132 (133)
6	245 (261)	287 (314)	374 (421)	374 (422)	358 (423)	304 (337)	218 (228)	186 (204)
7	276 (309)	340 (388)	341 (389)	344 (392)	324 (376)	275 (307)	337 (385)	213 (233)
8	494 (629)	494 (629)	494 (629)	494 (629)	494 (629)	494 (629)	494 (629)	494 (629)
Total net gross	2087 (2569)	2410 (2850)	2577 (3033)	2500 (2883)	2225 (2810)	1858 (2684)	1720 (1967)	1482 (1757)
Comparing with the total population of industrial companies*								
Number	2770	3042	3271	3135	2914	3168*	3102*	3044*
%-share:								
Net DB	75	79	79	80	76	59	55	49
Gross DB	93	94	93	92	96	85	63	58

\* Total number of companies [In Danish: Faglige enheder] with 20 employees. In 1995, 1996 and 1997 the figures for the whole population denote total number of firms [In Danish: Firmaer] in industry (with at least 20 employees). The numbers in these years are therefore difficult to compare with other figures (also due to a change in the collection of data). Source: Statistiske Efterretninger (Generel Erhvervsstatistik, 1999:9, 1998:11 and 1998:6).

Table Comparison of database and total industry

5.2

Year	Danish industry TJ	Gross database TJ	Share in gross database	Net database TJ	Share in net database
	1	2	3	4	5
<b>Total energy consumption (exclusive of transport fuels)</b>					
1983	88218	79419	0.90	48715	0.55
1985	96946	90190	0.93	56650	0.58
1988	98876	92553	0.94	57604	0.58
1990	99999	96320	0.96	52542	0.53
1993	104142	98961	0.95	49651	0.48
1995	113299	102888	0.91	45688	0.40
1996	114912	106114	0.92	45063	0.39
1997	116789	104833	0.90	41023	0.35
<b>Electricity</b>					
1983	18827	16992	0.90	12487	0.66
1985	21347	19767	0.93	14937	0.70
1988	23572	22036	0.93	16792	0.71
1990	25156	23909	0.95	17904	0.71
1993	26085	26141	1.00	16404	0.75
1995	29229	26240	0.90	15982	0.55
1996	28654	26762	0.93	16100	0.56
1997	29484	26406	0.90	15091	0.51
<b>Production in million DKK (annual prices)</b>					
1983	223116	198564	0.89	166634	0.75
1985	273106	244598	0.90	210521	0.77
1988	296031	271011	0.92	231522	0.78
1990	326787	289036	0.88	250508	0.77
1993	333255	320727	0.96	232419	0.70
1995	379296	329263	0.87	256198	0.68
1996	385568	332533	0.86	265771	0.69
1997	406256	340943	0.84	257216	0.63
<b>Value added in million DKK (annual prices)</b>					
1983	90801	83278	0.92	69678	0.77
1985	110833	108921	0.98	91732	0.83
1988	130849	121051	0.93	103424	0.79
1990	142785	131700	0.92	113311	0.79
1993	155221	148959	0.96	115151	0.74
1995	182030	158970	0.87	123508	0.68
1996	185079	154491	0.83	123014	0.66
1997	197524	163290	0.83	118521	0.60

Source: Production and value added in industry (companies with at least 20 employees) from Statistisk Tiårsoversigt (1997 and 1992) for the years before 1995. For the years 1995-97 production and value added denote respectively turnover and turnover deducted with purchased materials obtained from Statistiske Efterretninger (Generel Erhvervsstatistik, 1999:9, 1998:11 and 1998:6). Energy consumption in »Industry« does not include oil refineries (or refinery oil). Source for total energy consumption over time is also from Statistiske Efterretninger (Industri og Energi 1998:12).

## 5.3 Energy Agreements and Subsidies in the Database

Since the focus here is on the companies that have received subsidies or have made an agreement (or both) some detailed information about the representation of these companies in the database can be found in table 5.3.

Note that the information about energy agreements could only be matched at »firm« level (though this type of information should probably be related to the »companies« or the individual production sites). This means that in the case where a firm is covering more than one company it cannot be identified, which of the companies that actually should be attributed the agreement. For agreements we have therefore reported match in the database both at company and firm level. However, there is also a reasonable way to rectify this problem: It is only the most energy-intensive companies (i.e. production sites) that were offered to enter the agreements. Thus, in situations where there are more than one company within a firm, we assume (later) that the most energy-intensive company is the one with the agreement.

In table 5.3 we first show the number of companies with an agreement or given a subsidy according to information from the DEA. In 2. we show the number of companies with agreements and subsidies, which could be matched with the energy surveys and the account statistics in our gross database. Then in 3. we show the number of these companies that appear in our gross database, when we exclude companies with local production of district heating and electricity. Finally, in 4. we show the number of companies with agreements and subsidies which appear in the final net database.

Table Observations with either an agreement or a subsidy

5.3

Investment subsidies		Energy agreement			
	Number of companies	Amount in 1000 DKK		Company level	Firm level
<b>1. Data from DEA (subsidies given to Industry)</b>					
93	116	62,643			97
95 (94-95)	341	44,604			149
96	272	91,601	<b>heavy 96</b>		24
97	519	155,043	<b>light 97</b>		13
			<b>heavy 97</b>		59
<b>SUM</b>	<b>1248</b>	<b>353,891</b>			<b>342</b>
<b>2. Gross database incl. of oil refineries and producers of district heating/electricity</b>					
93	73	55,766		58	50
95 (94-95)	181	30,849		82	72
96	128	75,760	<b>heavy 96</b>	19	19
97	240	93,440	<b>light 97</b>	5	5
			<b>heavy 97</b>	41	37
<b>SUM</b>	<b>622</b>	<b>255,840</b>		<b>205</b>	<b>183</b>
<b>3. Gross database excl. of oil refineries and producers of district heating/electricity</b>					
93	60	34,734		42	38
95 (94-95)	168	23,729		57	53
96	109	29,286	<b>heavy 96</b>	8	8
97	201	44,906	<b>light 97</b>	5	5
			<b>heavy 97</b>	24	23
<b>SUM</b>	<b>536</b>	<b>132,639</b>		<b>136</b>	<b>127</b>
<b>4. Net database</b>					
93	52	33,012		35	35
95 (94-95)	128	14,760		47	47
96	90	24,957	<b>heavy 96</b>	6	6
97	170	38,025	<b>light 97</b>	4	4
			<b>heavy 97</b>	21	21
<b>SUM</b>	<b>440</b>	<b>110,754</b>		<b>113</b>	<b>113</b>

Note: Note that the »SUM« of the agreements is difficult to interpret, because e.g. the 149 companies with agreement in 1995 include the 97 companies that entered an agreement already in 1993.

It appears that there is a fairly large reduction in the number of companies with agreements and – to a lesser extent – with subsidies, when matching the information from the DEA with the energy surveys and the account statistics (i.e. going from 1. to 2.). However, there are often »good« explanations for the difference between the number of companies which were supplied from the DEA and the ones that could be matched with the information from Statistics Denmark. Thus, subsidies/agreements from the DEA may include companies with less than 20 employees (which are not in-

cluded in the energy surveys). Also, some of the companies from the DEA had between 20-50 employees. From 1995 Statistics Denmark only collected primary data for half of these companies.

As an example 149 cases of energy agreements in the year 1995 were reported from the DEA, but only 72 could be matched with both energy surveys and account statistics in this year. However, according to Statistics Denmark 25 of the 149 companies could not be labelled as industry according to the standard classification used by Statistics Denmark (in which case they would not be included in the energy surveys). 26 of the 149 cases were within industry, but had less than 20 employees, 14 of the companies had between 20-50 employees (where primary data were only collected for 50% of the companies), and 3 companies had been closed down. Finally, 6 companies could be matched with the energy surveys, but not with account statistics. Thus, it appears that most of the companies with agreements in 1995 that could be expected to be identified in the database also were identified.

There is also a reduction in the number of represented companies with agreements/subsidies –specially in the amount of subsidies given –when going from the gross database 2. to the net database 4. It can be seen from 3. that most of this reduction is related to the exclusion of companies with local production of electricity and district heating. With respect to the reduction in the amount of subsidies the proportionally large reduction reflects that the largest subsidies given to single industrial companies have been given to encourage these companies to start local production of electricity and/or district heating. Thus, a (limited) number of companies with very large subsidies are not included in the analysis. With respect to the later interpretation of calculated effects of subsidies and agreements it is important to keep in mind that subsidies given to encourage local production of energy are not included in the analysis.

Table 5.4 shows the distribution of agreements and subsidies according to sub-sector. All companies in the net database are included in the table (i.e. also companies that only existed in say 1983 and 1985). Compared with the number of companies in the net database (3,762) only 2% (60) have had an agreement, while 9% (348) at some point have received a subsidy for investments in energy efficiency.

Table 5.4 Companies according to industrial sub-sector

Industrial sub-sector (BR53)	All companies		Companies with an agreement		Companies with subsidies	
	N	%	N	%	N	%
Extraction of gravel, clay, stone, salt etc.	17	0.5	3	5.0	1	0.3
Food, beverages and tobacco	447	11.9	18	30.0	59	17.0
Textiles, wearing apparels and leather	438	11.6	0	0.0	17	4.9
Wood and wood products	87	2.3	1	1.7	18	5.2
Paper, printing and publishing	377	10.0	2	3.3	34	9.8
Chemicals	129	3.4	6	10.0	15	4.3
Rubber and plastic products	204	5.4	3	5.0	34	9.8
(Other) non-metallic mineral products	182	4.8	17	28.3	15	4.3
Basic metals (manufacturing and processing)	517	13.7	7	11.7	41	11.8
Machinery and equipment	595	15.8	2	3.3	37	10.6
Electrical and optical instruments	337	9.0	0	0.0	22	6.3
Transport equipment	154	4.1	0	0.0	16	4.6
Furniture and manufacturing n.e.c	278	7.4	1	1.7	39	11.2
Total	3762	100.0	60	100.0	348	100.0

## 5.4 Other Information

The data on energy consumption and activity have been supplemented with data from other sources.

With respect to *energy prices* the energy surveys include questions about expenditures as well as the consumption in physical units for electricity and district heating. Therefore, it is possible to calculate average prices for each company for these two sources of energy, where there is large variation in price, because of the large number of public utilities (e.g. there are about 100 electricity utilities in Denmark).

The use of that type of calculated average prices can be questioned in situations where the average price deviates from the marginal. For references to literature and a more detailed description of this issue especially

with respect to the electricity price see Bjørner, Tøgeby and Jensen (2000). Here, it is found (based on the same data set) that the use of average electricity prices does not seem to bias electricity demand parameters, when a panel data model (fixed effect) is applied. Thus, we would expect that the use of the average electricity price does not cause any endogeneity bias in the model for total energy including electricity. Potentially, the average prices for district heating may cause more serious problems, because the fixed cost associated with district heating is larger than for electricity. However, district heating only accounts for 3-5% of the total energy consumption and we therefore assume that the decreasing price schedule for this type of energy does not seriously bias the effect of price on total energy consumption.

The price of district heating is quite fluctuating. That could at least partly be explained by a rather large fixed payment. Table 5.5 shows the development in the mean price of district heating compared with information on the price of district heating obtained from Konkurrencestyrelsen. The two price series seem to follow the same pattern over time, but there are differences in the levels, which reflects that the figures from Konkurrencestyrelsen are based on a lower level of consumption.

Table 5.5 The mean price of district heating (DKK)

Year	1983	1985	1988	1990	1993	1995	1996	1997
Number of observations	531	626	655	676	607	567	538	474
Mean price of district heating in database	79.09	88.35	88.42	105.00	103.96	99.57	96.33	99.80
Mean price according to the Danish Competition Authority	94	95	102	112	109	107	107	-

With respect to fuel oil, gas oil and coal list prices obtained from the IEA publications have been used,<sup>4</sup> while information about price of LPG was obtained from the main supplier (BP). List prices of natural gas have also been obtained from the supplier (DONG). The list price of natural gas is a bit higher than the heavy fuel price, but the list price of natural gas over time closely follows the development of the heavy fuel price. Also, indus-

trial companies may negotiate individual discounts in the price of natural gas with the supplier. It has been chosen to use the price of fuel oil as price indicator for natural gas (assuming that the difference in the list price of natural gas and the list price of fuel oil corresponds to the individual discounts offered).

With respect to *deflators* for production and value added no deflators exist at company level. Therefore, aggregate deflators for production and value added for about 56 different industrial sectors have been obtained from the Danish national accounts. These deflators have been included in the database and have been used to calculate production and value added at 1995 price levels.<sup>5</sup>

The energy prices have been decreasing in nominal terms in the period from 1983 to 1988 (with LPG and District Heating as exceptions). From 1993 most energy costs were increasing in nominal terms both due to general price increases and because of the different energy-related taxes described in section 2 (recall that these vary according to type of use and depending on whether or not the company has signed an agreement). Figure 5.1a and 5.1b illustrate the levels and the development in the nominal energy prices (without taxes) for the most important types of fuels as well as for the weighted price of energy (PE8) we use in the econometric model. The average electricity price and PE8 price are weighted with electricity/energy consumption (in the net database). Non-weighted average measures of electricity price and PE8 are generally higher,<sup>6</sup> but the patterns over time are the same as shown in figure 5.1.

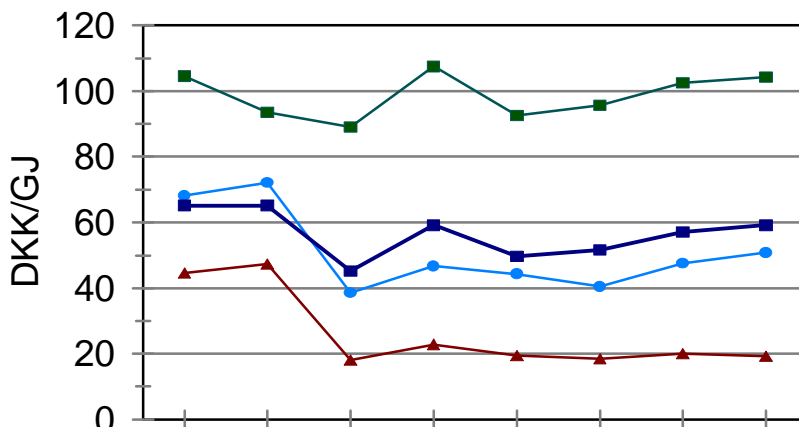
Figure 5.1 illustrates the rather drastic changes which have taken place in the nominal energy prices as well as in the average of PE8 within the period. Thus, the most important energy prices drop steeply from 1985 to 1988, then rise from 1988 to 1990, followed by a fall. In addition to the development illustrated in figure 5.1 energy cost increases (especially in 1996 and 1997) for most of the companies due to the high taxes on energy in these years, but there are large differences between the companies in those increases.

With respect to the price level for energy types not illustrated in figure 5.1 both district heating and LPG are relatively expensive per GJ, though they have (almost) always been cheaper than electricity (the only exception is the year 1997 where the average electricity price was lower than the LPG

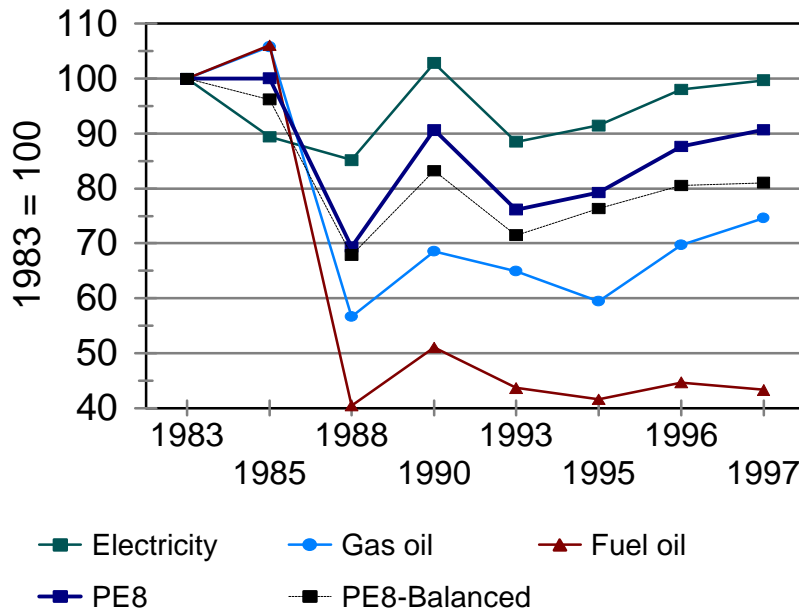
price). Coal has generally had the cheapest price per GJ. LPG, district heating and coal are the types of energy (of the eight) with the smallest shares of energy demand. Appendix 5.1 contains two additional graphs illustrating the development in energy prices (one illustrating the average taxes on energy and one illustrating the nominal and real mean energy costs).

Figure 5.1  
Energy prices

**Figure 5.1a: Energy Prices**  
Nominal (weighted prices without tax)



**Figure 5.1b: Energy Price Indexes**  
Nominal (weighted prices without tax)



The development in the average price (PE8) depends on the distribution between the different types of energy, because the price levels are rather different. The development in the distribution between different types of energy in the companies in the net database is illustrated in figure 5.2. In the figure the different types of energy are »ordered« according to the price levels (with electricity as the most expensive and coal as the cheapest). The most drastic change in the energy pattern is the large increase in the use of natural gas. Natural gas was (almost) not supplied in 1983, but in 1996 it had increased to cover almost a third of the energy consumption (at the expense of fuel oil).

It also appears from the figure that the share of electricity has risen over time from a fourth to a third of energy consumption (in the sub-sample of companies in the net database). The increase in the share of electricity is reflected/incorporated in the average PE8 price illustrated in figure 5.1. Note, however, that this increase to some extent has taken place due to shifts in the electricity intensity of new companies as opposed to old companies. Companies entering the database tend to have had lower energy intensity as compared with companies leaving the database. Thus, when looking at the distribution between different types of energy in companies that have existed during the whole period (i.e. in the balanced panel) the increase in electricity share is a little lower. This is reflected in the average PE8 for the balanced panel illustrated in figure 5.1b (the dotted line), which over time is lower than PE8 for the whole sample.

There is very large heterogeneity in the »pattern« of energy consumption between different companies, which also yields differences in the level of PE8. This is illustrated in figure 5.3, which shows the average energy pattern for four groups of all companies in 1996 divided into groups of equal size according to the level of PE8.

Figure 5.2 Distribution of fuel types

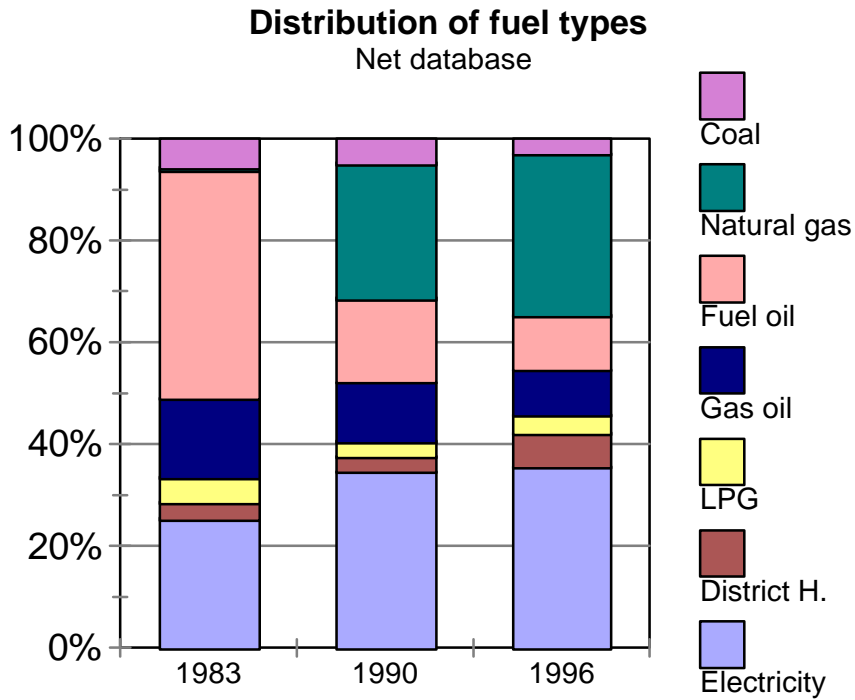
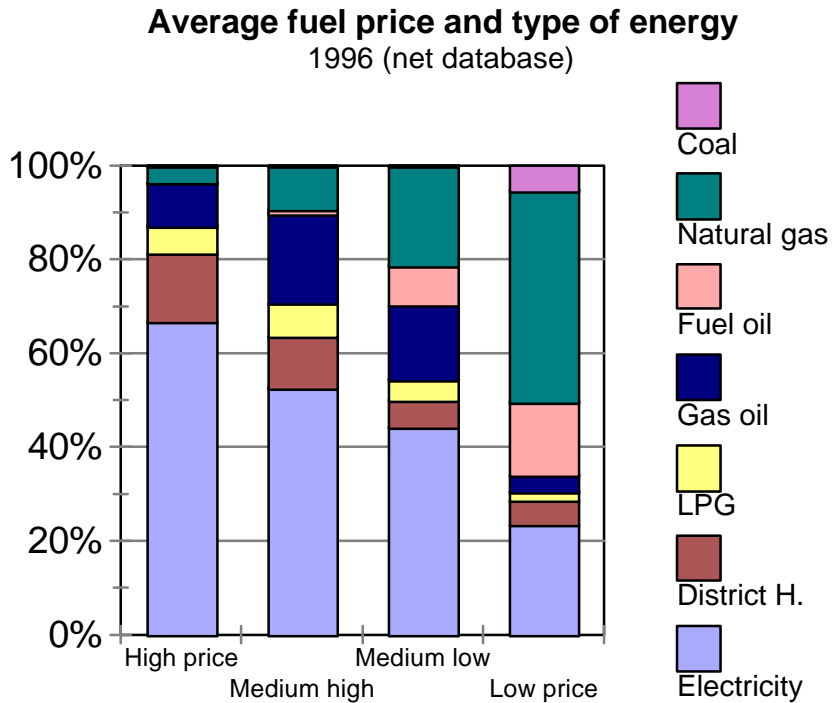


Figure 5.3 Average fuel price and type of energy



Very few companies use all the different available types of energy. Instead there are many different combinations of different energy sources represented in the database. This is illustrated in table 5.6 showing some of the most frequent combinations in 1983 and 1997. The use of coal is concentrated on few companies (i.e. 30 companies in 1996). Also, the consumption on (heavy) fuel oil is concentrated (122 companies in 1996). In 1983, natural gas was introduced in Denmark. However, the change in the patterns of energy consumption will not be addressed in the analyses carried out in this report, where focus is total energy consumption in the companies.

Table 5.6 Frequent combination of energy sources

Electricity	Light Fuel Oil	District heating	Natural gas	Other gas	Number of companies				Total consumption PJ			
					83 Gro. DB	97 Gro. DB	83 Net DB	97 Net DB	83 Gro. DB	97 Gro. DB	83 Net DB	97 Net DB
●	●				841	317	746	233	38	17	34	14
●		●			243	203	200	188	7	15	5	15
●			●		-	280	-	308	-	36	-	51
●	●	●			133	77	118	69	12	26	11	24
●	●		●		2	142	2	133	0	40	0	34
●	●			●	311	91	288	85	32	13	31	11
●	●	●	●		-	85	-	79	-	50	-	31
Other combinations					1039	562	733	387	734	943	407	231
Total					2569	1757	2087	1482	823	1140	488	411

## 5.5 Summary

Overall there is a fairly good match between the energy surveys and the account statistics collected by Statistics Denmark. As an example the gross database includes more than 90% of the industrial companies, total value added, production and energy consumption. It also appears that most of the individual companies can be followed over time.

There are a number of companies, which have entered an agreement or

obtained a subsidy from the DEA, which are not included in the database, but this can often be explained by the fact that Statistics Denmark does not collect primary data on energy consumption and/or production/value added for all industrial companies with less than 50 employees.

In the econometric models presented in this report a number of observations in the gross database are excluded. This includes e.g. companies that can only be identified in a single year and industrial companies, which have local production of district heating and/or electricity. The latter are excluded, because the calculation of »net« energy consumption is more complicated, and can only be carried out using average conversion loss factors.

## Notes

1. In Bjørner, Togeby and Christensen (1998) we estimate models on the first version of the database. In the first version of the database the sub-sector code for the years 1983 to 1990 was based on the DSE77 classification (conforming with the international ISIC classification). This change in nomenclature caused some problems with identification over time which are reduced in the current data set, where the DB93 code has been assigned also to observations older than 1993. Apart from that, the current database contains information from 1997, and information about subsidies to energy efficiency has also been added.
2. We have excluded all observations where the energy intensity in one year was four times higher or lower than the average energy intensity of the company in all years it appeared.
3. Say that a company in one year uses 100 GJ of electricity in its production. If the same company produces the 100 GJ electricity itself, with a primary input of say 200 GJ natural gas, then the company has had a high increase in (gross) energy consumption, even though the net energy consumption is the same. Instead of excluding the observations another possibility could have been to obtain information on the conversion loss associated with local industrial production of power and/or heating and thereby calculating net energy consumption. However, it is difficult to make such calculations without using some average measure for the conversion loss, which may not be correct at the individual level. In addition, there are also some problems with calculating the energy taxes for companies that produce local electricity and/or district heating, see section 7 and 8 in Ministry of Economic Affairs (1999).
4. Price of coal in 1996 and 1997 was, however, based on our own estimates (based on communication with coal importers and suppliers)

5. The deflators used are from the so-called new national account with 130 sectors in the Danish economy (56 belonging to industry), where production and value added in fixed prices are calculated in 1995 price levels).
6. The differences in the level of the unweighted versus weighted average of electricity price and PE8 over different companies reflect that large users of electricity also generally have a lower average electricity price while energy-intensive companies generally rely relatively more on cheaper types of energy.

# 6 Estimation Results in Models with Common Elasticities

This section presents estimation results from »simple« models, where the elasticities with respect to value added and energy price are restricted to be the same for all industrial companies. First, pooled and fixed effects models are compared and the functional form checked. Then, some alternative ways to specify the influence of the energy agreements and the subsidies are investigated. In section 7 we use the preferred specification of the simple model and investigate, whether the estimated elasticities depend on the industrial sub-sector or other characteristics of the company.

## 6.1 Cross-section Versus Fixed Effects Model

Estimation results for equation 4.1 are presented in table 6.1. The first eight columns show regression results, when a common intercept is estimated, i.e. when the panel structure of the data has not been taken into account. These are the cross-section estimates for each individual year and the pooled sample of all the years. Company specific fixed effects are introduced in the last column. It appears that the fixed effects have a large influence on the estimated parameters. As an example, the parameter to value added is about one (constant return to scale) in the common intercept model, while there is decreasing return to scale in the fixed effects model. Looking at the estimated elasticities for energy price the difference between the pooled and the fixed effects model is even larger. It also appears from the goodness of fit statistics that the fixed effects account for a large part of the variation in the endogenous variable. Parameters in the model with common intercept may therefore be biased due to omitted variables (the fixed effects). In the following focus will therefore be on the fixed effects model.<sup>1</sup>

In the fixed effects model the elasticity with respect to value added is about +0.6, while the elasticity with respect to energy price is about -0.5. In the fixed effects model the parameter to the energy agreement dummy also has the expected negative sign (the effect on energy consumption of the energy audit and energy management).<sup>2</sup> The sign of the parameter to the subsidies is also negative in the fixed effects model.

The estimated parameters should be interpreted as the micro level response of the companies in our database. It is reasonable to assume that there is decreasing return to scale at company level (as found here), but this does not necessarily imply that there is also decreasing return to scale at macro level. In this type of study the focus is on the behaviour of (continuously) existing companies. One can argue that estimates based on variation in the variables *between* companies may be better to capture some of these long-run effects. The elasticity to value added in the cross-section estimates was very close to one (i.e. constant return to scale), which would be a very reasonable long-run elasticity.<sup>3</sup> Thus, the estimates to value added seem to offer some support to the idea that within estimates should be interpreted as a short-run effect, while cross-section estimates capture long-run effects.

It is tempting to use the same arguments to the interpretation of the price elasticities in the cross-section models and the fixed effects model (suggesting that the very large price elasticities found in the cross-section models capture some long-run adjustments). However, it is not obvious that the same reasoning can be applied to interpret the price elasticities. One reason is that the cross-section price elasticities seem very high (even for the long run). Another reason (or perhaps rather the explanation for the high cross-section elasticities) is that the average price in the individual companies depends on the distribution between different types of energy in the companies. Coal is the cheapest of the eight types of energy focussed on here. But coal is often used in very energy-intensive processes and it is therefore only the most energy-intensive companies that use coal. These energy-intensive companies will have a low average energy price (e.g. compared with a company using only electricity, which is the most expensive type of energy).

Table 6.1 Comparing estimates in cross-section, pooled and fixed effects models

Model	Cross-section estimates ( $\hat{a}_i = \hat{a}$ )								Pooled ( $\hat{a}_i = \hat{a}$ )	Fixed effect ( $\hat{a}_i$ )
	1983	1985	1988	1990	1993	1995	1996	1997	1983-97	1983-97
Data										
LFVA	1.13 (0.02)	1.09 (0.02)	1.08 (0.02)	1.07 (0.02)	1.07 (0.02)	0.99 (0.02)	1.00 (0.02)	0.96 (0.02)	1.040 (0.012)	0.550 (0.013)
LPE8	-1.50 (0.04)	-1.61 (0.05)	-1.39 (0.04)	-1.40 (0.05)	-1.29 (0.05)	-1.40 (0.06)	-1.29 (0.07)	-1.65 (0.08)	-1.368 (0.036)	-0.495 (0.019)
DCO2AG	-	-	-	-	-	-	-	-	1.329 (0.100)	-0.172 (0.045)
SUBVA	-	-	-	-	-	-	-	-	0.599 (0.090)	-0.002 (0.032)*
$\hat{a}$ (const)	4.37 (0.24)	5.05 (0.33)	3.49 (0.24)	3.83 (0.29)	3.27 (0.30)	4.58 (0.35)	4.08 (0.39)	6.28 (0.46)	4.06 (0.20)	-
$\hat{\epsilon}_{83}$									0.52 (0.03)	-0.19 (0.02)
$\hat{\epsilon}_{85}$									0.30 (0.03)	-0.19 (0.01)
$\hat{\epsilon}_{88}$									-0.26 (0.02)	-0.35 (0.01)
$\hat{\epsilon}_{90}$	-	-	-	-	-	-	-	-	-0.09 (0.02)	-0.26 (0.01)
$\hat{\epsilon}_{93}$									-0.21 (0.02)	-0.19 (0.01)
$\hat{\epsilon}_{95}$									-0.25 (0.02)	-0.14 (0.01)
$\hat{\epsilon}_{96}$									-0.10 (0.02)	-0.03 (0.01)
$\hat{\epsilon}_{97}$									0 (base)	0 (base)
$\sigma_v^2$	0.833	0.777	0.751	0.767	0.745	0.814	0.782	0.732	0.7554	0.0867
$R^2$	0.679	0.684	0.689	0.672	0.670	0.646	0.642	0.658	0.6840	0.9718
$R^2$ within	-	-	-	-	-	-	-	-	-	0.4426
Parameters	3	3	3	3	3	3	3	3	12	3773
Observations	2087	2410	2577	2500	2225	1858	1720	1482	16859	16859

White standard error of estimates in brackets.  $R^2$  within is a measure of goodness of fit after the fixed effects have been controlled for. \* Not significant at 5% level.

The high »price elasticities« in cross-section estimates are therefore likely to be biased because they reflect differences in the distribution of energy types in the companies, instead of capturing actual responses to changes in the price of energy. However, in a fixed effects model this type of bias will be heavily reduced (or perhaps even disappear), because it is the variation in prices over time within the single companies that determines the price elasticities, see e.g. Baltagi (1995). A requirement for the bias to disappear in the fixed effects model is that the composition between different types of energy (and especially the composition between the relatively high-priced and low-priced types of energy) is fairly stable in the single companies. The composition of different types of energy is more stable over time within the individual companies as compared to the variation in the composition of energy between companies (in a given year). This suggests that the price elasticity in the fixed effects model is more reliable than the price elasticities in the cross-section models.

In section 4 the aggregation issue was discussed. The aggregate measure of energy used when estimating the parameters presented in table 6.1 is calculated simply by aggregating according to energy content (Btu-aggregation). However, it has been put forward that other ways of aggregating are more satisfying according to economic theory. Unfortunately, the latter type is not straightforward to calculate in our case where we have an unbalanced panel. Appendix 6.1 contains a comparison of parameters, which are estimated on data where the measure of aggregate energy and energy price are calculated respectively according to energy content and as a Fisher index (though only for a balanced subset of the data). It appears that there are only very small differences in the estimated parameters subject to the two different ways of aggregating. In the following we therefore rely on the Btu-aggregator, which is simple to calculate also for the unbalanced panel.

## 6.2 Functional Form

In table 6.2 estimation results for alternative functional forms are presented. To ease comparison the fixed effects model from table 6.1 is repeated as model 1 in table 6.2. In initial regressions an interaction term between price and value added (i.e.  $LFVA \times LPE8$ ) was also included, but this term was

not significant. It appears from the table that a second order term for price (model 2 and 3) yields a significant increase in the goodness of fit of the model.

Table 6.2 Functional form in the E8 fixed effects model

Model	1	2	3	4
LFVA	0.550 (0.013)	0.080 (0.105)*	0.542 (0.013)	0.179 (0.104)*
LPE8	-0.495 (0.019)	0.753 (0.137)	0.670 (0.135)	-0.488 (0.019)
LFVA×LFVA	-	0.023 (0.005)	-	0.018 (0.005)
LPE8×LPE8	-	-0.146 (0.016)	-0.137 (0.016)	-
DCO2AG	-0.172 (0.045)	-0.136 (0.045)	-0.135 (0.046)	-0.174 (0.044)
SUBVA	-0.002 (0.032)*	-0.012 (0.029)*	-0.014 (0.030) *	0.0007 (0.030) *
$\ddot{\epsilon}_{83} \dots \ddot{\epsilon}_{97}$	Included in model	Included in model	Included in model	Included in model
$\acute{o}^2$	0.0867	0.0854	0.0857	0.0865
R <sup>2</sup>	0.9718	0.9723	0.9722	0.9719
RSS	1134.04	1117.45	1121.67	1131.29
R <sup>2</sup> within	0.4426	0.4510	0.4490	0.4443
Parameters	3773	3775	3774	3774
Observations	16859	16859	16859	16859

White standard error of estimate in brackets. R<sup>2</sup> *within* is a measure of goodness of fit after the fixed effects have been controlled for. \* Not significant at 5% level.

When the second order term for value added is included, the first order term becomes insignificant (model 2 and 4). This probably reflects that there is a high correlation between LFVA and LFVA × LFVA.

When second order terms are included, the parameters become less straightforward to interpret because the elasticities depend on the level of the variables. Table 6.3 presents elasticities calculated from model 2 and 3 for high/median/low levels of value added and energy price. In the table »high« and »low« are defined as the 90% and the 10% fractals of the distributions of LFVA and LPE8 (for all years).

Table 6.3 Functional form and elasticities

Elasticity with respect to:	Level of variables (LFVA and LPE8 respectively)	Model 2	Model 3
Value added	Low (10% fractal = 8.98)	+0.49	+0.54
	Median (50% fractal = 9.99)	+0.54	+0.54
	High (90% fractal = 11.65)	+0.62	+0.54
Energy price	Low (10% fractal = 3.97)	-0.41	-0.42
	Median (50% fractal = 4.53)	-0.57	-0.57
	High (90% fractal = 5.10)	-0.74	-0.73

It appears that the price elasticities are highly dependent on the level of the energy price. The elasticities with respect to value added also appear to depend on the level of value added (model 2), but not as pronounced as the price elasticities. It also appears from model 4 that the inclusion of the second order term for value added only yields a modest increase in the goodness of fit as compared to model 1. It is therefore chosen to continue with model 3, because it makes interpretation of the elasticities with respect to value added more straightforward (keeping in mind that we later allow the demand parameters to vary between different industrial sub-sectors and therefore would like to keep the model structure as simple as possible).

The price elasticity is almost twice as high for the companies with a high average energy price as compared to companies with a low average price. As discussed in section 6.1 the level of the price depends on the composition between different types of energy in the company. One implication of model 3 is therefore that companies with a high share of cheap (expensive) types of energy also have a low (high) price elasticity. Another implication of model 3 is that the price elasticity change over time according to changes over time in the level of the relative prices.<sup>4</sup>

It is also interesting to note that the inclusion of the second order term for price reduces the estimated effect of an energy agreement. Recall that the presence of an energy agreement also affects the level of the energy price variable, because companies with an agreement obtain a tax discount. With a constant price elasticity (model 1) the effect of the energy agreement (derived from the energy audit and the commitment to energy management) is as high as a 17% reduction in energy demand. However, in model 2 and 3 the effect of the agreement is only a reduction in the use of energy at about 14%. The effect of the agreement will be studied more carefully in the

following section.

The effect of subsidies does not appear to be affected by the different functional forms presented in table 6.2 (consistently insignificant, but generally with the expected negative sign).

### 6.3 Estimating the Effect of the Energy Agreements

In this sub-section we take a closer look at the effect of energy agreements. We continue with the fixed effects model that includes a second order term for the energy price.

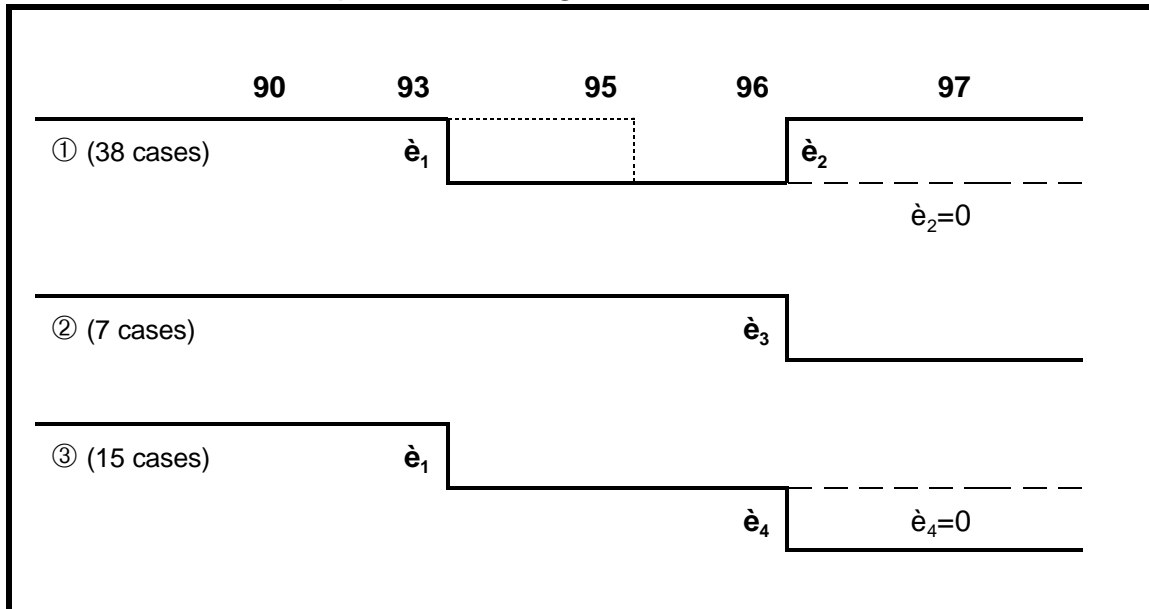
Until now it has been assumed that the effect of the energy agreements is »permanent« in the sense that the reduction in energy consumption associated with the energy-reducing actions of the companies with a commitment prevails also after the agreement is terminated (though only up to two years, because the first agreements expired at the end of 1995 and the latest year in the database is 1997). Furthermore, there has been no distinction between the »agreements« in the period from 1993 to 1995 and the agreements that started in the period 1996 to 1997, even though some changes have taken place in the commitments and gains of the companies entering an agreement.

In the database three potentially different patterns of agreements may be identified. In figure 6.1 this is illustrated, where the  $\delta$ -parameters are the change in energy consumption associated with an agreement.

Consider first the pattern illustrated in ① in the figure, which illustrates the situation where companies have an agreement in the period from 1993-95 (some of these agreements were signed in 1994, which is indicated by the dotted line), but did not sign up for the new agreements in the period 1996-1997. When entering an agreement (in 1993 to 1995) there may be a reduction in use of energy corresponding to  $\delta_1$ . When the company leaves the agreement (without entering a new agreement in 1996) there could be an increase in energy consumption illustrated by  $\delta_2$ . However, if the energy consumption is not increased, after the agreement period is terminated,  $\delta_2$  will be equal to zero. Another polar case is the situation where companies leaving the agreement increase energy consumption similar to the reduction

in energy consumption, when entering the agreement. In this case ( $\dot{\epsilon}_1 = -\dot{\epsilon}_2$ ) the effect of the agreements is strictly temporary.

Figure 6.1 The three different patterns of agreements



In the figure ② illustrates the situation where some companies enter an agreement in 1996/1997 without having had an agreement in the previous period. The initial effect of the agreement for these companies may be different from the effect of companies entering in the first period ( $\dot{\epsilon}_1$  different from  $\dot{\epsilon}_3$ ).

Finally, ③ illustrates the situation where some companies enter an agreement in 1993-1995 and also enter the new type of agreement in 1996 (or 1997). It is assumed that the initial effect of entering the early agreements (i.e.  $\dot{\epsilon}_1$ ) is the same as for the companies following pattern ① (though in principle this could be different). The effect of the new agreements starting from 1996 or 1997 for companies in this group is more complicated, because the energy consumption could still be influenced by the actions initiated in the first agreement period. The figure illustrates a situation, where entering a second agreement period gives an additional change in energy consumption corresponding to  $\dot{\epsilon}_4$ . As illustrated in the figure,  $\dot{\epsilon}_4$  could also be equal to zero, which would correspond to a situation where the effect on energy is constant in the first and second agreement period. In addition, one could also consider what should happen in the year 1996 for

companies which have agreements both in the first period and in the second period, but where they do not sign an agreement before the year 1997. Actually, most of the companies in pattern ③ did not have an active agreement in this year, because they did not sign up before 1997 (12 of the 15 companies in pattern ③ did not have agreement in 1996).

As figure 6.1 illustrates, a large number of alternative effects of agreements could potentially be modelled, but the limited number of observations with an agreement makes it unrealistic to identify all the different effects. Most of the companies with agreements in the net database belong to pattern ①, while only 7 companies follow pattern ② and 15 follow pattern ③.

The low number of companies following pattern ② makes it implausible to identify different (initial) effects of the first and second type of agreements. Therefore, the assumption that  $\delta_1 = \delta_3$  is maintained throughout the analysis. Also, the relatively small number of companies in pattern ③ makes it impossible to obtain significant estimates of the  $\delta_5$  parameter. In the following it is therefore assumed that  $\delta_5 = 0$  (actually this is also implicit in the parameter to the agreement effect estimated up till now).

Table 6.4 looks at the permanent/temporary character of the agreements, which corresponds to different restrictions in the  $\delta_2$  parameter.

Model 1 is the most unrestricted model, where both  $\delta_1 (= \delta_3)$  and  $\delta_2$  are estimated freely. In this model  $\delta_1$  is equal to -0.14 (i.e. a reduction in energy consumption equal to 14%), while  $\delta_2$  is very small and not significantly different from zero. In model 2 the  $\delta_2$  parameter has been restricted to be equal to zero, which corresponds to the permanent model estimated so far (thus model 2 in table 6.4 is identical to model 3 in table 6.3). Finally, in model 3 it has been assumed that the effect of agreements is temporary. In this case the (temporary) effect of the agreements is only -0.11. However, it appears from model 1 that it is reasonable to assume that the effect is permanent instead of temporary. An F-test for restrictions in model 2 and 3 also supports this conclusion, as the restriction in model 3 (as opposed to model 1) cannot be accepted (at a 5% level).

Table 6.4 Permanent or temporary effects of agreements

Model	1 Unrestricted model	2 Permanent model	3 Temporary model
LFVA	0.543 (0.013)	0.542 (0.013)	0.542 (0.013)
LPE8	0.669 (0.135)	0.670 (0.135)	0.681 (0.135)
LPE8*LPE8	-0.137 (0.016)	-0.137 (0.016)	-0.138 (0.016)
$\hat{\epsilon}_1 = \hat{\epsilon}_3$	<b>-0.141 (0.044)</b>	<b>-0.135 (0.046)</b>	<b>-0.106 (0.035)</b>
$\hat{\epsilon}_2$	<b>0.016 (0.042)*</b>	<b>= 0</b>	<b>= - <math>\hat{\epsilon}_1</math></b>
SUBVA	-0.014 (0.030)*	-0.014 (0.030)*	-0.027 (0.029)*
$\hat{\epsilon}_{83} \dots \hat{\epsilon}_{97}$	(Included)	(Included)	(Included)
$\hat{\sigma}^2$	0.0857	0.0857	0.0858
R <sup>2</sup>	0.9722	0.9722	0.9721
RSS	1121.66	1121.67	1122.19
R <sup>2</sup> within	0.4490	0.4490	0.4487
Parameters	3775	3774	3774
Observations	16859	16859	16859

White standard error of estimate in brackets. R<sup>2</sup> *within* is a measure of goodness of fit after the fixed effects have been controlled for. \* Not significant at 5% level.

*Summarising*, it appears that the activities carried out when entering an energy agreement have led to reduction in energy consumption (after controlling for the discount in energy taxes to these companies). It has not been possible to identify any differences in the effect on energy consumption of the agreements running from 1993-95 and those that started in 1996 and 1997 (due to the relative low number of companies with agreements that are present in the (net) database). However, data do offer support for a model, where the effect of agreements is assumed to be permanent (where »permanent« refers only to a persistent effect in 1996/1997 for agreements ending in 1995).

## 6.4 Effect of Agreements in a Sub-sample and with Alternative Time Effects

The companies that have made an agreement are different from the other

companies in the database, because only a limited number of companies – the most energy-intensive ones – have been given this option.

In the regressions carried out earlier all parameters (other than the fixed effects) are assumed to be equal for all companies, even though the companies are very different. It can be argued that it is better to compare the agreement companies with other energy-intensive companies instead of including all the industrial companies. Table 6.5 shows estimation results corresponding to the base-model where the effect of agreements is assumed to be permanent, but for different sub-samples from the net database. In alternative A in table 6.5 we rely on a sub-sample with the 50% of the companies with the highest energy-intensity, while we under alternative B show results for a sample consisting of roughly the 25% most energy-intensive companies. The base model represented by model 2 in table 6.4 (i.e. the same as model 3 in table 6.3) is repeated in order to ease comparison.

In the model based on the most energy-intensive half of the sample (alternative A) the effect of the agreements is the same as in the base model. However, when using only the 25% most energy-intensive companies (alternative B) the effect of the agreement becomes a little smaller (9% reduction in energy consumption).

The reduction in the agreement effect in model B could be caused by either the change in the parameters to value added and price or a change in the yearly time dummies, which capture the effect of unobserved variables (which change over time). To look further into this we have re-estimated the base model (on the whole sample), but allowed the yearly time dummies to vary for companies in four different groups of energy intensity (low, medium low, medium high and high energy intensity). In that model (not shown here) we get the same level of agreement effect as in alternative B. Thus, it appears that the effect of the unobserved variables (the time dummies) may be different in the most energy-intensive companies as compared to other companies, and if this is taken into account the agreement effect is reduced. Further along this line of reasoning, it can also be argued that four different patterns of time effects (according to the level of energy intensity) are still a strong restriction considering the large heterogeneity between the industrial companies.

Table 6.5 Estimation using a sub-sample

Model	Base model Whole sample in net database	Alternative A The half most energy intensive	Alternative B The 25% most energy intensive	Alternative C Individual time dummies
LFVA	0.542 (0.008)	0.550 (0.010)	0.504 (0.013)	0.319 (0.018)
LPE8	0.670 (0.098)	0.408 (0.116)	0.188 (0.141)*	-0.374 (0.152)
LPE8*LPE8	-0.137 (0.011)	-0.106 (0.014)	-0.074 (0.018)	0.017 (0.018)*
DCO2AG	<b>-0.1353 (0.036)</b>	<b>-0.1356 (0.036)</b>	<b>-0.094 (0.036)</b>	<b>-0.095 (0.051)*</b>
SUBVA	<b>-0.014 (0.031) *</b>	<b>-0.0133 (0.031)*</b>	<b>0.009 (0.034)*</b>	<b>-0.034 (0.037)*</b>
$\ddot{\epsilon}_{83}$	-0.130 (0.013)	-0.110 (0.018)	-0.066 (0.025)	941 individual trends
$\ddot{\epsilon}_{85}$	-0.169 (0.012)	-0.159 (0.015)	-0.115 (0.022)	
$\ddot{\epsilon}_{88}$	-0.356 (0.011)	-0.332 (0.015)	-0.254 (0.021)	
$\ddot{\epsilon}_{90}$	-0.261 (0.011)	-0.235 (0.015)	-0.144 (0.021)	
$\ddot{\epsilon}_{93}$	-0.203 (0.011)	-0.202 (0.015)	-0.142 (0.021)	
$\ddot{\epsilon}_{95}$	-0.147 (0.011)	-0.123 (0.015)	-0.069 (0.021)	
$\ddot{\epsilon}_{96}$	-0.036 (0.011)	-0.036 (0.015)	-0.016 (0.021)	
$\ddot{\epsilon}_{97}$	0 (base case)	0 (base case)	0 (base case)	
$\delta^2$	0.08572	0.08216	0.07656	0.04853
R <sup>2</sup>	0.972150	0.968808	0.970424	0.98648
RSS	1121.67	562.05	256.01	116.96
R <sup>2</sup> within	0.4490	0.4528	0.4261	0.7378
Parameters	3774	1893	953	1887
Observations	16856	8734	4297	4297

Standard error of estimate in brackets. R<sup>2</sup> *within* is a measure of goodness of fit after the fixed effects have been controlled for. \* Not significant at 5% level.

In alternative C in table 6.5 we have allowed a more flexible specification of time effects. Instead of a fixed effect an individual fixed effect together with an individual trend parameter have been estimated ( $\hat{a}_i = \tilde{a}_{1i} + \tilde{a}_{2i} \times t$ ).

It appears that this more flexible representation of the time effect also reduces the effect of the energy agreements to a level of 9-10% reduction in energy consumption. It also appears that the individual trends affect the estimated elasticities, which probably is due to correlation between the variables and the trends and/or to many parameters in the model. We will therefore not pursue the model with individual trend parameter further, but just take notice of the result that we – in the model with a very flexible representation of time effects at company level – obtain effect of energy agreements in the same range as in the other models.

Summarising again, it appears that the agreements in all the alternative models presented in table 6.5 yield a reduction in the use of energy, which is generally significant. The size of the effect is generally sensitive to the specification of the model. The effect in the models presented ranges from 9-14%.

## 6.5 On the Effect of Subsidies in Alternative Specifications

In the models presented so far the parameter to the subsidy variable has not been significantly different from zero. As compared to the agreement, which was only offered to relatively few industrial companies, all industrial companies have been able to apply for a subsidy, and (therefore) there are considerably more observations with a subsidy. The subsidy varies between the different companies (from a few thousand DKK to a couple of million DKK). Thus, there is more information/variation in the database on the subsidies as compared to the agreements, which was only a dummy variable for a restricted number of companies.

In the model we have used the accumulated subsidies given to the individual companies. This reflects that the effect of the subsidies is expected to be »permanent« in the time period covered by the database. These accumulated subsidies were measured as percent of the value added of the company (i.e. value added is used as a scale in order to compare subsidies given to different companies). A number of alternative specifications/models have been examined, but these have generally not given »better« results with respect to the effect of subsidies in the sense that the subsidy variable consistently has been insignificant (and the overall goodness of fit of the models has practically been unchanged). Estimates of these different attempts will not be shown, but they include the following alternatives:

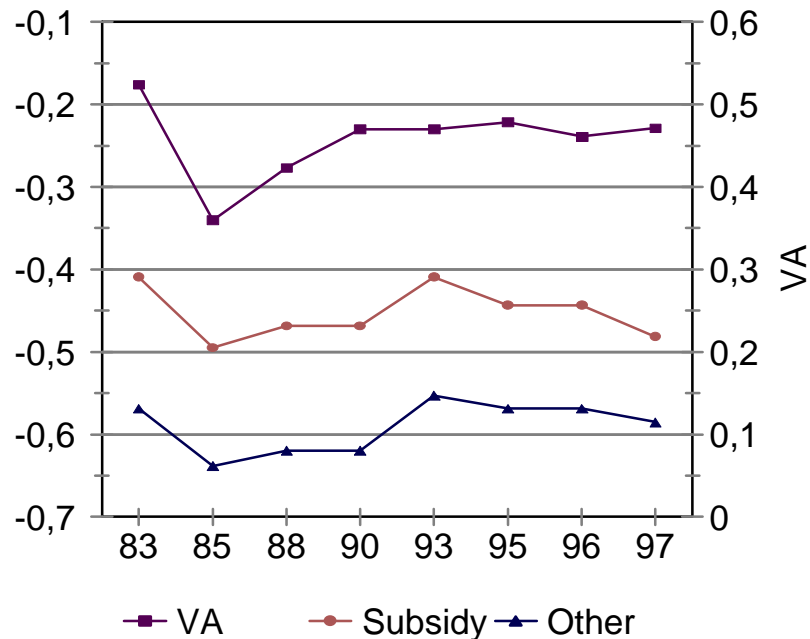
- S** Instead of using the accumulated subsidies only the subsidy given in each year was used (assuming that the effect of an investment subsidy is only temporary instead of permanent).
- S** The effect of the subsidies was estimated to affect the level of energy consumption the following year (delay in the effect both for permanent and temporary subsidy effect).

- S The effect of subsidies was modelled as a simple 0/1 dummy.
- S Subsidies were measured as percent of production value or total energy expenditure instead of using value added as scaling variable.
- S Only companies which at one point in time had obtained a subsidy were included in the estimation (investigating if the demand parameters of subsidy companies are different from other companies).
- S The variable SUBVA transformed in different ways (e.g.  $SUBVA^2$  and  $SUBVA^{1/2}$ ).
- S The parameter to SUBVA was allowed to vary with different levels of energy intensity or different industrial sub-sectors.
- S A model without log-transformation of the variables has also been estimated (here the level of subsidies was included without scaling with value added).

The (highly insignificant) parameter to the variable SUBVA in the base model is -0.014. The interpretation of the parameter is the following: A subsidy corresponding to 1% of value added yields a reduction in this company's energy consumption corresponding to 0.014%.

Figure 6.2 gives a visual illustration of the »missing« effect of the subsidies. The figure shows the development in the average energy intensity over time, for three different groups of the industrial companies: 1) companies that have signed an agreement (in the period 1993-1997), 2) companies that have obtained a subsidy (in the period 1993-1997 and which have not also signed an agreement) and 3) companies that have never received a subsidy or signed an agreement. The first group of companies are considerably more energy intensive than the other, so for this group the scale is on the vertical axis to the right.

Figure 6.2 Mean Energy Intensity (log(GJ/value added in fixed prices))



The graph is based only on companies which are present in the database in all years (the balanced net-sample) and therefore the first group only consists of 17 companies and the development in average energy intensity for this group should therefore be interpreted cautiously. In the second and third group there are a reasonably large number of companies (123 and 354 respectively). The figure illustrates that the energy intensity in companies with and without an investment subsidy has followed the same pattern over time, both before and after 1993, where the subsidies started. The energy intensity for companies obtaining a subsidy is reduced in the period from 1993 to 1997, but the energy intensity is also reduced for companies without subsidies.

The energy intensity of companies with agreements (keeping in mind the small number of companies in this group) seems to follow the same pattern as the other companies in the period up till 1993, e.g. energy intensity drops from 1983-1985 and increases from 1985 to 1993 for all companies). From 1993 to 1997 the energy intensity is increased in the companies with agreements. The development in energy intensity for the companies with agreement seems opposite to the effect of the agreements found in the econo-

metric model. However, the energy intensity in figure 6.2 does not take into account the differences in the energy cost of companies with agreements and the other companies. The agreement companies obtain a discount, so compared with the other companies this would tend to pull the energy intensity up. The energy-reducing activities carried out by the companies will on the other hand tend to pull energy intensity down.

Finally, it should be noted that the energy intensities in figure 6.2 represent companies that have been in the industry in the whole period and do therefore not need to mirror the »macro« energy intensity, which have been going down (i.e. improved) in the same period. The reason for the difference is that »new« companies that enter the industry have considerably lower energy intensity as compared with companies which leave the database. This type of structural adjustment, which influences the aggregate energy intensity can of course not be found in the balanced sub-sample illustrated in figure 6.2.

In the following section we will take a second look at the effect of agreements and subsidies, when we allow the demand parameters of the companies to vary between different industrial sub-sectors.

## Notes

1. The same conclusions can also be obtained for less restricted models with different constant terms and elasticities for different industrial sub-sectors.
2. The »wrong« positive sign to the energy-agreement dummy in the (pooled) cross-section models simply reflects that it is only the energy-intensive companies that are offered the agreement. The wrong sign in the (pooled) cross-section regressions can be seen as a result of selection bias (which, like with many other selection problems, is accounted for in the panel fixed effects model).
3. It appears to be a general phenomenon that the scale variable is reduced in fixed effects models as compared with cross-section estimates. See e.g. Griliches and Mairessee (1995) for other examples and alternative interpretations of this phenomenon (i.e. their view is that the result from panel data models (for firm or plants) like the fixed effects model has been rather unsatisfactory).
4. In an alternative model, where we apply the functional form of model 1 in table 6.2, but allow the price elasticity to be individually determined every year ( $\hat{\alpha}_{2t}$ ), it is also found that the price elasticity change over time with the price level.

# 7 Model with Differences in Demand Parameters Between Sectors

In the regressions reported so far the parameters to value added and the relative prices are assumed to be the same for all companies even if they belong to different industrial sub-sectors (though the price elasticities depend on the level of the relative price, because of the inclusion on the second order price term). It is, however, likely that the demand parameters vary between different sectors due to differences in technology. This restrictive assumption is relaxed in the following, where we have allowed the parameters to value added and the two price variables (LPE8 and LPE8×LPE8) to vary between 13 different industrial sub-sectors. However, due to the relative low number of observation with agreements and investment subsidies we still restrict the effect of the agreements and the investment subsidies to be the same across sectors. The modified (less restricted) model appears as:

$$\text{LE8}_{it} = \hat{a}_i + \hat{a}_{S1} \text{LFVA}_{it} + \hat{a}_{S2} \text{LPE8}_{it} + \hat{a}_{S3} \text{LPE8}_{it} \times \text{LPE8}_{it} + \hat{a}_4 \text{DCO2AG}_{it} + \hat{a}_5 \text{SUBVA} + \ddot{e}_t + v_{it}$$

$$v_{it} \sim \text{i.i.d } N(0, \hat{\sigma}_v^2 I) \tag{7.1}$$

where S = industrial sub-sector (1..13)  
t = time (83, 85, 88, 90, 93, 95, 96, 97)  
i = industrial company (1..3762)

Thus,  $\hat{a}_{S1}$  is now a vector consisting of 13 elasticities with respect to value added for each of the sub-sectors in the database.<sup>1</sup>

The estimated parameters in this model can be found in table 7.1. It appears that there are some differences in the demand parameters between

different industrial sectors, though it also appears, by comparing the goodness of fit statistics in table 7.1 with the simple models in section 6 that the large increase in the parameters only gives a little increase in the goodness of fit of the model. For instance,  $R^2$  within is 0.46 in table 7.1, while it was 0.44 in the preferred model in section 6. However, the increase in goodness of fit is significant even at 1% (using a standard F-test).

It can be argued that the yearly time dummies should also be allowed to vary among the 13 different sub-sectors, because these may reflect technological changes, which may vary between sub-sectors. Including sub-sector specific time dummies means that a large number of additional parameters have to be estimated ( $12 \times 7 = 84$  new time dummies). Inclusion of these dummies only gives a small (though significant) increase in the goodness of fit, and does (generally) not influence the estimated elasticities or the effect of agreements and subsidies. Therefore, it is chosen only to present the (more restricted) model with common time dummies for all industrial companies.

With respect to the size of the parameters in the model with sector specific elasticities it appears that the (permanent) effect of the agreements is 9%, i.e. lower than in models where demand parameters were restricted to be the same for all industrial companies. The effect of agreements is just outside the 5% significance level («white» t-value = 1.89, which corresponds to a p-value at 0.058), but the parameter is significant at a 10% level. The parameter to the subsidy variable is similar to the parameter found in the more restricted models in section 6, but the parameter is still insignificant.<sup>2</sup>

With respect to the parameters the elasticity with respect to value added is significant for all the industrial sub-sectors except for *Extraction* (of gravel, clay, stone, salt etc), but this sector also has far the smallest number of companies represented in the database (between 3 and 11 in the different years). With respect to the parameters to the price terms there are also problems with significance for *Extraction*, as well as for *Food* and *Chemicals*. *Chemicals* is also a sector with relative few observations (between 54 and 88 in the different years).

Table 7.1 Model with sector specific demand parameters

Industrial sub-sector	Sector specific parameters		
	LFVA	LPE8	LPE8xLPE8
Extraction of gravel, clay, stone, salt	0.19 (0.27)*	-0.30 (1.86)*	-0.017 (0.233)*
Food, beverages and tobacco	0.57 (0.03)	-0.21 (0.18)*	-0.031 (0.021)*
Textiles, wearing and leather	0.44 (0.04)	1.79 (0.26)	-0.259 (0.029)
Wood and wood products	0.55 (0.07)	1.45 (0.37)	-0.216 (0.041)
Paper, printing and publishing	0.56 (0.05)	2.06 (0.61)	-0.279 (0.065)
Chemicals	0.58 (0.07)	-0.13 (0.33)*	-0.047 (0.038)*
Rubber and plastic products	0.65 (0.05)	1.72 (0.61)	-0.250 (0.064)
(Other) Non-metallic mineral products	0.50 (0.06)	1.56 (0.38)	-0.228 (0.044)
Basic metals (manufac. and process.)	0.56 (0.04)	1.62 (0.28)	-0.244 (0.032)
Machinery and equipment	0.53 (0.03)	1.57 (0.30)	-0.232 (0.034)
Electrical and optical instruments	0.61 (0.04)	1.46 (0.31)	-0.243 (0.037)
Transport equipment	0.58 (0.06)	1.35 (0.35)	-0.224 (0.040)
Furniture and manufacturing n.e.c	0.49 (0.05)	1.96 (0.29)	-0.282 (0.033)
	Common parameters		
DCO2AG	-0.0927 (0.049)*		
SUBVA	-0.0173 (0.032)*		
$\rho_{83}$	-0.117 (0.018)		
$\rho_{85}$	-0.159 (0.015)		
$\rho_{88}$	-0.349 (0.012)		
$\rho_{90}$	-0.257 (0.011)		
$\rho_{93}$	-0.196 (0.012)		
$\rho_{95}$	-0.139 (0.010)		
$\rho_{96}$	-0.033 (0.008)		
$\rho_{97}$	0 (base case)		
$\sigma_v^2$	0.0847		
$R^2$	0.9726		
RSS	1104.53		
$R^2$ within	0.4574		
Parameters	3810		
Observations	16859		

White standard error of estimate in brackets.  $R^2$  *within* is a measure of goodness of fit after the fixed effects have been controlled for. \* Not significant at 5% level.

With respect to the assumptions of the error term it should be noted that there appears to be a rather strong auto-correlation in the model with positive correlation in the error terms in the short run and negative in the long run (see appendix 7.1 for a description of this correlation). One interpretation/explanation of this correlation is that there are some unobserved shifts in the level of energy intensity, which may be due to change in composition of output, large investments in capital etc.<sup>3</sup> Various ad-hoc formulations with lagged dependent variables have been examined, but these have not removed the auto-correlation. However, the white standard errors applied here corrects for auto-correlation (as well as heteroscedasticity).

Table 7.2 Price elasticities by industrial sub-sector

Industrial sub-sector	Value added elasticity	Price elasticities	
		Mean (simple) 1983-97	Weighted mean 1983-97
Extraction of gravel, clay, stone, salt	0.18*	-0.45*	-0.43*
Food, beverages and tobacco	0.57	-0.46*	-0.45*
Textiles, wearing and leather	0.44	-0.57	-0.35
Wood and wood products	0.55	-0.50	-0.39
Paper, printing and publishing	0.56	-0.60	-0.35
Chemicals	0.58	-0.55*	-0.51*
Rubber and plastic products	0.65	-0.64	-0.52
(Other) Non-metallic mineral products	0.50	-0.42	-0.21
Basic metals (manufac. and process.)	0.56	-0.60	-0.51
Machinery and equipment	0.53	-0.52	-0.48
Electrical and optical instruments	0.61	-0.72	-0.69
Transport equipment	0.58	-0.60	-0.56
Furniture and manufacturing n.e.c	0.49	-0.59	-0.56
<b>Total industry</b>	<b>0.54</b>	<b>-0.57</b>	<b>-0.44</b>

Note: \* indicates that the sub-sector parameters used to calculate the elasticity were not significant at 5%.

The parameters to the price terms cannot be interpreted directly, since the derived price elasticity depends on the price level. Table 7.2 reports demand elasticities with respect to value added (corresponding directly to the parameters in table 7.1) and with respect to price. The significant elasticities with respect to value added range from +0.44 to +0.65 and the weighted mean for the whole industrial sector is +0.54, i.e. almost identical to the elasticity in the simple model.

The derived price elasticities in table 7.2 are calculated respectively as simple means and means weighted by energy consumption based on all the observations in the net database. The weighted elasticities correspond to the aggregate effect on energy consumption. A comparison of the unweighted and weighted elasticities shows that the weighted price elasticities are lower. For instance, for the whole industrial sector the unweighted price elasticity is -0.57, while the weighted is only -0.44. This reflects that the most energy-intensive industrial companies generally have cheaper average energy cost (due to the composition between different types of energy and/or discounts in the electricity price) in which case they – according to the model – also have lower price elasticity.

Over time the calculated mean elasticity will change according to changes in the level of energy cost. However, mean price elasticities (weighted and unweighted) based only on observations in 1997 are very similar to the elasticities reported in table 7.2.

The weighted price elasticities for different industrial sub-sectors range from -0.21 to -0.69. The price elasticities for the sub-sectors where the parameters to price were not significant (*Extraction, Foods and Chemicals*) are in the middle of this range. Thus, the calculated price elasticity for these sectors seems plausible. In order to further validate the price elasticities for these three sub-sectors, we have estimated an alternative model, where the second order price term has been excluded (for all 13 sectors). In this simpler model the (constant) price elasticities for the three sub-sectors are very similar to the ones reported in table 7.2 and the (constant) price elasticities are significant (even at a 0.1% level). Thus, apparently collinearity between the first and second order price term have inflated the standard errors for these sectors, and the price elasticities described in table 7.2 for these sectors seem reasonable.<sup>4</sup>

Finally, it should be noted that for some observations the calculated price elasticity has the wrong sign, but this is only the case for ½% of the observations.<sup>5</sup>

In a previous study using a preliminary version of the database (reported in Bjørner, Togeby and Christensen, 1998) it was also found that companies with high energy intensity (which also tend to have a low energy price) had a lower (numerical) price elasticity than companies with low energy intensity. This was found using another specification of the model where all companies were divided into four groups according to their energy intensity. These energy intensity groups were included in the model, where also allowed variation in elasticities according to industrial sub-sector and energy intensity was allowed. In the current study it was also tried to allow the estimated parameters to price and value added to vary according to different levels of energy intensity of the companies, but the demand parameters are not influenced by level of energy intensity in a consistent way. This is probably because the lower price elasticity of the most energy-intensive companies (in the former study) already is captured by the second order price term included here. In the study by Kleijweg et al. (1989) described in section 3, it was also found that the most energy-intensive industrial

companies had lower price elasticity. Thus, the lower price elasticity for companies with low average energy price (high energy intensity) is supported by using another method to identify the difference (grouping companies according to energy intensity) and by another study.

With respect to the size of the price elasticities these appear to be similar to what is typically found in international studies based on time series, while it is higher than the elasticities found in previous Danish time series studies (see section 3).

In the next section we will discuss more carefully the interpretation of the estimated parameters to energy agreements, investment subsidies and the effect these instruments as well as of the taxes on energy used in Denmark. The calculations are based on the model presented in this section.

## Notes

1. The 13 sub-sectors corresponds to the industrial sub-sectors in Statistics Denmark's standard aggregation of all the DB93 codes in 53 different sectors – 13 of these are within industry.
2. The effect of agreement consists of a simultaneous change (reduction) in energy price and an implementation of energy-saving activities. The effect of the energy-saving activities may therefore be affected by the implicit assumption that agreement companies have the same demand parameters (to value added and the price terms) as other companies (in the same sub-sector). In order to check if agreement companies react in the same way to changes in price and value added as other companies we assigned dummies to companies that at one point in time have had an agreement. These dummies were included in the model in interaction with the parameters to value added and the price terms to test if the agreement companies »historically« have responded to observed changes in production and price in the same way as comparable companies without an agreement. However, the more flexible description for the agreement companies only had a small influence on the agreement effect (a bit higher effect). Same exercise was also carried out for the subsidy companies.
3. As an example, say that there is one shift (a reduction) in energy intensity in the middle of the period. In this case the fixed effect will be the average of the high energy intensity in the beginning of the period and a low energy intensity at the end of the period. Error terms within the first and second period (respectively) will therefore be positively correlated, while error terms in the first and second period will be negatively correlated.
4. Note that taken together the 13 second order price terms are significant even at a 0.1% level according to a standard F-test

5. Note that if these arbitrarily are given a price elasticity equal to 0 the mean price elasticities in table 7.2 are practically unchanged.

# 8 On the Effect of Taxes, Subsidies and Agreements

This section presents a discussion of the effect of the various policy instruments used to reduce industrial companies' use of energy and emission of CO<sub>2</sub>. The effect of the different taxes on energy consumption will be calculated using the parameters from the model presented in section 7, where a number of demand parameters are allowed to vary between different industrial sub-sectors.

The mean of the estimated price elasticity is -0.44. This price elasticity is a little higher than found in previous Danish studies based on time series (which have ranged from -0.1 to -0.3). The higher price elasticity suggests that the effect of energy taxes on energy demand (and ultimately CO<sub>2</sub> emission) is higher than previously found.

In table 8.1 we present the simulated/calculated increase in energy use if all energy taxes paid by industrial companies were abolished.<sup>1</sup> Thus, according to the model the companies in the (net) database would have had 10% higher energy use in 1997, if they had not paid the energy taxes.

Table 8.1 Increase in energy use in case of zero energy taxes

1993	1995	1996	1997
6%	6%	7%	10%

As described earlier the Danish industrial companies have since 1993 had the opportunity to apply for subsidies to invest in equipment to raise energy efficiency, and the most energy-intensive companies have also had the option of entering a voluntary energy agreement. Both the investment subsidies and a voluntary agreement are something the industrial company itself chooses to apply for. Evaluation of this type of instruments using cross-section data often suffers from self-selection bias (e.g. if companies

that choose a certain type of regulation are different – in an unobserved way – from the companies that do not choose that type of regulation). However, the fixed effects estimators applied here will produce consistent estimators of the above policy instruments, because the unobserved differences between companies will be captured by the company specific fixed effect (assuming the unobserved effects related to selection are time invariant).

It should, however, be noted that the fixed effects estimator yields the effect of the companies that have had an audit in the period from 1993 to 1997. The effect of agreements for companies which more recently have signed an agreement may be different from the effect estimated here.<sup>2</sup> See Heckman and Robb (1985) for a detailed discussion on this and the self-selection issues.

Regarding the effect of investment subsidies and agreements it should be noted that companies with local production of electricity and district heating have not been included in the analysis. Thus, the focus is on subsidies given to improvements in energy efficiency, while subsidies given to aid local production of electricity/district heating are not included in the analysis.

### **Subsidies to Investments in Energy Efficiency**

With respect to the investment subsidies we have obtained a negative parameter to the subsidy variable, but this parameter was not significantly different from zero (even though a large number of companies have benefited from this subsidy). Thus, we cannot reject that the subsidies have had no effect on the energy use.

With respect to the investment subsidies we have obtained a negative parameter to the subsidy variable, but this parameter was not significantly different from zero. Thus, we cannot reject that the subsidies have had no effect on the energy use.

Even though highly insignificant the parameter to the subsidy variable (SUBVA) has ranged from -0.012 to -0.017 in most of the estimated models. The highest effect of the subsidies was found in the model with sector-specific demand parameters.

If the high estimate at -0.017 to the subsidy variable is used to calculate the derived CO<sub>2</sub> reduction for each company obtaining a subsidy, the average amount of subsidies per ton reduced CO<sub>2</sub> is 4,611 DKK or 0.22 kg

CO<sub>2</sub> per DKK paid in subsidy per year. The latter number can be compared with the calculated effect of the subsidies in a recent evaluation presented in the Danish Energy Agency (2000b), where it was found that the latter number was 0.51 kg CO<sub>2</sub> per DKK paid in subsidy. Thus, our model suggests that the subsidies have had less than half the effect on CO<sub>2</sub> as compared with the Danish Energy Agency (2000b).

The effect of subsidies on CO<sub>2</sub> calculated in the Danish Energy Agency (2000b) was based on the expected reduction in use of energy and CO<sub>2</sub> in the description of the projects, which was part of the application for the subsidy. The calculations in the Danish Energy Agency also used an evaluation of the effects of a number of specific investment projects described in Ravn and Sørensen (1998). This study was based on visits to 96 of the companies, which had carried out an energy-saving project supported by the Danish Energy Agency in order to compare the realised energy savings (after the investment project had been carried out) with the expected a priori. Overall, it was found that the realised energy savings almost corresponded to the energy savings expected a priori. As part of this study the companies were also asked if they would have carried out the investment project even without the subsidy. Based on the companies' responses to these questions a free-rider share of 20% was used in the calculations carried out by the Danish Energy Agency (2000b).

A potential explanation for the discrepancy between the effect calculated here and the higher effect calculated by the Danish Energy Agency is that the database used in this study could be better to account for free riding (i.e. information on energy use before and after the subsidy has had an effect as well as information on companies both with and without a subsidy give good control groups). It seems likely that direct questions to companies about their free-riding behaviour may underestimate the share of free riding. In addition it can be argued that the model adopted here controls for the effect of e.g. changes in production levels on energy use. Finally, it should be recalled that subsidies given to support and/or improve the efficiency of local production of district heating or electricity in industrial companies are not included in our model.

It should be emphasised that the parameter at -0.017 is very badly determined (insignificant). The 95% confidence interval of this estimate ranges from +0.045 to -0.080. A reduction corresponding to 0.51 kg CO<sub>2</sub> per DKK

paid in subsidy corresponds to a parameter at -0.040, which is within the above confidence interval. Thus, the effect at 0.22 kg CO<sub>2</sub> per DKK paid in subsidy obtained here is not significantly different from the 0.51 kg CO<sub>2</sub> per DKK obtained by the Danish Energy Agency. However, it should also be noted that it – accepting the model at face value – is more likely that the subsidies have had no effect on energy use, than that the subsidies have had an effect as high as 0.51 kg CO<sub>2</sub> per DKK paid in subsidy.

In the model the effect of the subsidy is »permanent« in the sense that the effect persists during the entire period covered by the database (e.g. a subsidy given in 1995 is assumed also to affect energy use in 1996 and 1997). The effect of the subsidy can, however, not be indefinite. If it is assumed that the subsidy has a (constant) effect on CO<sub>2</sub> in exactly eight years and if future reductions in CO<sub>2</sub> are discounted at a 6% rate the amount of subsidies paid to obtain a one ton reduction in CO<sub>2</sub> (including the discounted future CO<sub>2</sub> effects) is 701 DKK.<sup>3</sup> However, due to the badly determined effect of the subsidy in the model the numbers related to the effect of the subsidy should be interpreted with care.

As noted in the introduction the primary purpose of the study has been to estimate the effect of the different instruments applied, while the issue of the efficiency of the different instruments is outside the scope of the report. However, some considerations related to the social costs of the investment subsidies are given below.

It is tempting to make a direct comparison between the »subsidy price« at 701 DKK per ton CO<sub>2</sub> and the social shadow costs of reducing CO<sub>2</sub> (a number of recent studies suggest that the social shadow cost of the Danish CO<sub>2</sub> targets – emission constraints – has a range of 100-300 DKK per ton CO<sub>2</sub>.<sup>4</sup>). However, generally subsidies cannot directly be interpreted as social costs, because they affect allocation and do not (necessarily) represent any resource costs. However, in this case it can be argued that the subsidies represent some additional investment costs carried out by the company (and therefore an additional resource cost).

One way to calculate the CO<sub>2</sub> shadow cost of the projects obtaining subsidies is carried out and presented in the Danish Energy Agency (2000b). Based on their estimated effect at 0.51 kg/year/DKK paid in subsidy a CO<sub>2</sub> shadow cost at 400 DKK per ton is obtained. The subsidies are generally given only up to 30% of the investment cost, so the companies have addi-

tional resource costs associated with the projects. The companies own investment costs are included in the calculations by the Danish Energy Agency, as well as the (social) value of the reduction in the energy costs (which can partly be seen as a benefit for the companies). However, the companies may have other gains associated with the project than the reductions in energy costs.<sup>5</sup> Thus, it may be argued that the companies would only pay their 70% of the project cost if they have a private benefit (e.g. energy savings, but also other things not identified in the application like replacement of outdated machinery etc.) at least as high as their contribution of the investment cost.

It should also be noted that there are additional social cost associated with the subsidized projects. Thus, there are distortionary effects (i.e. cost) and administrative costs of raising the tax revenue, which are needed to give subsidies. In addition there are administrative costs in the Danish Energy Agency associated with granting subsidies (but from Rigsrevisionen (1998) and the Danish Energy Agency(2000b) it appears that the latter is fairly limited) as well as cost in the companies associated with the application of subsidy. The two latter of these costs are included in the calculation of the CO<sub>2</sub> shadow cost while the former is not.

## **Agreements**

Turning to the agreements we have generally found that energy use in companies, which have (or recently have had) an agreement (in the period from 1993 to 1997) has been lower than before the agreement (after controlling for changes in value added and the energy cost). Same results – at least qualitatively – have been found in a number of alternative specifications/models for industrial companies' energy demand. Thus, in all alternative cases the parameter to the agreement variable is negative and generally also significantly different from zero, but the size of the parameter does depend on the model specification and the parameter is not very precisely determined (wide confidence interval). However, overall the analysis suggests that the agreements have had a real and substantial impact on energy use in the involved companies. Based on the models in sections 6 (table 6.5) and 7 it appears that the effect of the agreements is a reduction in energy use around 9%.

When entering an agreement the companies, on the one hand, have to

carry out an energy audit, to realize some of the proposed energy savings and to initiate energy management; on the other hand, they pay a reduced tax on energy. The estimated effects of agreements at 9% can be labelled as a »gross« effect. This gross effect relates to the effect of the audit and the energy management, which can be compared with the reduction in energy demand, if the companies had not entered (or been offered) the agreement, but instead paid the full tax on energy.

In table 8.2 it is shown how much energy use would have been reduced, if the agreement companies had paid the full tax.

Table 8.2 (Mean) effect on energy use of full tax for agreement companies

	1993	1995	1996	1997
	5%	5%	0% (very low)	1%

It appears that the tax discount only had little impact on agreement companies' energy demand in 1996 and 1997, while the companies with agreement – *ceteris paribus* – would have used 5% less energy with a full tax in 1993 and 1995. However, recall also that there are only relatively few companies with agreements in the database in 1996 and 1997.

Note that the relatively small effect of paying full energy tax also reflects that the companies with agreements are among the companies with the lowest price elasticity in their energy demand (reflecting that they are very energy intensive).

The estimated effect of audits and energy management (9%) is higher than the derived effect on energy demand of the tax discount. This suggests that companies (with an agreement) would have used more energy if they had not been offered the agreement, but just paid the full energy tax.<sup>6</sup> Thus, looking (only) at the effect on energy use the Danish energy agreement appears to have been a successful policy instrument.

With respect to later years it should be noted that the tax discount – as well as the number of companies with agreement – has been increasing in the period from 1998 to 2000, so the positive net effect of agreements on energy savings could have deteriorated in these years.

As emphasised we have »only« looked at the effect of the agreements on energy use and not dealt with the efficiency of the agreements as compared to other instruments. A broader comparison of the relative efficiency would

need to include aspects like the administrative cost of the agreements<sup>7</sup> as well as other issues. It should also be taken into account that the agreement scheme with tax discount was initiated, because it due to competition and employment considerations was not political feasible to put a CO<sub>2</sub> tax on the most energy-intensive companies. However, it has been suggested that the assistance to the most energy-intensive industries instead of tax exemption could be achieved by grandfathered tradable emission permits. In Jensen (1998) it is found that the social costs of the latter policy could be lower than for a policy with the tax exemption.<sup>8</sup>

It should also be noted that earlier evaluations of the effect of the energy agreements (including the »audits« as these arrangements were labelled from 1993 to 1995) have yielded a somewhat lower effect of the agreements than suggested by our estimates. However, it is difficult to carry out a direct comparison of the different evaluations because different periods of time are covered by this study as compared with previous studies and/or because the companies included in the different studies are not identical. (e.g. as described in section 5 it was chosen not to include companies with local production of electricity and district heating in this study, while some companies with agreements could not be matched to the gross database).

In addition the earlier evaluations have focussed on the effect of the energy-saving projects, which were identified in the energy audit, but they do not include the potential effect of better energy management etc. The latter effects should be included in the results derived here (i.e. the short/medium run effect). In addition the earlier evaluations have generally been performed without including any control groups (but have included the majority of the companies with agreements).

An (early) evaluation of the first generation of energy agreements (denoted »audits«) from 1993 to 1995 was carried out at the end of 1993, see Ravn et al. (1994). According to this study potential energy savings corresponding to 5-6% of the energy consumption were identified by the energy audits. Based on detailed studies of (only) 11 of the 137 companies that entered the arrangement at the beginning of 1993 it was found that only about a quarter of the potential energy-saving projects had been »realized« during 1993 (i.e. steps were taken to carry out the project). This suggests that the overall short-term effect (or perhaps first-year effect) of the first generation of agreements would be less than a 2% reduction in energy

consumption. Potential effects of energy management and potential effects to be realized after 1994 were not included in this study.

Two other quantitative evaluations/studies were carried out in 1998 (as separate parts of a joint evaluation also including two qualitative studies), which looked at the effect of agreements initiated in 1996 or 1997. One of these studies (Togebjerg and Hansen, 1998) was based on a questionnaire where companies with an agreement<sup>9</sup> were asked to indicate the expected reduction in energy consumption associated with energy projects specified by the energy audits (which also were part of the new agreements starting in 1996). On average the companies reported reductions in CO<sub>2</sub> derived from the energy-saving project corresponding to 4.8%. The companies also reported that 40% of the projects would probably have been carried out even without the energy agreement, so the net additional reduction in energy use derived from the agreement would only be a 2.8% reduction in CO<sub>2</sub> (the respective numbers weighted with energy consumption are 2.2% and 1.4%). In the study it was also found that the presence of agreements had strengthened the energy management (and/or the energy managers).

The other evaluation (Ahé et al. 1998) was based on information from the Danish Energy Agency on the projects agreed upon as part of the agreements. This study gave similar results as compared with the study described above.<sup>10</sup>

It should be noted that the effects from the 1998 studies cannot be directly compared with the 9% reduction in energy use estimated in this study, because the studies from 1998 only focussed on the effect directly derived from the agreements starting in 1996 and 1997. However, most of the companies that entered an agreement in 1996/1997 also had an agreement in the period from 1993 to 1995. For companies with agreements in both periods the 2.8% reduction from Togebjerg and Hansen (1998) measures the additional effect of the latter starting in 1996/1997 (i.e. above the effect of the agreement /audit which was in effect before 1996). In comparison the effect of 9% estimated here captures the effect of both generations of agreements (and may include some long-run effects of the early agreements which were not observed in Ravn et al. (1994)).<sup>11</sup>

Finally, as described above the other studies have focussed on the effect of the energy saving projects, which were identified in the energy audit, but do not generally include effects of increased energy management and

spillover effects. The effect of agreements presented in this report would include potential (short and medium term) effects of increased energy management.

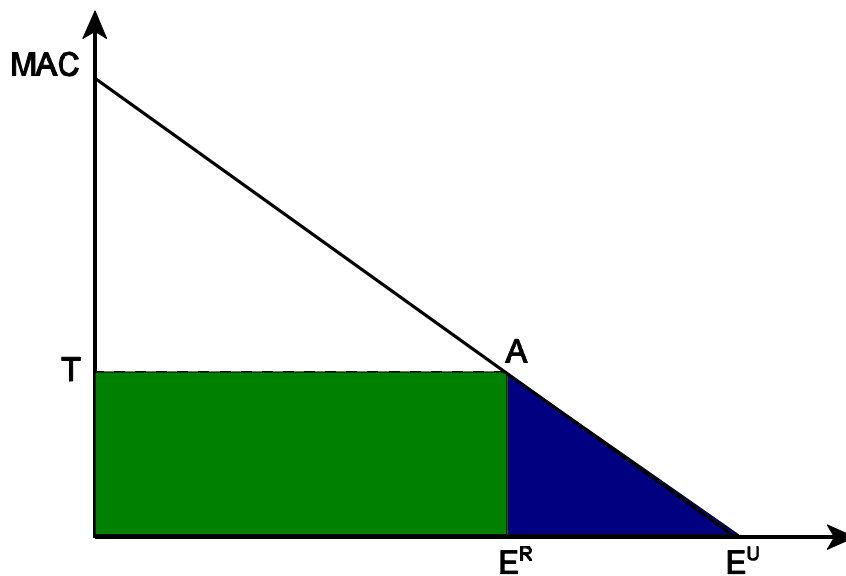
It is interesting to relate the empirical results on the effect of agreements to the (theoretical) findings in Segerson and Miceli (1998). They concluded that when the threat of alternative regulation is high – like the Danish energy agreements – voluntary agreements may be as effective in reducing emissions as the alternative type of regulation, when the latter has a command and control nature. However, if the alternative threat is command and control regulation combined with a subsidy inducing participation in agreements, then the agreements may lead to reductions in emissions, which exceed the level that otherwise may have been imposed (super-compliance).

The Danish agreements with tax exemption are similar (in spirit) to Segerson and Miceli's model with a subsidy. The finding that the Danish energy agreements, which are backed up by a form of subsidies, lead to reductions in energy exceeding the levels subject to alternative regulation can therefore be seen as support for Segerson and Miceli's results. A simple illustration is given in figure 8.1,<sup>12</sup> where the vertical axis measures the marginal abatement costs (MAC), while the horizontal axis is the level of emissions/energy use.  $E^U$  is the unregulated level of emissions, where MAC equals zero.

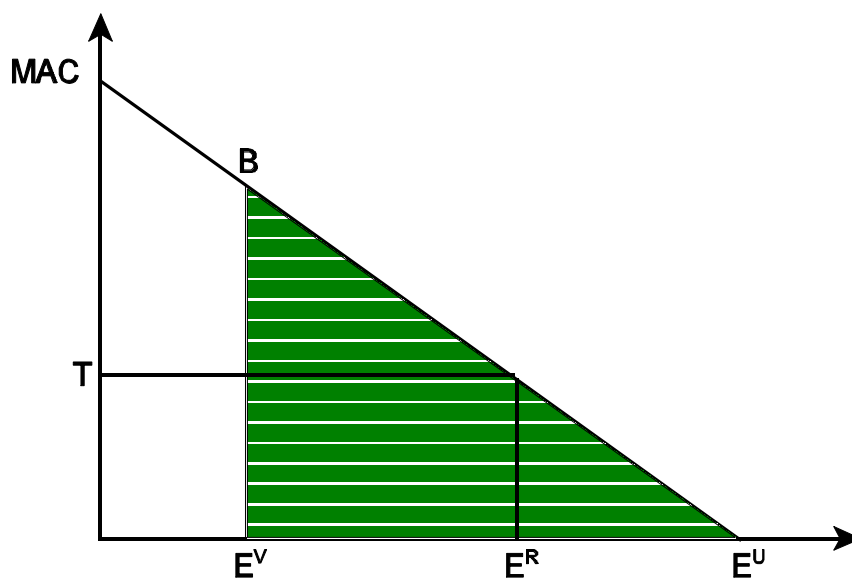
Let us first consider the situation where the alternative regulation is command and control. Let  $E^R$  be the regulated level of emission. For the company the costs of this regulation are equal to the black area ( $E^R A E^U$ ). The company cannot be persuaded to »voluntarily« reduce the emission level beyond  $E^R$ , because it would then have higher cost than with regulation.<sup>13</sup> If the company »voluntarily« reduces emissions at a level somewhere between  $E^R$  and  $E^U$  it will obtain a benefit, if it by this action avoids being regulated. The higher the threat of alternative regulation the more reductions in emissions the company will be willing to carry out (but only down to  $E^R$ ).

Figure Quantitative/tax threat  
8.1

Quantitative threat



Tax threat



The regulated level of emissions may instead of quantitative regulation also be achieved by imposing an emission tax equal to  $T$ . In the case the cost for the firm is considerably higher, because it also pays the tax. The tax cost equals the grey area ( $OTA E^R$ ), while total costs are the black and the grey area.

Say that the company can get a tax exemption by reducing emissions down to  $E^R$ . In this case it will get a benefit equal to the tax cost. It is also obvious that the company may be willing to reduce emission level even more. When the alternative regulation is a tax (and the threat is high) the company may be persuaded to »voluntarily« reduce emissions down to a level equal to  $E^V$  (on the lower part of figure 8.1). In this case the striped area indicating the costs to the firm ( $E^V B E^U$ ) is equal to the cost subject to tax regulation.

Summarising, it is not implausible to observe that the Danish companies with energy agreements have reduced their energy consumption more than they would have done, if they had not had the agreement.

## Notes

1. Taxes removed both for companies with and without agreements.
2. Note also that the gains and obligations of the companies with agreements both have changed over time (also for agreements starting in 2000), which makes it rather complex to model/forecast the number of companies with agreements.
3. In Danish Energy Agency (2000b) it is assumed that the projects have an effect on CO<sub>2</sub> as long as 15 years. The 15 years appear to be related to the technical lifetime of the projects. However, it is widely recognised that the economic lifetime of investment projects may be considerably lower than the technical lifetime (companies may close down, change production equipment due to change on product lines or technological progress may lead to replacements of equipment). If a 5 and 10 years time horizon is used instead the subsidy cost per future discounted (6% discount rate) CO<sub>2</sub> reductions are respectively 591 and 1033 DKK per ton CO<sub>2</sub>.
4. Actual estimation of the marginal damage of CO<sub>2</sub> emissions is by nature difficult to carry out and varies considerably. However, a number studies have calculated the social shadow cost of the Danish CO<sub>2</sub> targets (emission constraints). These studies are based on CGE models, see e.g. Hauch (1999a and b), DØR (1997), Jensen (1998) and finally Gørtz, Hansen and Larsen (1999). The scenarios used to calculate the CO<sub>2</sub> shadow cost appear to vary in the

different studies (different assumptions with respect to e.g. the effect of liberalisation in the electricity sector or the way the CO<sub>2</sub> target is reached). In some studies the emission cost is increasing over time. In this case we have relied on the (relatively low) shadow cost for the year 2000.

5. If the company have additional benefits (besides the reduction in energy use) not included in the calculation this suggest that the CO<sub>2</sub> shadow cost at 400 DKK per ton calculated by Danish Energy Agency (2000b) are too high. On the other hand the shadow cost at 400 DKK are based on the assumption that the investments have an effect for a relative long period of time (15 years) on CO<sub>2</sub> emission (see also note 3 above). If the actual effect is shorter this would tend to increase the shadow cost as calculated by Danish Energy Agency (2000b). In these calculations some deduction for the cost and gains of projects associated with free-riding is also carried out. Thus, CO<sub>2</sub> and energy savings attributed to free-riding are not included, the companies own investment cost associated with free-riding are not included either, but the subsidies associated with free-riding are included.
6. This does not really coincide with the visual impression from figure 6.1, but note that this figure includes a fraction of the agreement companies (those in the balanced net-database).
7. According to Rigsrevisionen (1998), the direct administrative costs (in e.g. DEA etc.) associated with the agreements were about 30 million DKK per year.
8. However, it should be recognised that the tax exemption scenario in Jensen (1998) does not correspond directly with the agreement tax exemption policy carried out in Denmark. As one example the scenario focusses on energy-intensive sub-industries, while Danish policy has focussed on energy-intensive companies. In addition the Jensen scenario includes only tax exemption – not the agreement part (i.e. obligation of the companies and its effect on energy use).
9. A control group of companies without agreement were included in some additional analysis on indicators of energy saving activities of companies. In the additional analysis it was found that companies with agreements also carried out more energy saving activities as compared with companies without agreements.
10. In the joint conclusion of the 1998 evaluation (Pedersen et al. 1998) based partly on the two above studies it was concluded that the agreements could lead to a reduction in energy use in the companies with agreements at 6% by the year of 2005, but more than half of this effect were assumed to derive from better energy management giving a yearly (and accumulating) effect at 0.5% per year. The later quantification of the effect of the energy management was described as very uncertain.

11. As described in section 6 it was not been possible - based on the database - to identify any differences in the effects of the type of agreements running from 1993-95 and the type starting in 1996.
12. The figure captures some of the points in Segerson and Miceli (1998), but in a simplified way. As an example Segerson and Miceli allowed the MAC with agreements to be lower as compared with the MAC subject to command and control. They also considered explicitly the bargaining power of companies and the cost of public funds.
13. Here, we rule out situations where the company may get some kind of private benefit (i.e. like green marketing etc.) from carrying out a »voluntary« action.

## 9 Discussion and Some Issues for Future Research

In this report we have presented one application of the extensive database including information on most of the industrial companies from 1983 to 1997. A number of other types of analyses/models can be carried out using the database. This will briefly be discussed below.

There may also be a need to follow up on the analysis presented here. One of the major conclusions was that the activities carried out by the agreement companies appear to cause a significant reduction in energy consumption. However, in the study it was not possible to get separate estimates for the effect of the »agreements« in the first period 1993-95 and in the second period 1996-1997, which (perhaps) reflected that only relatively few companies with agreements in the second period were included in the database. In recent years more companies have signed agreements, so when (if) the year of 1999 is included in the database,<sup>1</sup> it may be possible to identify separate effects of the early agreement (i.e. the »audits«) and the later agreements. When the database covers more time periods after the agreements have been used it may also be possible to further investigate the dynamic effects of the agreement. Thus, it may be possible to investigate if the effects are permanent or fade out over time (and how fast they fade out). It should also be noted that the commitments of the agreement companies have recently been changed. Starting in 2000 companies entering and agreement no longer need to obtain an external energy audit, but instead increased attention seems to be given to the companies' own energy management. These changes may influence the net effect of the agreements.

As a result of the separate tax rate on different types of energy consumption starting from 1996 the energy surveys distinguish between energy used for process (heavy and light) and space heating. Therefore, it may be possible to investigate separately the price elasticity of energy demand for space

heating and process. This could give better insight on the effect of the complex energy taxes used in Denmark (and increase the understanding of the factors behind energy demand). Currently, there is only information on energy consumption for different types of use in the years 1996 and 1997, and it therefore seems more appropriate to carry out such an analysis at a later stage, where at least one additional year (1999) is included.

In the analysis presented in the report it was chosen to exclude companies with local production of electricity and district heating, because it may be difficult to correctly calculate the net energy consumption of these companies and because such a measurement error might bias the effect of subsidies, since these partly are given in order to start local production of electricity/district heating.<sup>2</sup> However, given these industrial companies' large share of total industrial energy demand, it could be worthwhile to study these companies in more detail.

Even though the estimated single equation models yielded plausible results it should be pointed out that these models are rather simple in their description of the behaviour of the companies. In the single equation models we have made the simplifying (but also arbitrary) assumption that companies only use two inputs: Energy and »other inputs«. Thus, we assumed that changes in the price of energy had the same effect on say use of labour and capital. This is a rather restrictive assumption. In fact some macro studies on this issue suggest that energy and capital are complements instead of substitutes. The database contains information that makes it possible to estimate micro models that can describe the substitution between various types of energy as well as the substitution between capital, labour and energy.

A methodological survey of estimation of energy consumption is offered by Griffin (1993). As previously noted most studies of industrial energy consumption are based on aggregated data like time series. These macro studies often estimate energy consumption in two steps using a nested production function. First, they estimate the demand for various types of energy. This yields information about substitution between say electricity and coal. Then they estimate the substitution between aggregate energy and other factors like labour, capital and materials. Each of the two steps is often estimated using a so-called flexible function form that can be regarded as a second order approximation to an unknown cost function. Typically, the

translog function is used, where the different factor demand equations are estimated simultaneously.

A translog function can be used to estimate the substitution between labour, capital and energy using the micro panel data set. However, estimation of substitution between various types of energy is more challenging with micro data compared with aggregate data. The reason for this is that it is very rare that companies use some of all the different available types of fuels. It appeared from the database that there is a large variety in the combinations of energy sources between companies. Practically all companies use electricity. In 1997, almost half the companies combined electricity with just one other type of fuel, which most frequently was heating oil, natural gas or district heating. The rest of the companies used electricity combined with more than two other types of energy.

At a micro level companies may respond to changes in the relative cost of different types of energy in two ways. First, they may substitute between various types of fuels by changing the combination of fuel types, e.g. an increase in the relative price of heating oil versus natural gas may induce some companies to change their combination of fuel types from electricity-heating oil to electricity-natural gas (replace heating oil with natural gas). Secondly, companies may change the use of the various types of fuel subject to the chosen combination of energy types. As an example, say that a company uses electricity, heating oil and natural gas. If the relative price of heating oil versus natural gas increases, the company may respond by using less heating oil and more natural gas. In an econometric terminology the first response (change in combinations of fuel type) has a *discrete* nature, while the second response (change in the use of fuels) has a *continuous* nature.

With aggregate macro data only continuous responses are observed since the discrete changes in fuel combinations are aggregated away. Mixed discrete-continuous models are less straightforward to estimate than the continuous models usually employed in aggregate energy demand model systems, but a discrete-continuous version of the translog model has been formulated by Lee and Pitt (1987) and used successfully on micro-data (but only cross-section). See also section 3 for a discussion on other micro studies applying simultaneous demand systems. In the current context it should also be taken into consideration that the combinations of different

fuel types to some extent (perhaps even to a large extent) are not determined by the companies, but instead by supply or exogenous factors. For instance, some companies do not have the option to use natural gas or district heating.

With respect to the advantages of observations at company level it has also been argued that studies solely based on macro data do not really reveal the behaviour of companies due to aggregation problems. In order to understand the behaviour of individual companies one has to employ information at the level of the decision unit. As an example related to long-run energy efficiency Solow argued back in 1987 that macro studies cannot capture the technical substitution between energy and capital. But yet it appears that hardly any researchers in Europe so far have employed micro data to investigate to what extent energy and capital are substitutes or complements in production.

Within applied production analysis a line of studies uses production frontier models to look at total factor productivity, factor efficiency and technological change. Examples include Schmidt and Sickles (1984), Hjalmarsson, Kumbhakar and Heshmati (1996) and Kumbhakar and Heshmati (1995). The database can also be used to carry out empirical analysis within this framework.

## Notes

1. Primary data on energy consumption in industry was not collected for the year 1998, but energy data for the year 1999 will be collected during 2000.
2. Thus, a number of large subsidies will be correlated with start up of local production of district heating/electricity.

# Appendix 5.1

Figure A5.1

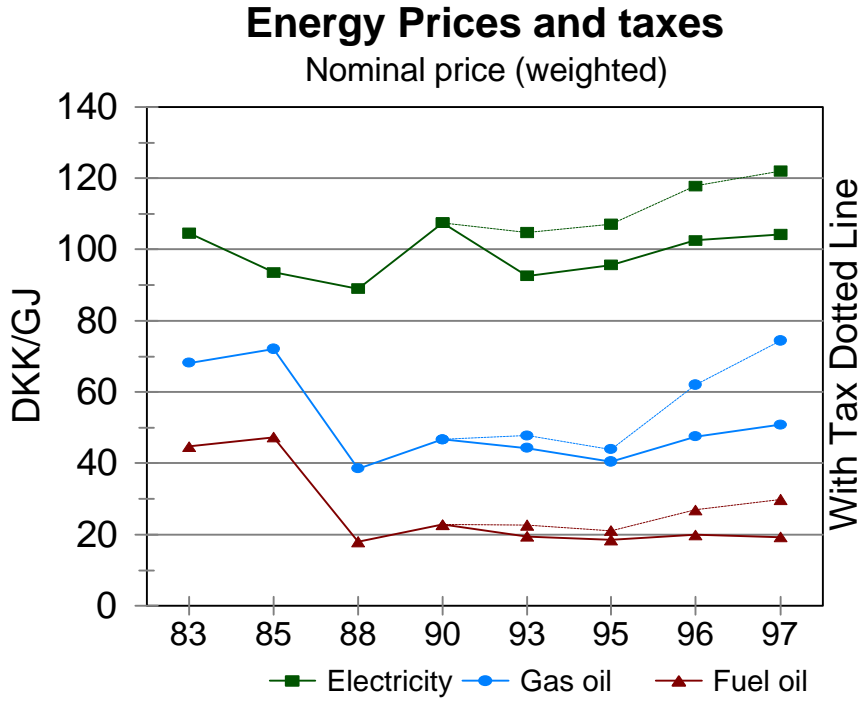
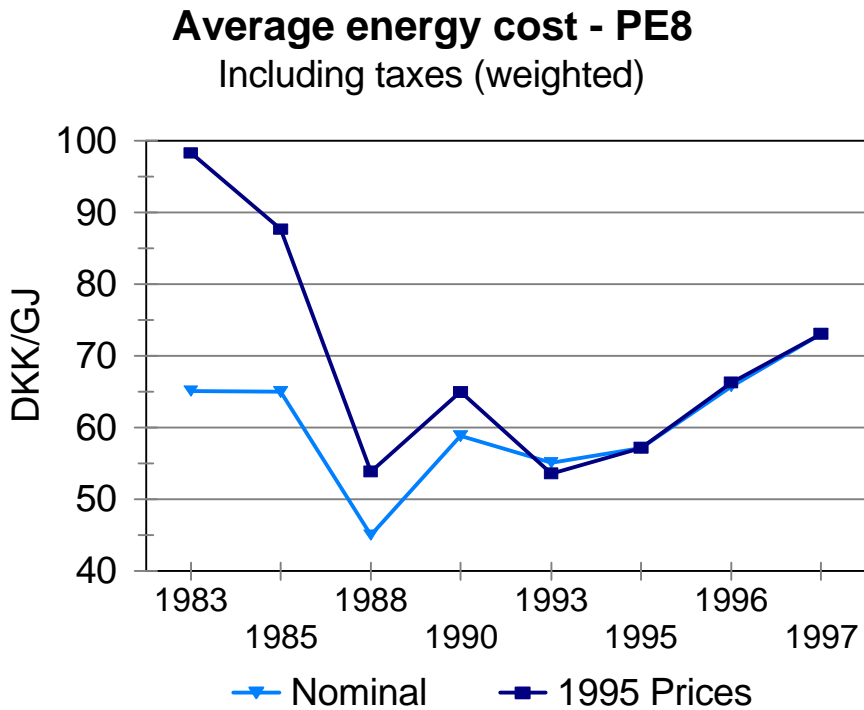


Figure A5.2



## Appendix 6.1

### Comparing Btu and Fisher Aggregation

When aggregating different types of energy into a single unit a choice between two different approaches must be made. Either the aggregation can be made according to the energy content measured in Joules – also known as a Btu aggregation. The Btu aggregation has the advantage that it is very easy to calculate. For instance, it is not necessary to include information about lagged prices and lagged demand, when calculating the energy content in a single year. However, the Btu aggregation can also be criticised because it implicitly assumes that one Joule of say coal has the same value in production as one Joule of electricity (the large differences in the price of electricity and coal suggest that this is not the case).

Alternatively, by the use of index theory, information about the prices can be utilized in order to aggregate the different types of energy according to their economic value. However, the prices only reflect the marginal rate of substitution if the markets are in equilibrium (and since energy markets have been characterised by high regulation and natural monopolies this may not be the case). Nguyen (1987) finds somewhat different elasticities using the different ways of aggregating, whereas Statistics Denmark (1998) only finds modest differences when using Danish macro time series.

To check if the results presented in this paper depend on which approach is chosen the Btu aggregator and a Fischer index (chain) are compared. The Fischer index is the square root of a Paasche index multiplied by a Laspeyres index, which includes lagged prices. However, the latter type of index is not straightforward to calculate in our case, where we have a combination of an unbalanced panel and company specific prices for some types of energy (thus one would need to make a number of ad-hoc solutions to find the lagged electricity prices for a company that is included in the database say only in the years 83, 93 and 95).

In order to simplify the construction of the Fischer index we have only looked at a sub-sample of the net database including a *balanced panel of 841 companies included in the six years from 1983 to 1995*. Observations from 1996 and 1997 were not included because the different energy taxes on energy used for space heating and in the industrial process raise some additional aggregation issues. When calculated the Fisher price index we

have also ignored that the time span between the observations varies (e.g. 1985 prices are the lagged prices for observations in 1988).

Table A6.1 shows estimation results of fixed effects models using respectively the Btu and the Fisher aggregator for energy and energy price. Though based on a sub-sample of the database the results presented above do not indicate that the parameters are affected by the choice of aggregator. Therefore, we rely on the Btu aggregator, which is more straightforward to calculate.

Table A6.1 Comparing estimates in models with Btu and Fisher aggregation (fixed effects models for balanced panel of companies from 1983-95)

	Common price elasticity		Model with different price elasticity according to energy intensity		
	Fischer index	Btu-aggregator	Level of Energy intensity	Fischer index	Btu-aggregator
LFVA	0.6004 (0.0126)	0.5701 (0.0138)		0.5982 (0.0126)	0.5682 (0.0138)
LPE8	-0.5487 (0.0150)	-0.5845 (0.0205)	Low	-0.6456 (0.0267)	-0.6530 (0.0350)
	-	-	Medium low	-0.5718 (0.0199)	-0.5574 (0.0290)
	-	-	Medium high	-0.5373 (0.0204)	-0.5790 (0.0274)
	-	-	High	-0.4783 (0.0219)	-0.5778 (0.0285)
DCO2A G	-0.2080 (0.0488)	-0.1662 (0.0514)		-0.1655 (0.0493)	-0.1622 (0.0523)
$\hat{\epsilon}_{83}$	-0.1508 (0.0204)	-0.0265 (0.0216)		-0.1492 (0.0204)	-0.0259 (0.0216)
$\hat{\epsilon}_{85}$	-0.1367 (0.0179)	-0.0319 (0.0185)		-0.1329 (0.0178)	-0.0314 (0.0185)
$\hat{\epsilon}_{88}$	-0.2360 (0.0143)	-0.1997 (0.0150)		-0.2323 (0.0143)	-0.1995 (0.0150)
$\hat{\epsilon}_{90}$	-0.1068 (0.0145)	-0.0858 (0.0154)		-0.1044 (0.0145)	-0.0854 (0.0154)
$\hat{\epsilon}_{93}$	-0.0541 (0.0141)	-0.0372 (0.0148)		-0.0535 (0.0140)	-0.0369 (0.0148)
$\hat{\epsilon}_{95}$	0	0		0	0
$\hat{\sigma}_v^2$	820	907		814	907
R <sup>2</sup>	8100	9672		8115	9672
Para- meters	848	848		851	851
Obser- vations	5046	5046		5046	5046

(Std.error of estimates in brackets.)

# Appendix 7.1

## Description of Auto-Correlation

The description of auto-correlation below applies to the model presented in table 7.1. However, the simpler models in section 6 have similar correlation. Below »RES83« is residuals. In the cross-table the first (top) number is correlation coefficient, the middle number is significance level, while the lowest number is the number of observations used to calculate the correlation coefficients (edited SAS output).

Simple Statistics							
Variable	N	Mean	Std Dev	Sum	Minimum	Maximum	
RES83	2087	0	0.28296	0	-1.14303	1.67676	
RES85	2410	0	0.26138	0	-1.66529	1.61878	
RES88	2577	0	0.25415	0	-1.30182	1.56645	
RES90	2500	0	0.24865	0	-1.27430	1.56886	
RES93	2225	0	0.25345	0	-1.37985	1.27600	
RES95	1858	0	0.25113	0	-1.19675	1.41067	
RES96	1719	0	0.24255	0	-1.45419	1.36538	
RES97	1482	0	0.24776	0	-1.19585	1.76624	

Pearson Correlation Coefficients / Prob >  R  under Ho: Rho=0 / Number of Observations								
	RES83	RES85	RES88	RES90	RES93	RES95	RES96	RES97
RES83	1.00000 0.0 2087	0.21315 0.0001 1984	-0.20389 0.0001 1727	-0.35615 0.0001 1508	-0.40467 0.0001 1215	-0.47499 0.0001 939	-0.45029 0.0001 857	-0.45320 0.0001 732
RES85	0.21315 0.0001 1984	1.00000 0.0 2410	-0.07453 0.0007 2052	-0.27962 0.0001 1766	-0.37839 0.0001 1407	-0.48739 0.0001 1065	-0.48676 0.0001 967	-0.52018 0.0001 835
RES88	-0.20389 0.0001 1727	-0.07453 0.0007 2052	1.00000 0.0 2577	-0.01144 0.5935 2179	-0.30310 0.0001 1668	-0.39251 0.0001 1256	-0.43125 0.0001 1122	-0.44430 0.0001 968
RES90	-0.35615 0.0001 1508	-0.27962 0.0001 1766	-0.01144 0.5935 2179	1.00000 0.0 2500	-0.03586 0.1225 1856	-0.27814 0.0001 1360	-0.38222 0.0001 1224	-0.36488 0.0001 1058
RES93	-0.40467 0.0001 1215	-0.37839 0.0001 1407	-0.30310 0.0001 1668	-0.03586 0.1225 1856	1.00000 0.0 2225	-0.02810 0.2803 1478	-0.16104 0.0001 1329	-0.18686 0.0001 1173
RES95	-0.47499 0.0001 939	-0.48739 0.0001 1065	-0.39251 0.0001 1256	-0.27814 0.0001 1360	-0.02810 0.2803 1478	1.00000 0.0 1858	0.18684 0.0001 1410	0.11948 0.0001 1075
RES96	-0.45029 0.0001 857	-0.48676 0.0001 967	-0.43125 0.0001 1122	-0.38222 0.0001 1224	-0.16104 0.0001 1329	0.18684 0.0001 1410	1.00000 0.0 1719	0.40923 0.0001 1294
RES97	-0.45320 0.0001 732	-0.52018 0.0001 835	-0.44430 0.0001 968	-0.36488 0.0001 1058	-0.18686 0.0001 1173	0.11948 0.0001 1075	0.40923 0.0001 1294	1.00000 0.0 1482

# References

Ahé, Gert, Klaus Fafner and Troels Christensen (1998). *Vurdering af Energistyrelsens databateriale vedrørende aftaleordningen* (Baggrundsrapport til Evaluering af energiaftalernes effekt). August 1998 (available from the Danish Energy Agency).

Andersen, F.M.; H.K Jacobsen, P.E, Morthorst, A. Olsen, M. Rasmussen, T. Thomsen and P. Trier (1998): EMMA: En energi- og miljørelateret satellitmodel til ADAM. *Nationaløkonomisk Tidsskrift*, 136, pp. 333-349.

Apostolakis, B.E. (1990): Energy-capital substitutability/complementarity – The dichotomy. *Energy Economics*, 1990, pp. 48-58.

Arora, S. and T.N. Cason (1995): An Experiment in Voluntary Environmental Regulation: Participation in the EPA's 33/50 Program. *Journal of Environmental Economics and Management*, 28, pp. 271-286.

Atkinson, Jago and Neil Manning (1995): A survey of international energy elasticities. In Barker, Terry; Paul Ekins and Nick Johnstone (eds): *Global Warming and Energy Demand*. Routledge, London.

Baltagi, B. H. (1995): *Econometric analysis of panel data*. John Wiley and Son, New York.

Bentzen, J. and T. Engsted (1993): Short- and long-run elasticities in energy demand – A cointegration approach. *Energy Economics*, 15, pp. 9-16.

Berndt, Ernst R. and David O. Wood (1975): Technology, Prices, and the Derived Demand for Energy. *Review of Economics and Statistics*, 57(3), Aug. 1975, pp. 259-68.

Bjørner, T.B.; M. Togeby and J. Christensen (1998): *Industrial Energy Demand – a Micro Panel Data Analysis*. AKF memo, AKF Forlaget, Copenhagen.

Bjørner, T.B.; M. Togeby and H.H. Jensen (2000): Industrial Companies' Demand for Electricity: Evidence from a Micro Panel (resubmitted to *Energy Economics*).

Bousquet A. and M. Ivaldi (1998): An individual choice model of energy mix. *Ressource and Energy Economics*, 20, pp. 263-286.

Carraro, Carlo and Domenico Siniscalco (1996): Voluntary agreements in environmental policy: a theoretical appraisal. Chapter 5 in: Xepapadeas, Anastasios (ed.) *Economic Policy for the Environment and Natural Resources*. Edward Elgar, UK.

Chidiak, Martina (1999): *The choice between a tax and a »menu voluntary agreement« under asymmetric information*. Paper presented at the CAVA workshop on The Efficiency of Voluntary Approaches, May 25-26, 1999, Copenhagen, Denmark.

Danish Energy Agency (2000a): *Indgåelse af aftaler om energieffektivisering*. January 2000.

Danish Energy Agency (2000b). *Energistyrelsens tilskudsordninger – beskrivelser og vurderinger*. February 2000.

Doms, Mark E. and Timothy Dunne (1993): *Energy Intensity, Electricity Consumption, and Advanced Manufacturing Technology Usage*. Bureau of the Census Centre for Economic Studies Discussion Paper: CES 93-9, July 1993.

DØR (1997): *Danish Economy – Autumn 1997*. Danish Economic Council, Copenhagen.

Glachant, Matthieu (1999): The Cost Efficiency of Voluntary Agreements for Regulating Industrial Pollution. Chapter 5 in Carraro, C. and F. Lévêque (eds): *Voluntary Approaches in Environmental Policy*. Kluwer Academic Publishers.

Griffin, James M. (1977): Interfuel Substitution Possibilities: A Translog Application to Intercountry Data. *International Economic Review*, 18(3), pp. 755-70.

Griffin, James M. (1993): Methodological Advances in Energy Modelling: 1970-1990. *Energy Journal*, 14(1), 1993, pp. 111-24.

Griffin, James M. & Gregory, Paul R. (1976): An Intercountry Translog Model of Energy Substitution Responses. *American Economic Review*, 66(5), pp. 845-57

Griliches, Zvi and Jacques Mairesse (1995): *Production Functions: The Search for Identification*. National Bureau of Economic Research, Working Paper 5067, March 1995.

Gørtz, M.; J.V. Hansen and M. Larsen (1999): *CO<sub>2</sub> taxes, double dividend and competition in the energy sector: Applications of the Danish CGE model ECOSMEC*. Working Paper 1999:1, Danish Economic Council, Copenhagen.

Halvorsen, Robert (1977): Energy Substitution in U.S. Manufacturing. *Review of Economics and Statistics*, 59(4), Nov. 1977, pp. 381-88.

Hauch, J. (1999a): *The Kyoto Agreement Consequences for Nordic Electricity Markets*. Working Paper 1999:5, Danish Economic Council, Copenhagen.

Hauch, J. (1999b): *Nordic Carbon Dioxide Abatement Costs*. Working Paper 1999:6, Danish Economic Council, Copenhagen.

Heckman, J.J. and R. Robb (1985): Alternative Methods for Evaluating the Impact of Interventions: An overview. *Journal of Econometrics*, 30, pp. 239-267.

Hjalmarsson, L.; S.C. Kumbhakar and A. Heshmati (1996): DEA, DFA and SFA: A Comparison. *Journal of Productivity Analysis*, 7(2-3), pp. 303-27.

Jensen, J. (1998): *Carbon Abatement Policies with Assistance to Energy Intensive Industry*. Policy Paper Series, Ministry of Business and Industry, Copenhagen.

Johannsen, K. and A. Larsen (2000): *Voluntary Agreements – Implementation and Efficiency: The Danish Country Study – Case Studies in the Sectors of Paper and Milk Condensing*. AKF Forlaget, Copenhagen.

Johannsen K.S. and M. Togeby (1999): *Evaluations of the Danish CO<sub>2</sub> Agreement Scheme*. Paper presented at the European Network on Voluntary Approaches' (CAVA) workshop in Gent, Belgium, November 26-27, 1998. (<http://allserv.rug.ac.be/~mdeclerc/CMM/CAVA/papers/johannsen.html>)

Kleijweg, A.; G. Van Leeuwen, R. Huigen and K. Zeelenberg (1989): *The demand for energy in Dutch manufacturing; A study using panel data of individual firms, 1978-1986*. Research Paper 8906, Research Institute for Small and Medium-sized Business in the Netherlands, Department of Fundamental Research.

Krarpup, Signe (1999): *The Efficiency of Voluntary Approaches – A CAVA Literature Survey*. CAVA Working Paper no. 99/08/2. (<http://www.ensmp.fr/Fr/CERNA/CERNA/Progeuropeens/CAVA/index.html>)

Krarrup, S. and A. Larsen (1998): *Energieffektivisering gennem aftaler (Energy Efficiency through Voluntary Agreements)*. AKF Forlaget, Copenhagen.

Kumbhakar, S.C. and A. Heshmati (1995): Efficiency Measurement in Swedish Diary Farms: An Application of Rotating Panel Data, 1976-88. *American Journal of Agricultural Economics*, 77(3), pp. 660-74.

Lee, L.-F. and M. Pitt (1987): Microeconomic models of rationing, imperfect markets, and non-negativity constraints. *Journal of econometrics*, 36, pp. 89-110.

Millock, Katrin (1999): *The combined use of carbon taxation and voluntary agreements for energy policy – a model based on Danish policy*. Paper presented at the CAVA workshop on The Efficiency of Voluntary Approaches, May 25-26, 1999, Copenhagen, Denmark.

Ministry of Economic Affairs (1999): Modelling af CO<sub>2</sub>-, SO<sub>2</sub>- og energiafgiftspolitikken på virksomhedsniveau. Working Paper no. 3/99 (made by Rasmus Westerlin Nielsen, Anita Holst and Jakob Hald).

Ministry of Finance [Finansministeriet] (1994): *Grønne afgifter og erhvervene*. Mid-term report from the inter-ministerial committee on green taxes. April 1994.

Ministry of Finance [Finansministeriet] (1995): *Energy Tax on Industry in Denmark*.

Ministry of Finance et al. [Finansministeriet et al.] (1999): *Evaluering af grønne afgifter og erhvervene*.

Ministry of Taxation (1998): *Energy Taxes. The Danish Model*. (<http://www.skm.dk/publika.htm>)

Nguyen, Hong V. (1987): Energy elasticities under Divisia and Btu aggregation. *Energy Economics* 9(4), p. 210-14.

Pedersen, Preben Buhl, Christina Ingerslev, Mikael Tøgeby and Gert Ahé (1998). *Evaluering af energiaftalernes effekt*. August 1998. (available from Danish Energy Agency). Dansk Teknologisk Institut. June 1998.

Pindyck, Robert S. (1979): Interfuel Substitution and the Industrial Demand for Energy: An International Comparison. *Review of Economics and Statistics*, 61(2), pp. 169-79.

Ravn, Ole; Christina Ingerslev and Mikael Tøgeby (1994). *Evaluering af CO<sub>2</sub>-energisynd*. Dansk Teknologisk Institut.

Ravn, Ole and J.C. Sørensen (1998). Undersøgelse af effekterne af tilskud til energieffektivisering i erhvervslivet. Dansk Teknologisk Institut.

Rigsrevisionen (1998): *Beretning om indførelse, administration og kontrol af den grønne afgiftspakke*. Rigsrevisionen 2/98, Copenhagen.

Schmidt, P and R.C. Sickles (1984): Production Frontiers and Panel Data. *Journal of Business and Economic Statistics*, 2(4), pp. 367-74.

Segerson, K. and N. Li (1998): *Voluntary Approaches to Environmental Protection*. Working paper, Department of Economics, University of Connecticut.

Segerson K. and T. J. Miceli (1998): Voluntary Environmental Agreements: Good or Bad News for Environmental Protection? *Journal of Environmental Economics and Management*, Vol. 36, pp. 109-130.

Solow, J.L. (1987): The Capital Energy Complementarity Debate Revisited. *American Economic Review*, 77, pp. 605-14.

Statistics Denmark (1997): *Energi- og emissionsmodeller til ADAM (Energy and Emission Models for ADAM)*. Udarbejdet af Danmarks Miljøundersøgelser, Forskningscenter Risø og Danmarks Statistik, Danmarks Statistik.

Stranlund, John K. (1995): Public Mechanisms to Support Compliance to an Environmental Norm. *Journal of Environmental Economics and Management*, vol. 28, pp. 205-222.

Thomsen, Thomas (1995): Faktorefterspørgsel på kort og langt sigt. *Nationaløkonomisk Tidsskrift*, 133(1), pp. 52-65.

Togebj, Mikael and Elsebeth Hansen (1998): *Industriens Energiaktiviteter – resultater fra 150 virksomheder*. (Baggrundsrapport til Evaluering af energiaftalernes effect). August 1998 (available from the Danish Energy Agency).

Woodland, Alan D. (1993): A Micro-econometric Analysis of the Industrial Demand for Energy in NSW. *Energy Journal*, 14(2), pp. 57-89.