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Nordic Carbon Dioxide Abatement Costs

Jens Hauch

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Nordic Carbon Dioxide Abatement Costs

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Abstract:
Marginal costs of reducing emissions of CO_2 differ among countries. Some countries have a low emission level and by that high marginal reduction costs while the opposite is true for some other countries. Also geographical and technological differences affect the costs of emission reduction. Reduction costs in the Nordic countries are estimated here using the multi country equilibrium model Elephant. Denmark and Finland can reduce emissions from electricity production which gives relatively low reduction costs. Sweden and Norway have an almost emission free electricity production which implies that emissions must be reduced elsewhere at higher costs. If the focus is on total Nordic emissions rather than national, costs are minimized by international trading of emission permits. If also international trade of electricity is possible, emission reduction costs are reduced further for emission reductions of “medium” size. Free electricity trade can therefore be an environmental advantage.

Keywords: Abatement costs, environmental taxes, energy, international emission permit trading.

JEL: D2, Q2, Q4.

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1. Introduction[1]

The focus on carbon dioxide (CO_2) as a source of the global warming has been increasing in the recent years. This led in the Kyoto agreement "annex one" countries to decide to reduce emissions, see United Nations (1998). Differentiated percentual reductions were decided among the participating countries. There are several possible explanations for the differentiated percentages: Firstly, the countries have different costs of reducing emissions, e.g. because of differences in technological possibilities and choices, which imply that uniform percentual reductions are "unfair". Secondly, some countries have higher preferences for emission reductions, which may lead them to accept higher reductions to put pressure on other countries. Thirdly, some countries may have a higher bargaining power than others. This can, e.g., be caused by differences in welfare levels or in initial levels of CO_2-emissions. International trading of emission permits was agreed upon, which implies that reduction costs can be minimized internationally.[2] Obtaining this minimization should therefore not influence the distribution among countries of reduction obligations decided in Kyoto.

Knowledge on reduction costs ought to be background information when accepting international agreements like the Kyoto agreement.[3] These costs are, however, generally not estimated. This paper calculates the costs of reducing CO_2 in the Nordic countries, Denmark, Norway, Sweden and Finland, under different assumptions about electricity trading.

1) The views presented in this paper are not necessarily shared by the Chairmanship of the Danish Economic Council. Financial support from Nordic Energy Research Programme and The Danish Environmental Research Programme is greatly acknowledged.

2) The possibilities of achieving the lowest possible costs of emission reductions in the Nordic countries through bilateral negotiations have been analysed by Bohm (1997). The background for that study was marginal abatement costs in the countries. The result was that 97 per cent of the potential gain was realised by the negotiators that were national teams. It may, therefore, not be unrealistic to expect the potential gains from emission trading on the basis of abatement costs curves to be realised. An evolutionary report of the Bohm study states, however, that the result is a surprisingly high efficiency, much higher that in real world cases in USA, see Barrett et al. (1997).

3) Also knowledge on damages from CO_2 emissions is important information when deciding optimal level of emissions. See Tol (1999) for an overview of estimates of these damages.

Emissions of CO_2 come from several different sources. In some countries, electricity production is an important source while it in other countries is free of emissions. Other main sources are transportation and use of fossil fuels in industries and households. In this paper emission sources will be separated into two groups, sources related to electricity and district heating production and other sources.

It will first be analysed how the national reduction cost curves are composed of reduction possibilities in different areas of the economy. Then the efficiency costs of different kinds of fixed international sharing of reduction obligations will be analysed. The costs will be compared with the costs of an efficient system of international permit trading. Finally, the importance of free electricity trade will be analysed. The hypothesis is that international electricity trade can increase the reduction possibilities even when international permit trading is allowed. The argument is that a potential production of low emission electricity in a country can only be utilized with trading of electricity.

Section 2 gives a brief overview of the conditions for the Nordic electricity markets. In Section 3 the modelling background for the analyses is described. In Section 4 the analyses are presented and Section 5 concludes the paper.

2. Electricity supply and demand in the Nordic countries

Electricity production is in the Nordic countries based on very different technologies. The Norwegian system is solely based on hydro power, i.e. there are no emissions of CO_2 from Norwegian electricity production. Combined heat and power production (CHP) is widely used in Denmark. The large scale CHP plants are primarily based on coal, while subsidizing has recently implied investments in small scale natural gas based CHP plants. In Sweden a large part of the electricity production is based on nuclear power, but also a large hydro power production takes place. The Swedish power production is therefore primarily based on technologies that does not cause emissions of CO_2. The Finnish production is based on several different technologies: Largest of those are nuclear, hydro and coal based production, but also a significant production of small scale wood based production exists. The Finnish power production is therefore not without emissions of CO_2, though the emission per unit electricity is lower than the Danish.

Several cable connections exist between the Nordic countries and electricity is widely traded among the countries. The electricity sectors have historically been regulated, but are now liberalised.[4] Traditionally the electricity trade has had security of supply as its main purpose, but international competition in the sector has in the recent years gained increasing importance in determining the trade pattern.

The demand structure for electricity is different in the four countries. Norwegian and Swedish electricity consumption per capita is a third higher than the Danish and around 15 per cent higher than the Finnish. Differences in electricity consumer prices can partly explain this as the Danish household consumer price is twice the price in the other countries and the industry price is around 50 per cent larger. Also the colder Swedish, Finnish and Norwegian climate influences the consumption levels.

Use of fossil fuel elsewhere than in electricity production is a very important source of CO_2 emissions in all the countries. The demand and possibilities of substitution of fossil fuels are therefore important factors in determining costs of emission reduction. In Norway the final demand for other energy types than electricity is concentrated on oil products, while Sweden apart from oil products also use district heating. In Denmark and Finland the final demand is composed of both oil products, district heating and natural gas, see Hauch (1999).

3. Modelling framework

One suitable model for calculating abatement costs is the Elephant model (**E**lectricity, **L**iberalisation, **E**quilibrium, **P**roduction **H**eterogeneity **A**nd **N**ordic **T**ransmission), see Hauch (1999).[5] The appendix gives a graphical overview of the model. Elephant is an partial equilibrium model covering the Nordic countries, Denmark, Sweden, Norway and Finland. In standard use the energy markets from the base year 1995 to 2020 are analysed. In each country five energy consuming sectors and one household that demands energy for final consumption are modelled. These sectors demand electricity, district heating, natural gas, coal, oil and an aggregate of other inputs following a top down system of nested production and utility functions. Their demand levels depend

4) The Danish electricity sector has not yet been fully liberalised, but the decision has been made and an almost full liberalisation is planned by 2003.

5) Elephant is partly based on the Normod model, see Bye et al. (1995).

among other things on economic activity, energy prices, taxes and technological development.

An electricty and district heating producing sector is included by a bottom up modelling. This sector chooses production level and technology use depending on relative input and output prices as well as technological possibilities. Both supply level and choice of technology are determined endogenously in the model. The available technologies are described by technological parameters determining type of fuel, efficiency, electricity-district heating output ratio, emissions of pollutants, business economics etc. The technologies use different fuel inputs and several technologies using coal, natural gas, hydro power, nuclear fuels, bio fuels and wind power are included. Emissions of CO_2 depend on technology choice in electricity and district heating production and final consumption of fossil fuels. The level of emissions can, e.g., be regulated by imposing an emission constraint. Such constraints can be interpreted as emission taxes or tradeable emission permits and will affect final energy consumption and technology choice in electricity and district heating production.

International trade of electricity is possible through cable connections of a size corresponding to the existing connections. If the transmission capacity is insufficient it will endogenously be extended if the shadow value of capacity is sufficiently high.

The model is based on a large data set determining the above mentioned parameters for the Nordic countries. A throughout description of the data set is given in Hauch (1999).

The way the model is used here is different from the standard use. The first point is that the model is solved for the countries separately, i.e. international electricity trading is not possible in the calculation of the abatement cost curves for the individual countries. The reason is that the abatement costs for a country will be very low if electricity trading is allowed. For example, Denmark could reduce CO_2-emissions significantly by importing electricity from countries without emission constraints. Importing electricity from another country would, however, not reduce global emissions if a polluting technology is used for the imported electricity and the reduction curve would not represent a reduction in the CO_2-emissions caused by Danish energy consumption. The point is that we are interested in costs of reducing global emissions by measures undertaken in a specific country, and must therefore in the national curves leave out the possibility of reducing national emissions by importing electricity. Cost curves for common Nordic emission reductions will also be calculated. In that case electricity trading can be allowed or not, and the difference is determined.

The abatement costs are calculated for the base year 1995 under the assumption that new technologies can be used instantly.[6] The location of the curve depends on the year for which it is calculated as it depends on which technologies are installed. This can be illustrated by an example: If an existing Danish coal fired plant shall be substituted by a new gas fired plant, the cost would be the difference between the short run marginal costs of the coal plant and the long run marginal costs of the new gas plant. If calculations were made for a future year, the coal plants that existed in the base year might have been scraped. The cost of pollution abatement would then be the difference between the long run costs of a new coal fired plant and the long run costs of a new natural gas fired plant, i.e. less than in the base year. The curves are not calculated for future years as their dependence of intermediate investments makes them relatively hypothetical.

How can emissions be reduced? In electricity and district heating production it is possible to substitute towards less polluting technologies. These technologies are more costly than the existing technologies. If they were cheaper, they would already have been used in the unconstrained case. In other parts of the economy emissions will be reduced by substitution in households and firms, which will also be costly. The model will therefore not find any “free” emission reduction.

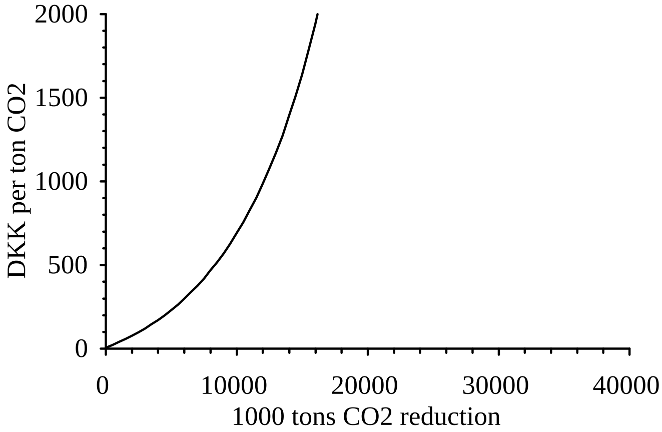
4. Results

4.1 National Abatement Costs

The Norwegian curve is shown in Figure 1. In Norway, CO_2-emissions can be reduced only by substitution in households and in other production sectors than electricity. Costs of emission reductions are rapidly increasing and a reduction of for example 10 million tons would require a tax of around 700 DKK per ton CO_2. The marginal cost curve is smooth as emission reductions are caused by input substitution within a system of continuous and twice differentiable utility and production functions.

6) See Knapp (1999) for a discussion of adjustment time and Jacoby and Wing (1999) for model simulations.

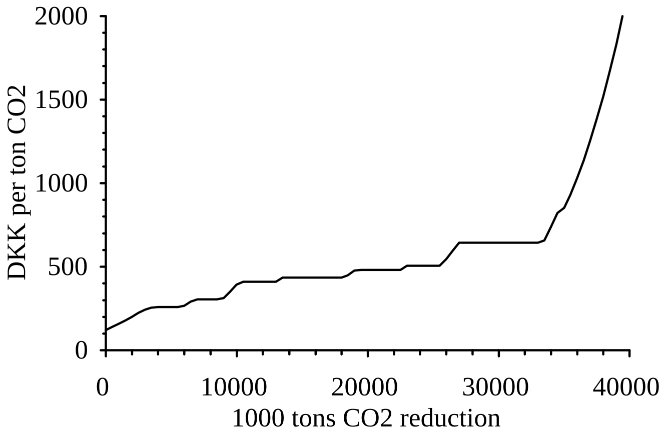
Figure 1 Marginal abatement costs for Norwegian CO_2-reductions



Source: Scenarios with Elephant.

Costs of emission reductions in Denmark are presented in Figure 2. The cost curve is different from the Norwegian as it is much lower and has horizontal segments. These horizontal segments represent technological changes in electricity and district heating production, while the smooth increasing parts of the curve represent input changes in final consumption of fossil fuels. At certain cost levels it is possible to substitute a polluting electricity producing technology with a less polluting one. The installed amount of the polluting technology will determine the total pollution reduction from this substitution and by that the length of the horizontal segment. The first part of the curve is increasing, i.e. the cheapest way to obtain a small Danish emission reduction is by input substitution in households and industry. When the marginal cost of emission reduction is around 250 DKK per ton CO_2, it becomes beneficial to change the technology bundle in electricity and district heating production. At this level the marginal costs of using natural gas are equal to the marginal costs of using some of the existing coal fired plants. The marginal costs of substituting these coal fired plants with natural gas are constant until they have all been replaced. The combination of technology changes in electricity and district heating production and input substitution elsewhere continues until emissions have been reduced by 35 million tons. There is at this point almost no CO_2 emissions from electricity and district heating production as all production is made with renewable energy sources such as wind power and bio fuels. The possibilities of further emission reductions are therefore limited to input substitution elsewhere. As emissions from final energy consumption at this level have already been heavily taxed, costs of further reductions are increasing very fast.

Figure 2 Marginal abatement costs for Danish CO_2-reductions

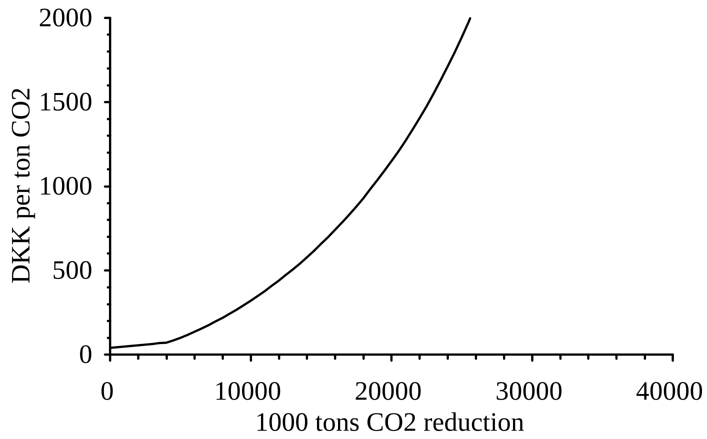


Source: Scenarios with Elephant.

There was in the base year a high Danish taxation on CO_2. This implies that the marginal reduction curve does not intersect origo; it is costly even to realize the base year emission level.

The marginal abatement cost curve for Sweden is shown in Figure 3. A central assumption behind the curve is that nuclear power production at the base year level is a possibility in Sweden. This is obviously the case in the base year for which the costs are calculated. The curve in Figure 3 can therefore not be used to analyse the costs of Swedish emission targets in combination with an assumption of nuclear phase out. If a nuclear phase out is assumed, marginal costs of emission reductions are higher.

Figure 3 Marginal abatement costs for Swedish CO_2-reductions

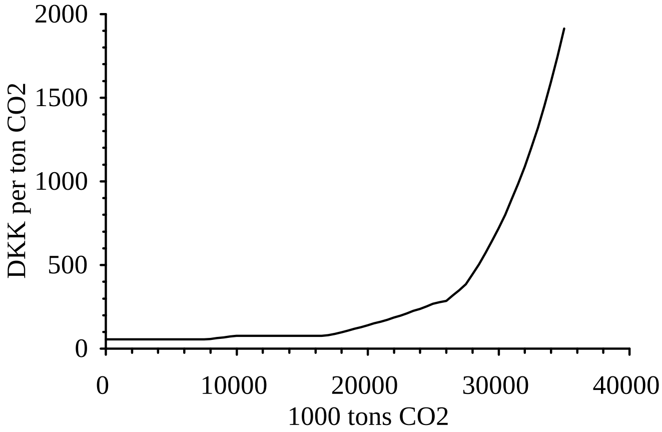


Source: Scenarios with Elephant.

The Swedish marginal cost curve is similar to the Norwegian curve, but lower. Swedish electricity production is primarily based on hydro and nuclear power. The possibilities of substituting between technologies in electricity and district heating production are therefore limited, i.e. reduction possibilities are therefore primarily input substitution in industry and households. The Swedish economy is, however, larger and the unconstrained emission level in Sweden is almost twice the size of the unconstrained Norwegian emission level. The marginal costs of the same absolute reduction will therefore be around half the size of the corresponding costs in Norway. The marginal costs of similar percentage national reductions are, however, similar in Norway and Sweden.

The Finnish marginal abatement cost curve presented in figure 4 is similar to the Danish in the sense that it is composed of increasing and horizontal segments. The Finnish abatement cost curve does like the other curves have a take off for the highest reductions. The long horizontal segment at the start of the Finnish abatement cost curve represents a technological change away from coal fired plants towards the use of more wood fired plants.

Figure 4 Marginal abatement costs for Finnish CO_2-reductions



Source: Scenarios with Elephant.

4.2 International trade of Electricity and Emission Permits

International trading of emission permits can help minimizing costs of emission reductions internationally. With emission trading, emissions will in the standard case be reduced where it is cheapest.[7] Electricity trading can, however, reduce costs of emission reductions further. It will here also be analysed how electricity trading can help.[8]

Let us first consider the case where emission trading is possible among the included countries, while electricity trading is not possible. In this case the costs are calculated by a horizontal summation of the national abatement costs curves. Consider a total reduction of 20 per cent (approximately 41 million tons CO_2), Table 1 gives the average marginal reduction cost under different assumptions of how the reduction is met.

7) See Heal (1995) for a discussion of necessary conditions for this to hold.

8) Cole et al. (1998) find that general trade liberalisations increase emissions of CO_2 primarily via higher consumption.

Table 1 Marginal costs of a 20 per cent emission reduction in the Nordic countries

	Equal absolute reductions [a)]	Equal percentage reductions [a)]	Free permit trading [a)]	Free permit and electricity trading
	----- DKK per ton CO_2 -----			
Marginal cost	400	320	250	110

a) Electricity trading is not possible.

Note: The marginal costs in "Free permit trading" and "Free permit and electricity trading" are equal in the countries. Marginal costs in "Equal absolute reductions" and "Equal percentage reductions" are averages of the national marginal costs.

Source: Scenarios with Elephant.

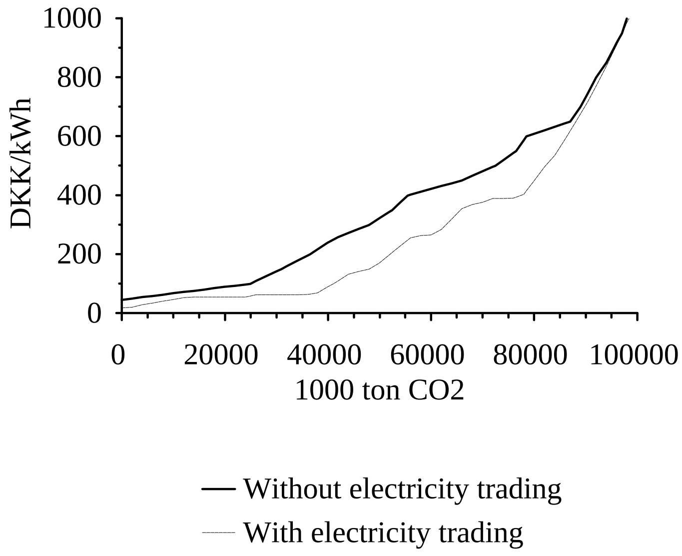
The most expensive way to reduce emissions considered here is equal absolute reductions as countries with initially low emission levels make the relatively highest reduction. This distribution of reduction obligation is probably not acceptable to small countries or countries with low initial emissions and would in general be considered unrealistic.[9] The situation is significantly improved if equal percentual reductions are decided instead, as the marginal cost is reduced from 400 to 320 DKK per ton CO_2. This solution is, however, far from being optimal as marginal reduction costs differ among countries. The solution to this problem is free international permit trading that can reduce the marginal cost to 250 DKK per ton CO_2. In this case emissions are reduced cheapest possible.

An assumption underlying the above curves is that international trade of electricity is not possible. This is important as abatement costs might be lower with free electricity trade than without. This can be illustrated by an example: Consider Denmark and Norway. Norway cannot reduce emissions by changes in electricity production as it already takes place without emissions of CO_2. The Norwegian hydro power production could, however, be increased at relatively low costs without further emissions. This production could substitute away some Danish coal-based production and by that reduce total Nordic emissions. In Table 1, the marginal abatement cost of emission reduction is calculated when electricity and emission permits can be traded freely. This reduces the marginal cost to 110 DKK, which is significantly lower than without electricity trading.

9) See Kverndokk (1995) for a discussion of this justice problem.

It is, however, questionable whether electricity trading reduces emission reduction costs for all reduction levels. Emission reduction costs with and without electricity trading are calculated for different levels of emission reductions, see Figure 5.

Figure 5 Marginal abatement costs with free international permit trading



Source: Scenarios with Elephant.

The marginal abatement cost curves for the Nordic countries are like the national curves composed of changes in electricity and district heating production and input substitution elsewhere in the economies. The curves take off around a CO_2-reduction of 80 million tons. This is where all possibilities of substitution in electricity and district heating production are exploited and all further reductions must be made elsewhere. At this point all possible investments have been made in Norwegian hydro power and electricity is produced using this, existing nuclear power and renewable energy in the countries.

Figure 5 shows that free electricity trading is not equally important for all levels of emission reductions. When emission reduction are either small or large the importance of electricity trading is minor. There are two different explanations for that. Firstly, for high emission reductions electricity production is solely based on renewable fuels and nuclear power, and there are no more gains from producing electricity in one country rather than another, which implies that electricity trading is unimportant. Secondly, for low emission reduction levels marginal reduction costs are relatively low in Finland that can substitute towards the existing wood based capacity at low costs. Electricity trading is not important to realize this gain. For medium reduction levels electricity trading is, however, of importance. The explanation is, as considered above, primarily that Norway has a potential for hydro power production that can only be utilized with free electricity trading.[10]

5. Conclusion

The Nordic countries are very different with respect to CO_2 emissions in total and per capita. This is primarily caused by differences in geographical and political possibilities of using different technologies, e.g. nuclear power. This gives the countries different costs of reducing emissions of CO_2.

The Elephant model is used for calculating marginal abatement costs for 1995. Norway and Sweden have almost no emissions of CO_2 from electricity production. They can therefore only reduce emissions elsewhere in their economies. Their reduction costs are consequently relatively high. Finland and especially Denmark have large emissions of CO_2 from electricity production. There emission reduction costs are minimized by reductions in emissions from both electricity production and elsewhere. Their marginal reduction cost curves consist of both increasing and horizontal segments. The horizontal segments represent substitution from a polluting electricity production technology to another. The possibilities for reducing emissions from electricity production imply lower emission reduction costs in Denmark and Finland.

The distribution of reduction obligations among countries is important because of the cost differences. Equal absolute reductions is unfair towards small countries or countries with low initial emissions and is very costly. A better solution is equal percentual reductions that reduce total reduction costs significantly, but is still not optimal. Free international trading of emission permit can in the standard case help minimizing reduction costs. Emission

10) Ammundsen et al. (1998) find that the gain from electricity trading is increasing with increasing emission reductions. Very large emission reductions are, however, not analysed. Their result does therefore qualitatively support the above result with respect to small reductions and does not contradict the result with respect to large reductions.

reduction costs are here reduced significantly when emission trading is possible, which supports the theoretical result.

International trading of electricity can in some cases reduce emission reduction costs further, even when international trading of emission permits is already possible. For small and large emission reductions electricity trade is less important, but for medium size reductions costs can be reduced significantly by allowing electricity trade. The reason is a larger flexibility in technology choice that makes a better utilization of emission free technologies possible.

The calculated cost curves depend among other things on what technologies are installed initially. This implies that the location of the curves will be different if some future year is considered. This should be remembered if the curves are used in actual policy making.

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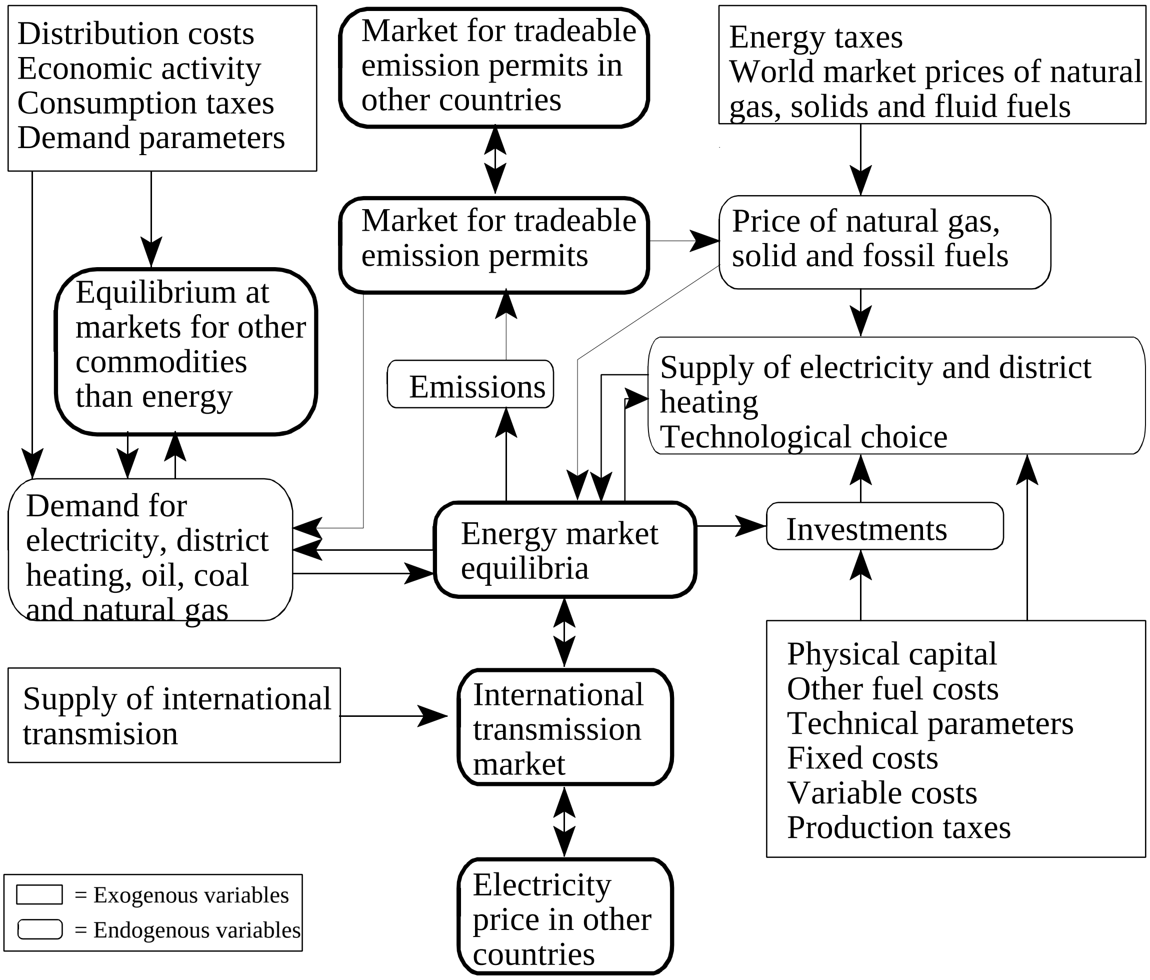
Appendix: The Elephant model



Note: Bold frames indicates market equilibria.