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Regulation of Danish Energy Markets with Imperfect Competition

Mette Gørtz and Jan V. Hansen

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Abstract:
In this paper we use a new CGE model of the Danish economy with the acronym ECOSMEC (Economic COuncil Simulation Model with Energy markets and Carbon taxation). The model is a hybrid of two existing static models developed by respectively the Secretariat of the Danish Economic Council and by the MobiDK project in the Ministry of Business and Industry. Distinct features of the ECOSMEC model are a rather disaggregated modelling of energy demand and supply, introduction of various market structures in the energy sector, and a consistent specification of different household types.

The simulations presented in the paper have the following implications: First, a uniform CO_2 tax of approximately 300 DKK per ton CO_2 could reduce emissions by 20 per cent in a scenario with perfect competition in the energy sector. However, assuming different market structures in the energy sector influences the uniform CO_2 tax needed to reach a given emission target. In the paper we assume that the Danish energy sector is a natural monopoly regulated to comply with average cost pricing, but we also discuss alternative descriptions of imperfect competition. Second, the empirical arguments for differentiated CO_2 taxes motivated by imperfect energy markets are weak. This is in line with earlier international studies on environmental taxes and imperfect competition. Third, the Danish economy could benefit from a deregulation of the electricity and district heating sector with respect to welfare and economic activity. This result holds also if CO_2 emissions are kept constant.

Keywords: CGE model, double dividend, CO_2 taxes, imperfect energy markets.

JEL: D4; D5; H2; Q4.

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1. Introduction[1,2]

Historically, the Danish energy sector has been one of the most regulated and sheltered sectors in the Danish economy. While competition in the electricity supply industry has been introduced in other Scandinavian countries, the Danish development has until now been much more modest and limited. In recent years Danish politicians have taken some initiatives towards improved competition, but the consequences of the reform process and the future market structure of the Danish energy sector are uncertain. For an updated discussion of the latest Danish development in a North European perspective see Olsen (1998).

The Danish climate policy aims at both international coordination and substantial reductions of national CO_2 emissions. Energy and CO_2 taxes, substitution of fuel inputs and cleaner technologies are important measures in the Danish climate policy. The reserved and reluctant attitude of the Danish government towards liberalisation is primarily motivated by the ambitious national emission reductions targets. Objectives of liberalised energy markets and national climate policy are considered difficult to combine.

In this paper we discuss regulation of the Danish energy sector with special emphasis on electricity and district heating production. We focus on general equilibrium implications of assuming different markets structures. A motivation for assuming different market structures is the uncertain outlooks for the future regime of the energy sector. The market structures under consideration are i) perfect competition, ii) monopoly with average cost (AC) pricing, iii) pure monopoly, and iv) oligopoly with free entry. Free competition and pure monopoly are extremes when describing the market structure in the Danish energy sector. Monopoly with AC pricing probably best describes the intention of the present institutional setup. Imperfect competition is introduced by assuming increasing returns to scale due to large fixed costs in the energy sector.

1) The model simulations in this paper have benefited from valuable assistance from Anders Hoffmann and Jesper Jensen working with the MobiDK model project in the Danish Ministry of Business and Industry. We are also grateful for comments from Peter Brixen from the Secretariat of the Danish Economic Council. However, we are solely responsible for the presented model simulations and conclusions. The views expressed in the paper are not necessarily shared by the Chairmanship of the Danish Economic Council.

2) The research work leading to this paper has been financed by the Nordic Energy Research Programme. A preliminary version of the paper was presented at the Nordic Energy Research Programme seminar at Skjoldnæsholm, 3-4 December 1998. The paper has benefited from fruitful discussions and comments from the seminar participants.

We will discuss both environmental and efficiency aspects of regulation. The analyses are based on simulations with a static CGE model of the Danish economy containing a rather disaggregated modelling of energy demand and supply. Another distinct feature of the model is a consistent modelling of different household types. This allows the simulation of distributional impacts of regulation of the energy sector. The applied model with the acronym ECOSMEC (Economic Council Simulation Model with Energy markets and Carbon taxation) builds upon a static CGE model developed by the MobiDK project in the Danish Ministry of Business and Industry, cf. Harrison et al. (1997). However, ECOSMEC differs from MobiDK in various areas. Thus, the formulation of input demand in industries, consumer demand and a number of chosen elasticities is inspired by the GESMEC model of the Secretariat of the Danish Economic Council, cf. Frandsen et al. (1995).

The paper is organized as follows. In section 2, we present existing analyses on the extent and implications of imperfect competition in the Danish energy sector. Selected aspects of the ECOSMEC model with focus on energy demand and supply are described in section 3. In section 4, we discuss the way in which imperfect competition is introduced into the ECOSMEC model. In section 5, we present the implications of a uniform CO_2 tax under different assumptions about the market structure for the macro economy, welfare, and distribution. In section 6, we discuss whether there is a case for differentiated CO_2 taxes motivated by imperfections in the energy sector. Section 7 contains very stylized calculations on the impact of deregulation in the energy sector modelled by exogenously reducing fixed costs in the sector. Section 8 concludes the paper.

The main conclusions are the following: Firstly, assuming different market structures influences the uniform CO_2 tax needed to reach a given emission target. Secondly, the empirical arguments for differentiated CO_2 taxes motivated by imperfect energy markets are weak. This is in line with results found by Oates and Strassman (1984). Thirdly, the Danish economy will benefit from a deregulation of the electricity and district heating sector with respect to welfare and economic activity. This result holds also if CO_2 emissions are kept constant.

2. Extent and consequences of imperfect competition in the Danish energy sector

The Danish electricity and district heating sector acts under imperfect competition and is therefore subject to a high degree of public regulation.[3] Public regulation is directed towards determining output prices for electricity and district heating based on a principle of selfsupporting production and "consumer ownership" in the energy sector. This implies that firms in the sector are not permitted to make a profit, but they are allowed to make large appropriations for future investment. In the electricity and district heating sector a very large share of total costs is in fact fixed costs which have been locked-up in a large long-lived capital stock. This is particularly characteristic for capital devoted to transmission and distribution in the network facilities of electricity and district heating. In electricity supply, transmission is shared by two companies according to their geographical location. Distribution is carried out by a number of firms, each responsible for a certain region of the country. Electricity supply is dominated by vertically integrated monopolies. The supply of district heating has similar characteristics, cf. Olsen and Munksgaard (1997). The absence of competition from both domestic and foreign suppliers can lead to inefficiency in production and thus too high electricity and district heating prices, see for instance Danish Economic Council (1997 and 1995).

An analysis of productivity in the electricity sector points at efficiency problems in distribution, cf. Hougaard (1994). Thus, the potential for cost reductions in distribution amounts to between 17 and 44 per cent. The Danish Ministry of Finance estimates that there is a large potential for efficiency gains in the whole electricity sector as labour productivity is somewhat lower than in Sweden, Japan and the United States, cf. Finansministeriet (1997). Furthermore, there is excess capacity in capital equipment; in 1995 it was no less than 70 per cent.

The Danish competition authorities estimate that there is also room for improving labour and capital productivity in the district heating sector, cf. Konkurrence-styrelsen (1998a). The district heating network has a large geographical coverage and investment costs are more or less fully written off.

3) Over time, public regulation of the energy sector has also been politically motivated by considerations about the economy, security in supply and the environment. For a further discussion of aspects of competition in the Danish energy sector see Danish Economic Council (1997).

3. Aspects of the ECOSMEC model emphasising demand and supply of energy

The ECOSMEC model describes a small open economy with external trade characterized by absence of market power of Danish firms on markets abroad. Similarly, foreign firms have no market power on the Danish markets. Thus, the world market prices of exports and imports are exogenously fixed ruling out any terms of trade effects by assumption. The current account is kept constant due to endogenous changes in the real exchange rate.

Net investment is assumed to be zero implying a constant aggregate stock of capital. Capital is assumed to be mobile across all sectors except energy sectors producing combined heat and power (CHP). This ensures a uniform rate of return to capital. The aggregate endowment of time is exogenous, but a labour supply curve is included. Thus, the supply of labour to industries is endogenous.

The model includes 34 production sectors of which six are energy sectors, nine manufacturing industries and 15 service sectors. Production is characterized by constant returns to scale in all sectors except energy sectors producing CHP. Individual firms behave competitively, selecting output levels where the marginal cost equals the market price. Output is differentiated between goods for the domestic and export markets. Technically, the split of production is determined by a Constant Elasticity of Transformation function (CET).

Households maximize utility subject to a budget constraint. Household income consists of capital and labour plus net transfers to consumers by the government. Utility is derived from consumer goods and leisure. Labour supply of all households is characterized by an uncompensated real wage elasticity of 0.1. At the most disaggregated level, the model includes 36 consumer goods of which five are energy goods. Public consumption and investment demand are exogenous, and during simulations the public account is kept constant by means of endogenous changes in taxes or subsidies. The base year of the model is 1992. Elasticities of substitution and other central parameters reflect a balanced synthesis of current Danish econometric work and qualified “guesstimates”.

The ECOSMEC model consistently describes flows of 25 energy goods and inputs at the most detailed level corresponding to the detailed energy matrices of the national accounts. The presentation below will focus on aggregate energy goods as the energy demand of households and industries is directed towards a choice between broad energy groups. The energy related CO_2 emissions are calculated by multiplying the 25 energy goods with their corresponding CO_2 emission coefficients.

Energy demand by industries except energy sectors producing CHP is determined simultaneously with input demand for labour, capital and other intermediates subject to relative input prices and output, cf. figure 1. Input demand is determined by nested CES functions; the elasticities of substitution used are indicated on the top of the relevant nests in figure 1.

Beginning from the top, the composite of capital, labour and energy substitutes for other intermediates. At the next level profit maximizing industries trade off labour with the capital-energy bundle with an elasticity of substitution of 0.6. Energy and capital are assumed to substitute each other with an elasticity of 0.3. The resulting energy bundle is split into electricity and other energy. The split is based on relative prices and industry specific elasticities of substitution in the interval of 0 to 1.6. Next, other energy is divided into gas and energy excluding electricity and gas. The sub energy bundle excluding electricity and gas consists of 21 energy goods which are assumed to substitute each other. At the last two levels the elasticities of substitution are assumed to be 0.25.

Energy consumption is determined simultaneously with the demand for other goods subject to relative prices and disposable income, cf. figure 2. Consumption goods are split into eight broad categories. The five energy goods are placed in the following three categories: “Transport”, “Energy for heating purposes” and “Durables and electricity”. The eight consumption categories compete subject to the budget constraint of the consumer, and all income elasticities are assumed to be 1. The empirical foundation behind this categorisation of consumption goods is found in the Danish macroeconomic model ADAM, cf. Danmarks Statistik (1995).

The consumption category “Transport” is split in two sub categories: “Motorvehicles, gasoline and oil, auto insurance etc.” and “Public transport”. The consumption category “Energy for heating purposes” is also split into two sub categories: ”District heating etc.” and “Gas and liquid fuels”. In both cases the elasticity of substitution between the two sub categories is 0.25.

Figure 1. Production in all industries except the electricity and district heating sector

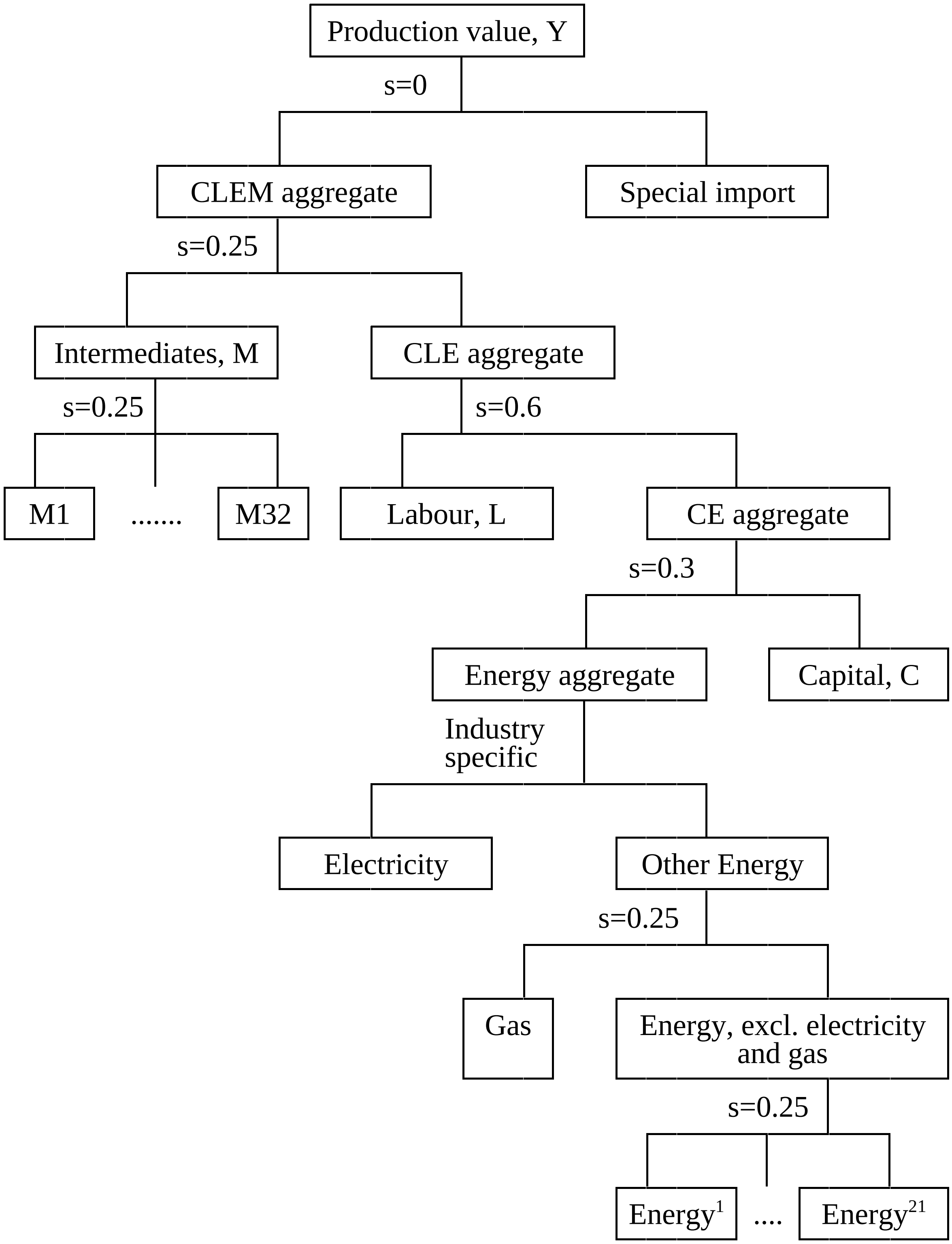
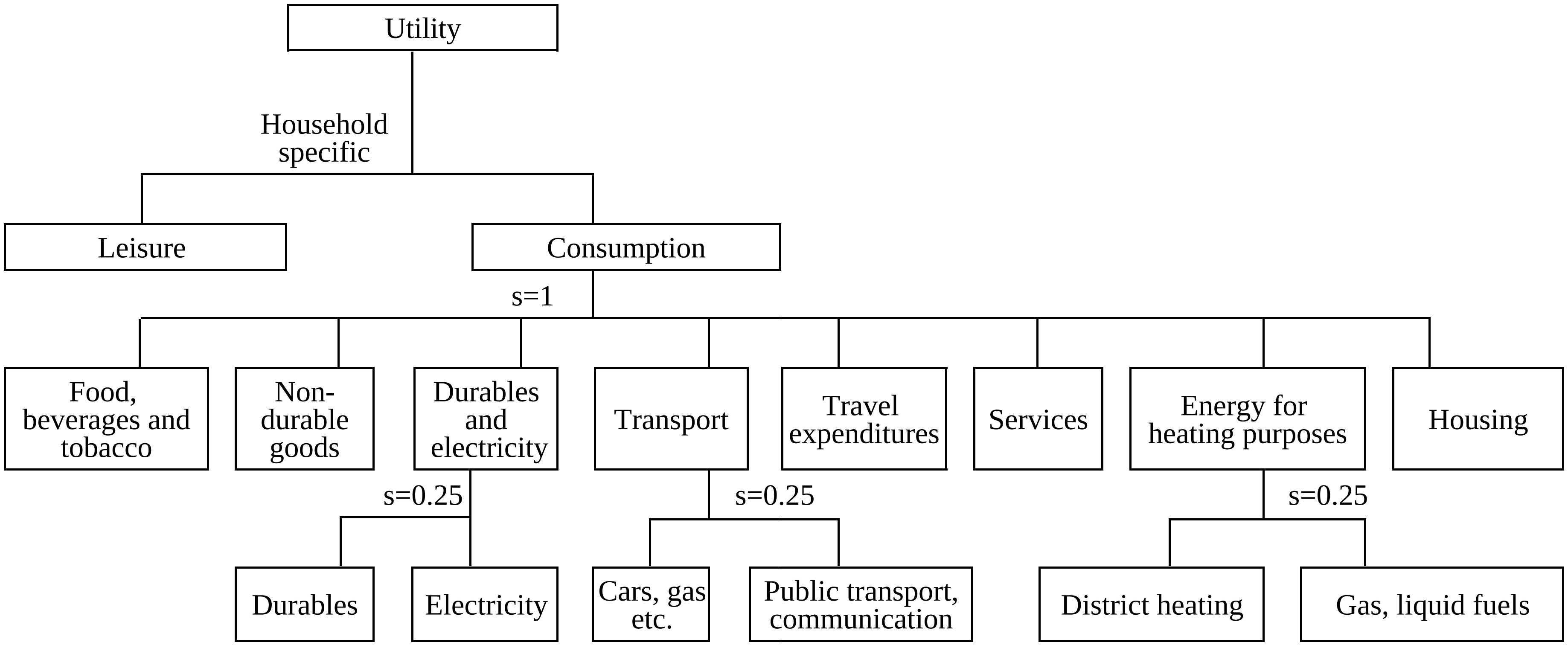


Figure 2. Utility specification for household HH



There are six energy industries in the model including forestry, extraction of oil and gas in the North Sea, oil refineries, gas utilities, electricity utilities and district heating utilities. Four of the energy industries, namely forestry, extraction of oil and gas in the North Sea, oil refineries and gas utilities, have the same input structure as the non-energy industries. However, they are characterized by producing more than one energy output (except forestry). Technically, the output split is determined by a CET function.

Production of electricity and district heating includes electricity from wind mills and heat produced by burning waste. The market shares of these two "green" technologies are considerable, cf. table 1. A special feature of the model is the joint production of electricity and heat in the CHP sector. Electricity and heat can be produced jointly with coal and gas technologies. The amount of waste for heat production is assumed constant and independent of the level of "output" in the waste producing industries. Consequently, there is no possibility of substitution between heat produced by coal and gas technologies and heat produced by burning waste.

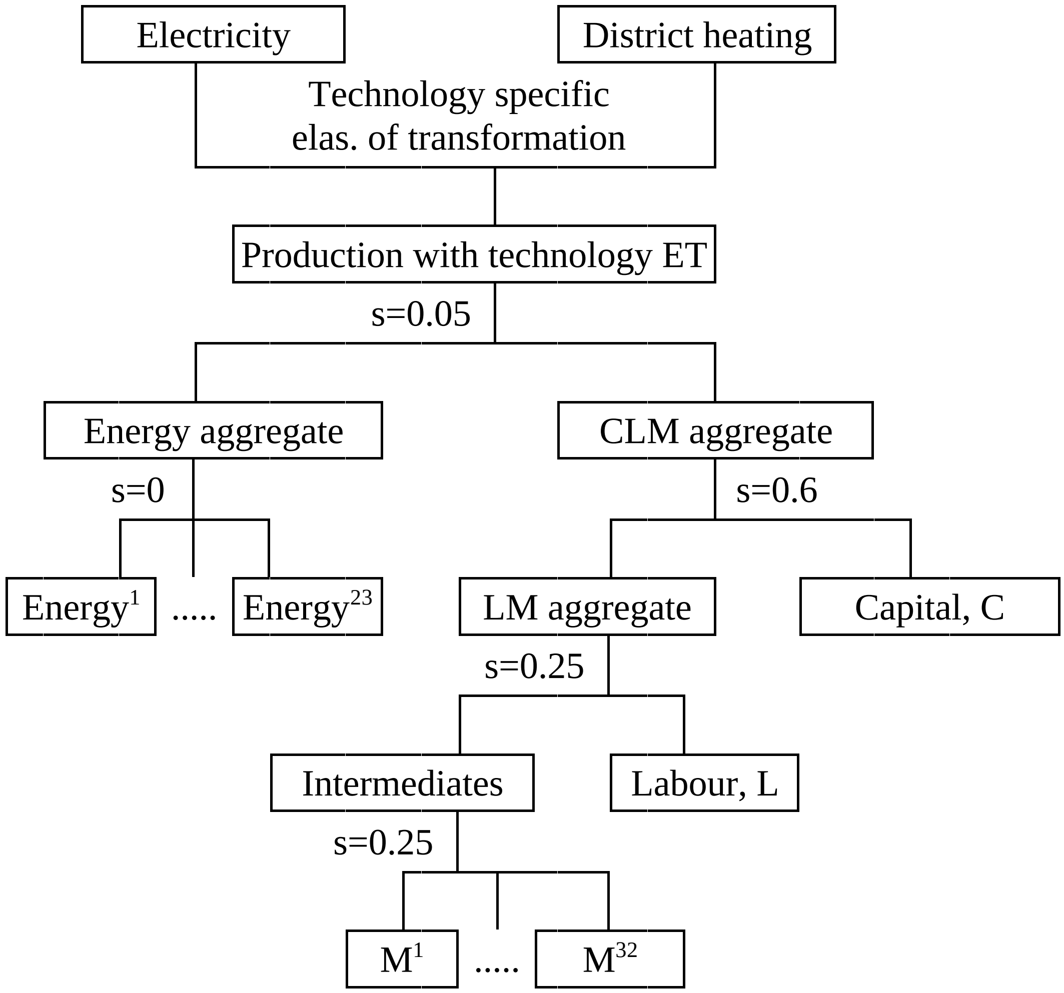
Table 1. Production of electricity and district heating in different technologies, per cent

	Coal fired CHP	**Gas fired CHP**	**Wind**	**Waste combustion**	**Total**
Electricity	85	10	5		100
District heating	55	20		25	100

The coal fired CHP plants can vary the split between electricity and heat according to relative output prices. Technically, this is described by a CET function. The gas fired CHP plants are not able to vary the output split. Wind mills contribute to the production of electricity only.

The technologies demand inputs in accordance with the structure of the other industries, cf. figure 3. The elasticities of substitution are chosen rather small to avoid "unrealistic" substitution between energy and especially capital. Contrary to other industries, capital producing CHP is assumed industry/technology specific. This assumption reflects the "stranded asset" in the energy industries generated by eventually rising CO_2 taxes. The rate of return to capital in the CHP producing technologies compared with the return to capital in the rest of the economy is an indicator of the extent of "stranded asset".

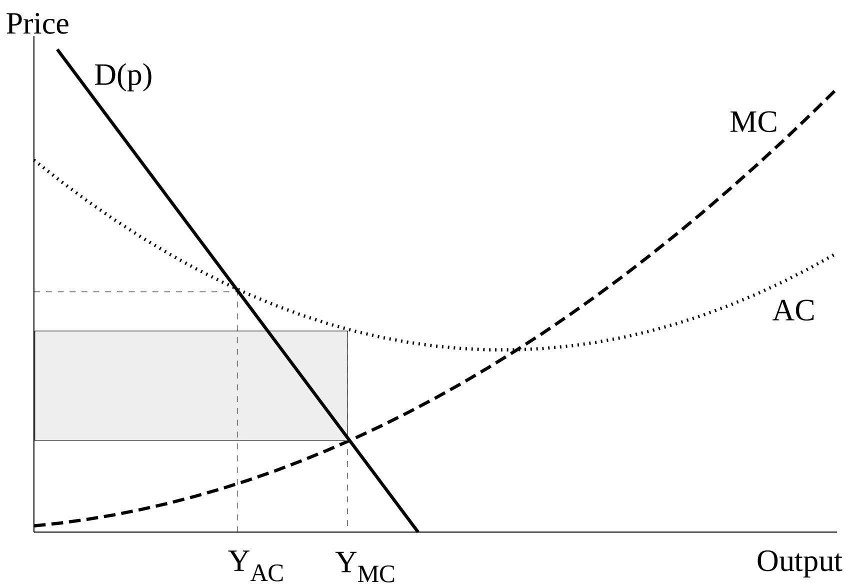
Figure 3. Production of electricity and district heating



4. Introducing imperfect competition in ECOSMEC

ECOSMEC is inherently a stylized model where production in all industries is submitted to perfect competition in all markets. Such a simplifying assumption is convenient when developing a model and interpreting the results of various simulations. However, as described in section 1 and 2, reality seldomly lives up to the neat world of models. In practice, a large share of the energy sector's long term costs is actually fixed. This is especially true for network costs, which to a certain extent are independent of the quantity of electricity and district heating transmitted and distributed through electric networks and cables and district heating tubes. In a situation where fixed costs constitute a relatively large part of total costs, average costs (AC) are high compared to marginal costs (MC) in the relevant domain with increasing returns to scale, see figure 4. Consequently, that part of the marginal cost curve lying above the average cost curve, in perfect competition defined as the supply curve, corresponds to a relatively high production and has no intersection with the demand curve. If the producer could be forced to produce Y_{MC}, which is the optimal production under perfect competition, he would not be able to cover his fixed costs and would in the long run suffer from bankruptcy. The situation with high fixed costs and low marginal costs is often characterised as a natural monopoly.

Figure 4. Costs and demand for the natural monopolist



The transmission and distribution activity in the energy sector is an example of a natural monopoly due to increasing returns to scale. The network facilities of the energy sector has a large geographical coverage and capacity is adequate. Public regulation of natural monopolies often aims at forcing the natural monopolist to set his price equal to P_{AC} where demand equals average cost. The corresponding supply, Y_{AC}, is lower than Y_{MC}.

In ECOSMEC there is no distinction between production and transmission/ distribution of electricity and district heating. The electricity and district heating sector covers the whole process from burning fuels to delivering the end product at the customers. Furthermore, the model treats the electricity and district heating sector as a whole in order to take into account the joint production of electricity and district heating. In the electricity sector, distribution costs account for more than 20 per cent of total costs, according to Konkurrencestyrelsen (1998a). The district heating sector is mainly a distributor of hot water from the CHP plants, although some production of hot water takes place in the sector as well. Based on information from the Danish competition authorities, cf. Konkurrencestyrelsen (1998b), we roughly estimate that approximately 20 per cent of total costs are direct network costs. Given the large potential efficiency gains in distribution, it seems reasonable to assume that only a part of distribution costs are true fixed costs. Consequently, in the following we take a prudent approach and choose a fixed cost share of only 10 per cent.[4]

In the scenarios below we assume average cost (AC) pricing as we believe that AC pricing is the form of imperfect competition that best describes the pricing of electricity and district heating in Denmark. For illustrative purposes, we have also tried to model two other types of imperfect competition, oligopoly with free entry and pure monopoly (without entry).[5] The modelling of production in the energy sector is more or less the same in the three different types of imperfect competition as it is assumed that the producer optimizes profits based on only variable costs. In all three imperfect competition examples, the model is calibrated assuming zero (pure) profits. This means that the deviation between total revenue and variable costs constitutes a kind of "rent", which exactly covers fixed costs in the benchmark scenario. In a counterfactual equilibrium, there may be a positive or a negative difference between the "rent" and the fixed costs, depending on changes in mark-up revenue and fixed costs. With AC pricing the rent is transferred to the public sector, which also has the responsibility for paying fixed costs. In pure monopoly the rent after deduction of fixed costs subsequently ends with the consumers in order to replicate the principle of "consumer ownership". In oligopoly with free entry, i.e. Cournot competition, net profit is competed away. Technically, this is done by assigning net rent to a consumer who then demands a commodity with the composition of fixed costs. When net rent changes in model simulations, "demand for fixed costs" changes

4) In the MobiDK model, the presence of fixed costs and possible increasing returns to scale is represented by a Cost Disadvantage Ratio (CDR) which symbolizes the share of fixed cost out of total cost. The CDR-values applied in MobiDK are based on a study of European industries, cf. Harrison et al. (1993). For the electricity and district heating sector, this study assumes a CDR of only 2.5 per cent. Based on cost studies of the Danish energy sector, we choose a fixed costs ratio which is somewhat bigger than what is assumed in the MobiDK model.

5) The programming of imperfect competition in ECOSMEC is inspired by the programming examples of different types of imperfect competition by Markusen and Rutherford (1995). In principle, the models with imperfect competition could be calibrated by assuming i) a fixed cost ratio, ii) a mark-up or iii) a number of firms. Here we assume a fixed cost ratio.

as well. Changes in the activity level of the firm producing fixed costs can be interpreted as changes in the number of firms, i.e. entry or exit of firms.

5. Implications of a uniform CO_2 tax under different competition regimes

In the following, we study the implications of a uniform CO_2 tax reducing CO_2 emissions with 20 per cent under different competition regimes in the electricity and district heating sector. Apart from perfect competition we analyse the three imperfect competition possibilities described above using the ECOSMEC model. We assume that the revenue from the CO_2 tax is redistributed to tax payers as lump sum transfers avoiding any double dividend discussion. Model simulations show that the macro and welfare effects are of a similar magnitude irrespective of the form of market structure, see table 2.[6]

Table 2. Welfare and macro effects of a CO_2 tax under different competition regimes, percentage change

	Perfect competition	**AC pricing**	**Pure monopoly**	**Free entry oligopoly**
Welfare	-0.9	-0.9	-1.1	-0.9
Real GDP	-0.2	-0.2	-0.3	-0.2
Private consumption	-1.1	-1.1	-1.3	-1.0
Exports	-1.4	-1.4	-1.4	-1.3
Imports	-1.8	-1.8	-1.8	-1.6
Employment	-0.2	-0.2	-0.2	-0.2
Real wages	-2.0	-2.1	-2.2	-1.7
Real capital return	-3.8	-3.8	-3.5	-3.3
Real exchange rate	-1.2	-1.2	-1.2	-1.0

The differences between the effects found in the illustrated competition regimes are very small at a macro level. However, our model simulations suggest that reduction in CO_2 emissions can be obtained with a somewhat smaller CO_2 tax rate

6) Welfare changes are calculated by dividing the equivalent variation, which is defined as the exogenous income change that produces the same change in utility as the policy experiment in consideration, by the initial consumption.

in the case of imperfect markets, see table 3. The lower CO_2 taxes under the imperfect competition forms can be explained by the fact that a tax on the input of an industry with market power (monopoly or oligopoly) is more than reflected in the market price due to the mark-up. This implies of course that the revenue from the CO_2 tax is lower.

Table 3. CO_2 tax rate and CO_2 tax revenue under different competition regimes

	Perfect competition	**AC pricing**	**Pure monopoly**	**Free entry oligopoly**
CO_2 tax, DKK per ton CO_2	304	277	271	247
CO_2 revenue, billion DKK	13.2	12.0	11.7	10.7

Internally between the three different imperfect competition forms, differences in the necessary CO_2 tax are rather small. The differences can mainly be ascribed to income effects stemming from the different treatment of the net "rent" from imperfect competition pricing. Changes in the production structure in the energy sector are very much the same in the four regimes, cf. table 4.

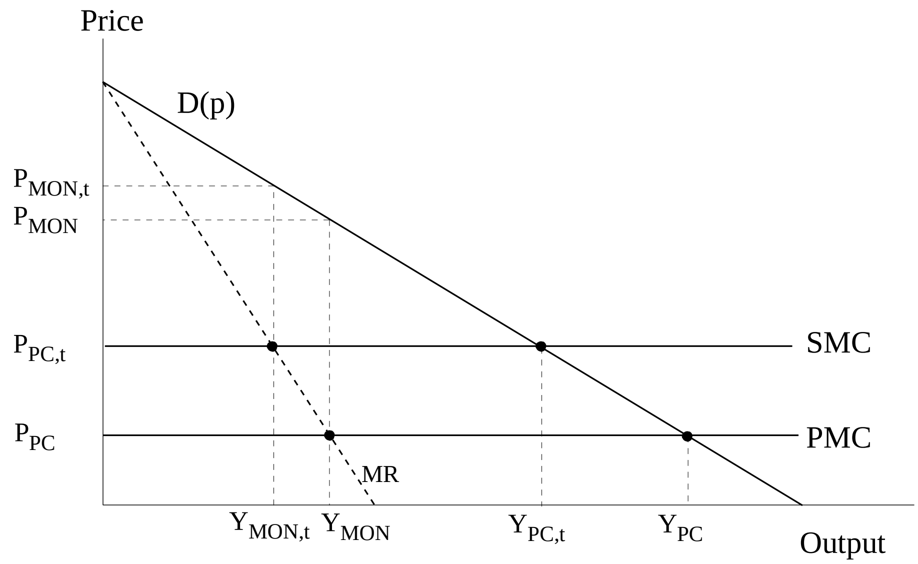
Table 4. Change in activity in CHP technologies under different competition regimes, per cent

	Perfect competition	**AC pricing**	**Pure monopoly**	**Free entry oligopoly**
Coal fired	-18.5	-19.8	-19.5	-17.9
Gas fired	9.7	11.1	10.8	11.9
Wind	14.8	15.8	15.5	15.2

6. Is there a case for differentiated CO_2 taxes?

In the literature of optimal taxation it is often discussed to what extent a Pigouvian tax should be modified in order to take into account existing distortions like e.g. imperfect competition, cf. Cropper and Oates (1992), Baumol and Oates (1988), Misiolek (1980) and Oates and Strassmann (1984). The core of the problem is that under imperfect competition production is already sub-optimal. This situation can be aggravated by a Pigouvian tax, even though the Pigouvian tax might be correct in a first-best setting. The policy implications could be differentiated CO_2 taxes depending on the market structure of the industries.[7] The problem is illustrated in the diagram below for pure monopoly (i.e. no entry) and natural monopoly with AC pricing, see figure 5a and 5b, respectively.

Figure 5a. Production and price under pure monopoly

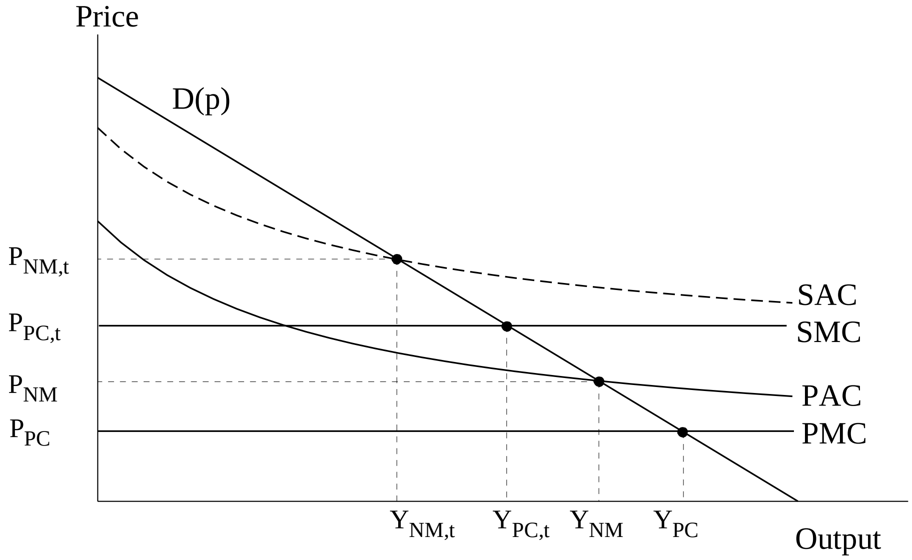


The pure monopolist supplies goods until marginal revenue (MR) equals private marginal cost (PMC), cf. figure 5a. Here, production is Y_{MON} and the corresponding price is P_{MON}. The producer enjoying a natural monopoly, if regulated according to AC pricing, sets price P_{NM} equal to average cost (PAC) and thus produces Y_{NM}, cf. figure 5b.[8] To compare, in a perfect competition situation the price, P_{PC}, would equal PMC and production would be Y_{PC}. Of course, in this situation with high fixed costs, perfect competition revenues would not cover total costs in the long run where production would have to stop.

7) Another strand of literature discuses to what extent a homogeneous Pigouvian tax should be modified in order to take into account existing distortionary taxes, cf. e.g. Bovenberg and Goulder (1996).

8) Both pure monopoly and natural monopoly with AC pricing lead to lower production than the production which could have been generated in a market with perfect competition. Whether the production in AC pricing natural monopoly is larger or smaller than in pure monopoly depends on the size of fixed costs. If fixed costs are relatively high compared to marginal costs, prices will be higher and supply will be lower in natural monopoly compared to pure monopoly.

Figure 5b. Production and price under natural monopoly with AC pricing



Unfortunately, production generates externalities. The social cost of one unit of production is SMC. If production externalities are taxed with a Pigouvian tax, the producer will experience private costs equal to social costs as the externality costs are internalized in the production costs of industries. Consequently, the producer lowers production to $Y_{MON,t}$ in the case of a pure monopoly and $Y_{NM,t}$ in the case of an AC pricing natural monopoly, as shown in figures 5a and 5b, respectively.

Two effects working in opposite directions arise as a consequence of the Pigouvian tax. On the one hand, reduced pollution leads to a welfare gain. On the other hand, when production is already sub-optimal due to imperfect competition, a welfare loss arises due to a further reduction in production below the optimal level. The net outcome of these two effects is uncertain.

If production had been submitted to perfect competition, full internalisation of external costs would have led to production of $Y_{PC,t}$. To achieve this production level under imperfect competition, two policy tools could be introduced: a Pigouvian tax on emissions and a unit subsidy on output (to compensate the producer for high fixed costs). In reality, environmental authorities seldomly have the competence to subsidise production in order to solve problems of competition, cf. Cropper and Oates (1992). However, a policy designed to solve both problems should be possible in the case of the Danish energy sector which is characterized by some form of natural monopoly and a high degree of public regulation on both the supply side and the input and environment side.

The second-best solution is to correct the environmental tax according to the element of monopoly in production, cf. Baumol and Oates (1988). This corrected environmental tax (t^*) is lower than the true Pigou tax (t_{PC}) to take account of the production loss associated with the reduction in pollution. In pure monopoly the second-best tax (t^*) is found by correcting the true Pigou tax (t_{PC}) with a factor reflecting the net value of a reduction in production (y) associated with a reduction in emissions (s), see (1). The correction consists of two parts. First, the correction rises with the degree of monopoly indicated by the difference between price (P) and marginal cost (MC). Second, the more sensitive production is to cut-backs in pollution, the larger correction of the optimal tax is needed.

$$t^* = t_{PC} - (P - MC)\frac{dy}{ds} \tag{1}$$

A similar formula for the situation with a natural monopoly regulated by the authorities to secure AC pricing is derived in the appendix. We find that in natural monopoly with AC pricing, the optimal tax corresponds to the Pigouvian tax minus an expression reflecting the welfare loss from reduced output. This expression depends on the change in production associated with a change in emissions, dy/ds, and average fixed costs, FC/y. In natural monopoly with AC pricing, average fixed costs, FC/y, exactly equal the price, P, minus marginal costs, MC, and (2) is equivalent to (1).[9]

$$t^* = t_{PC} - \frac{FC}{y}\frac{dy}{ds} \tag{2}$$

With growing production, the importance of average fixed costs declines, and t^* approaches t_{PC}.
Based on simulations with the model, we find that production falls by approximately 0.15 billion DKK (dy) and CO_2 emissions are cut back by approximately 0.32 mio. tonnes (ds) in the electricity and district heating sector as a result of a marginal CO_2 tax. Furthermore, we assumed that average fixed costs are 10 per cent of total costs. Thus, we find that the correction of the Pigouvian tax is approximately 45 DKK. Compared to a CO_2 tax of more than

9) Unless fixed costs are *very* large compared to variable costs, the correction for pure monopoly will be larger than the correction for natural monopoly because pure monopoly usually generates a higher price and a lower level of production and thus a higher welfare loss than natural monopoly.

300 DKK, a correction of around 45 DKK to take account of prior distortions in the electricity and district heating sector seems modest.

Several other studies have tried to quantify the size of the welfare loss arising when monopoly production is subjected to some kind of Pigouvian tax. These studies conclude that there are only weak empirical arguments for differentiated taxes, i.e. the welfare gains from a better environment typically more than offset losses from reduced monopoly production, cf. Oates and Strassmann (1984). Therefore, the attractive qualities of Pigouvian taxes are apparently not under serious threat from the disadvantages of imperfect competition. Thus, given that differentiated environmental taxes seem difficult to defend on grounds of principles as well as for administrative reasons, it does not seem worthwhile to correct a CO_2 tax to account for imperfect competition in energy markets.

7. Assessing the impacts of deregulation in the energy sector

The attempts to liberalise the electricity sector in Denmark and the rest of the Nordic countries have concentrated on improving competition in both production and distribution. So far, liberalisation has not been aimed at the district heating sector. This is partly due to the fact that competition in district heating can only be established in areas where several producers supply hot water to an integrated network. Nevertheless, Danish competition authorities estimate that in the long run it is possible to enhance competition in the district heating market, too. This would induce efficiency and competitiveness of district heating suppliers, cf. Konkurrencestyrelsen (1998a).

A correct method of describing enhanced competition would attempt to take into account all gains from improved efficiency. However, we choose a more simple and pragmatic approach. We assume that improved competition can be described by an exogenous reduction in the share of fixed costs in total costs.[10] Table 5 shows the results of a scenario where the fixed cost share is reduced from 10 to 5 per cent. As stated earlier, we believe that AC pricing provides the best description of the determination of production levels and prices in the Danish energy sector, but for illustrative purposes we show simulations with pure monopoly and oligopoly with free entry as well.

Table 5. Macro effects of improved competition in the energy sector, percentage change

	AC pricing	**Pure monopoly**	**Oligopoly with free entry**
Welfare	0.6	0.7	1.0
Real GDP	0.2	0.3	0.5
Private consumption	0.7	0.9	1.2
Exports	0.6	0.7	1.0
Imports	0.9	1.0	1.2
Employment	0.1	0.1	0.1
Real wages	1.0	1.2	1.3
Real capital return	1.8	1.6	2.1
Real exchange rate	0.8	0.8	0.9
CO_2 emissions	8.9	9.1	11.3

Both economic activity and economic welfare benefit from improved competition in electricity and district heating. The positive effects are initiated by a price reduction for electricity and district heating, see table 6. As a consequence of enhanced efficiency, employment falls for both coal and gas fired CHP and for windmill electricity. This puts, ceteris paribus, wages under pressure and, combined with lower energy prices, reduces production costs for the other industries who raise their activities accordingly. Eventually, total employment is higher than before deregulation. However, the higher activity induces a rise in CO_2 emissions by 9 per cent.

10) We have not tried to analyse the possible effects of improved competition related to cheap imports of electricity. Imports of electricity and district heating are exogenous in our model simulations. For a partial analysis of a liberalisation of the Nordic energy markets, we refer to Danish Economic Council (1997). For a general equilibrium analysis of Danish imports of electricity see also Jensen and Rutherford (1997).

Table 6. Effects of improved competition with AC pricing

		Activity[1]	**Employment**	**CO_2 emission**
		---------------- Per cent -----------------		
CCHP	Coal fired CHP production	16.2	-29.9	17.5
GCHP	Gas fired CHP production	9.5	-34.3	10.5
WIND	Wind energy	28.1	-20.1	0.0
AGH	Agriculture. horticulture etc.	0.2	0.1	0.7
FRS	Forestry	0.0	-0.5	-0.1
FIS	Fisheries etc.	-0.3	-0.6	-0.9
EXT	Extraction of oil etc.	5.1	1.4	0.6
OMI	Other mineral extraction	1.2	1.0	1.7
FOP	Food products, beverages and tobacco	0.1	0.0	-6.2
TXL	Textiles, leather and footwear	0.9	0.8	-3.7
FRN	Wood products and furniture	2.0	1.9	1.9
PRP	Paper, printing and publishing	0.4	0.3	-1.2
CHP	Chemicals	1.9	1.9	-1.4
PET	Petroleum etc.	1.1	1.0	1.0
NMP	Non-metallic mineral products	1.7	1.5	2.7
MET	Metal works and casting	9.8	5.8	-19.0
MPM	Metal products, machinery, electrics etc.	1.0	0.9	-4.2
JTO	Gold, silver and toys	-0.1	-0.5	-1.2
GAS	Gas supplies	4.4	4.8	4.7
WAT	Water supplies	2.1	-0.1	-75.4
CON	Construction	0.9	0.9	0.6
WTR	Wholesale trade	0.7	0.5	0.3
RTR	Retail trade	0.9	0.7	-1.7
RES	Hotels and restaurants	0.0	-0.4	1.5
TRP	Transport services	0.1	-0.2	0.4
COM	Communications	0.1	0.2	1.5
FIN	Financial institutions	0.3	0.2	2.0
INS	Insurance	0.0	0.0	1.7
DWE	Dwellings	-1.0	-0.6	3.0
BUS	Business services	0.8	0.8	1.4
EDH	Private education and health	-0.2	-0.1	0.2
REC	Recreational and cultural services	0.4	0.4	1.0
MHS	Rep. of cars and household services	0.1	0.1	1.5
DNP	Domestic services and non-profit inst.	-0.2	-0.2	1.4
GOV	Public services	0.0	-0.2	3.4
All industries		0.6	0.1	8.9

1) Activity change is measured as change in production value.

Consumers also benefit from improved competition in electricity and district heating. Real prices are reduced by approximately 1/3 and 1/4 for electricity and district heating, respectively, depending on the form of imperfect competition. At the same time, consumption of the other goods is cut slightly back.

The welfare effects are unevenly distributed among households, cf. table 7. The low income groups experience a reduction in welfare, while high income households enjoy welfare gains. For the low income groups, this picture is partly explained by the fact that the now cheaper electricity and heat only amounted to a limited share of their initial consumption while other consumption goods with rising relative prices are more important in low income households' consumption bundle. Furthermore, the rising real net wages do not improve real net income much in low income groups where a large part of total incomes stems from public transfers. The latter phenomenon is a matter of model formulation: an alternative model formulation would be to index public transfers with the development in wages in accordance with the present regulation of public transfers. Another effect from higher wages is a rise in labour supply, which improves households' purchasing power and therefore welfare. At the same time, more work means less leisure. The latter effect tends to reduce welfare.

Table 7. Changes in household welfare from improved competition with AC pricing

Total income		**Consump-tion**	**Net real wage**	**Labour supply**	**Welfare**	**Welfare**
	DKK	-------------------	Per cent	------------------		DKK
TI1	Below 50,000	0.2	1.0	0.6	-0.4	-300
TI2	50,000-99,999	0.3	1.0	0.4	-0.1	-100
TI3	100,000-199,999	0.1	1.0	0.2	0.0	0
TI4	200,000-299,999	1.0	1.0	0.1	0.8	1,600
TI5	300,000-399,999	1.1	1.0	0.0	0.9	3,000
TI6	400,000-499,999	0.9	1.0	0.0	0.8	3,300
TI7	Above 500,000	0.3	1.0	0.0	0.3	1,400
All households		0.7	1.0	0.1	0.6	1,300

Model simulations point out economic gains in the form of enhanced welfare and higher GDP when competition in the electricity and district heating sector is improved. These gains are of a relatively considerable size taking into account that electricity and district heating production is only a small fraction of total production in Denmark. The rise in CO_2 emissions following the higher demand for electricity and heat and the subsequent increased activity in other industries can be neutralised by a CO_2 tax. With AC pricing, the positive welfare effects of increased competition are 0.3 per cent and the GDP rise is only 0.2 per cent. Thus, the positive effects on welfare and the macro economy remain also if CO_2 emissions are kept constant. The revenue from the CO_2 tax can be redistributed in a way that best compensates for the slightly unfavourable distributional effects of improved competition. This indicates that the negative effects on production and welfare from a CO_2 tax complying with ambitious CO_2 targets could be partly offset by improved competition.

8. Concluding remarks

In this paper we have illustrated some consequences of imperfect energy markets for public regulation. Probably, in the coming years imperfect competition of some kind still remains the most realistic description of Danish energy markets. The main conclusions with respect to environmental aspects of regulation, i.e. CO_2 targets, are the following: Firstly, market structures with imperfect competition imply lower CO_2 taxes than energy markets with perfect competition. The lower CO_2 taxes under imperfect competition can be explained by the fact that a tax on the input of an industry with market power (monopoly or oligopoly) is more than reflected in the market price due to the mark-up. Thus, model based calculations of the impact of CO_2 taxes not taking imperfect competition into account could overstate the necessary CO_2 tax.

Secondly, general equilibrium simulations indicate that there are only weak empirical arguments for differentiated CO_2 taxes motivated by imperfect energy markets. The theoretical arguments for differentiated CO_2 taxes have been made by Oates and Strassman (1984) in the case of pure monopoly. In this paper we derive a theoretical result for the case of a natural monopoly with AC pricing. Our general equilibrium analysis for pure monopoly and monopoly with AC pricing are in line with the results of Oates and Strassman (1984) achieved through partial analyses on US data.

Thirdly, the Danish economy will benefit from a deregulation of the electricity and district heating sector with respect to welfare and economic activity. The latter result holds also if CO_2 emissions are kept constant.

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Appendix

Below, we derive a formula for correcting the Pigouvian tax in the case of an AC pricing natural monopoly. As in pure monopoly, society wishes to choose an environmental tax, t, that maximizes net welfare coming from production in the monopoly sector, i.e. the difference between society's willingness to pay, f(y) (equal to the price, P), for the monopolist's production, y, and total production costs for society, i.e. the monopolist's private production costs, C, which are a function of the production level, y, as well as the level of pollution abatement, a, and the social damage costs from pollution, D(s).

$$W = \int_0^y f(y)\,dy - C(y,a) - D(s) \qquad \text{(A1)}$$

As production, y, depends on the size of the tax, t, the first-order condition is found by differentiating W with respect to t:

$$\frac{dW}{dt} = f(y)\frac{dy}{dt} - \frac{\partial C}{\partial y}\frac{dy}{dt} - \frac{\partial C}{\partial a}\frac{da}{dt} - \frac{dD}{ds}\left(\frac{\partial s}{\partial y}\frac{dy}{dt} + \frac{\partial s}{\partial a}\frac{da}{dt}\right) \qquad \text{(A2)}$$

$\partial C/\partial y$ is analogous to marginal cost, MC. The producer's total costs, C, are given from private production costs and payment of the environmental tax. In the case of natural monopoly, production costs equal fixed costs, FC, plus variable costs. If we assume that marginal costs are constant, variable costs are equal to marginal costs, MC, multiplied by the level of production, y:

$$C = C(y,a) + s \cdot t = FC + MC \cdot y + s \cdot t \qquad \text{(A3)}$$

Public regulation of a natural monopoly fixes a price that exactly covers average costs, AC:

$$AC = \frac{FC}{y} + MC + \frac{s \cdot t}{y} = f(y) \qquad \text{(A4)}$$

Also, the usual assumption from the theory of optimal environmental taxation applies. Thus, the producer chooses to engage in abatement until the marginal abatement cost exactly corresponds to the tax payment for a marginal emission:

$$\frac{\partial C}{\partial a} = -t \cdot \frac{\partial s}{\partial a} \tag{A5}$$

From (A4) and (A5), we find respectively f(y) and ∂C/∂a which are substituted into (A2). After rearranging (A2) we find:

$$t\left(\frac{s}{y}\frac{dy}{dt} + \frac{\partial s}{\partial a}\frac{da}{dt}\right) = \frac{dD}{ds}\left(\frac{\partial s}{\partial y}\frac{dy}{dt} + \frac{\partial s}{\partial a}\frac{da}{dt}\right) - \frac{FC}{y}\frac{dy}{dt} \tag{A6}$$

To simplify this neat formula, we assume that emissions follow production proportionally, i.e. the emission intensity of marginal production equals the average emission intensity, ∂s/∂y = s/y. In addition, we note that the expressions in the two parenthesises equal ds/dt. Finally, we know that dD/ds, which denotes the change in damage costs generated by a change in emissions, exactly corresponds to the Pigouvian tax, t_{PC}. With this information, (A6) can be reduced and the optimal tax deducted:

$$t^{*} = t_{PC} - \frac{FC}{y}\frac{dy}{ds} \tag{A7}$$

As noted, the simplified formula (A7) rests on the assumption that the marginal emission intensity is equal to the average emission intensity. This assumption is in fact a rather strict assumption. In the CO_2 case where abatement can be interpreted as activities directed towards reducing energy use, the assumption implies a constant CO_2 emission intensity.