

Market structure and the price of electricity: An ex ante analysis of the deregulated Swedish electricity market.¹

by

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1. Introduction

The Swedish electricity market is about to be deregulated. As of January 1, 1995, the almost century-old institutional framework of the markets for high- and low-voltage electricity will be replaced by new legislation more conducive to competition. This means that the system of regional and local monopolies characterizing the Swedish electricity market will be replaced by a system with competition in production and supply. The key institutional change is that, unlike in the past, transmission and distribution networks will be operated by separate companies and be open to all producers, suppliers and traders at non-discriminating prices.

There is no formal decision to open a spot market for electricity, but it is most likely that such a market will be organized during the next few years. The short term development of electricity prices obviously depends on the existence of a spot market and the particular trading rules of that market. But the general level of electricity prices to a large extent reflect generation and distribution costs as well as the degree and nature of competition on the market for electricity.

The Swedish high-voltage electricity market exhibits a very high degree of concentration on the seller side. In terms of Herfindahl's index the degree of concentration is 0.32, which corresponds to a market with only three sellers of equal size. In the case of the Swedish market for high-voltage electricity, however, the high value of the Herfindahl index is primarily due to

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the size of the two biggest firms. Thus, the market share of the state-owned company Vattenfall is close to 50 %, while the second biggest producer, Sydkraft, has a market share close to 25 %.

Against this background it is a real possibility that there will be a considerable degree of monopolistic pricing on the "new" electricity market in Sweden. The purpose of this paper is to explore this issue, using a simple numerical model of the market for high-voltage electricity in Sweden. In particular we will explore the relation between, on the one hand, the Cournot-equilibrium price and, on the other hand, the number of firms and the size distribution of firms on the market.

2. The model

The model is static and designed to endogenously determine the volume as well as the market clearing prices of one-year contracts for electricity. Assuming that there is a spot market for hourly contracts and no uncertainty, the market prices of the one-year contracts are equal to weighted averages of the 8760 hourly spot market prices. It is a short term model in the sense that the production capacity of each firm is exogenously determined.

The market demand for electricity is the sum of the demands by a large number of relatively small domestic and foreign industrial, commercial, public sector and residential consumers. Assuming that all other product and factor prices are given, and the price elasticity of electricity demand (η) is constant, the demand function can be written

$$E = E_0 \left(\frac{P_E}{P_E^0} \right)^\eta \quad (1)$$

where E is total electricity consumption, P_E , the market price of high-voltage electricity and superscript 0 the (exogenous) pre-reform value of the variable in question.

The electricity consumed is partly produced by the F domestic firms and partly imported. In equilibrium the sum of domestic production and import equals demand. Denoting production in domestic firm f by X_f and import by M , the equilibrium condition becomes

$$E = \sum_{f=1}^F X_f + M \quad (2)$$

Substitution of (2) in (1) yields the following expression for the equilibrium price as a function of domestic production and import

$$P_E = P_E^0 \left(\frac{\sum X_f + M}{E^0} \right)^{1/\eta} \quad (3)$$

Imported electricity is supplied by price-taking importers. The importers are able to buy electricity from foreign suppliers at the price P_M defined by

$$P_M = P_E^W + dP_E^W \left(\frac{M}{T} \right)^\rho \quad (4)$$

where P^W is the supply price in the foreign country, d is the transmission loss per unit of electricity imported and T is the transmission capacity. The parameter ρ is a positive number such that P_M increases rapidly as M exceeds T . Thus the transmission capacity limit is defined in terms of the losses; whenever capacity utilization exceeds T , the transmission losses exceeds $d \cdot 100\%$.

Importer behaviour is summarized by the following complementarity conditions

$$P_E - P_M \leq 0 \quad (5)$$

$$M(P_E - P_M) = 0 \quad (6)$$

$$M \geq 0 \quad (7)$$

Thus import is constrained in the model through the transmission capacity and as a result imported electricity only has a marginal effect on the simulation outcomes.

Before turning to the producer behaviour assumptions the technological constraints and the specification of cost functions should be discussed. Concerning the technological constraints two categories of production capacity are distinguished, "Base load" and "Peak load" capacity. This terminology is not entirely correct as hydro power, which to some extent is used for peak production, is regarded as "Base load" capacity. The other type of "Base load" capacity is nu-

clear power. It should be mentioned that hydro and nuclear power together accounts for more than 95 % of the production of power in Sweden, and that the annual hydro production is roughly equal to the annual nuclear production. The "Peak load" capacity is an aggregate of primarily fossil fuelled plants, ranging from combined heat and power production units in operation more than 4 000 hours per year to gas fuelled units operated only a few hours per year. Each one of the F firms has a "portfolio" of Base and Peak production units.

Output in Base load plants of type i in firm f is denoted X_{fi} while output in Peak load plants is denoted X_{jf} . For a given firm f total output is constrained by the existing capacities K_{fi} and K_{jf} of Base and Peak production units. The total output in firm f , X_f , is given by

$$X_f = \sum_{i=1}^2 X_{fi} + X_{jf}; \quad f=1,2,\dots,F. \quad (8)$$

and at a given level of firm output the utilization of the different types of plants is determined by cost minimization considerations.

The marginal cost of production in Base load units is defined by

$$\frac{\partial C_{fi}}{\partial X_{fi}} = c_i + \lambda_{fi}; \quad i=1,2.; f=1,2,\dots,F. \quad (9)$$

where c_i is a firm-independent unit cost of operation and λ_{fi} is a firm-specific scarcity rent on the firm's production capacity of type i . As usual λ_{fi} is positive only if the capacity in question is fully utilized, i.e. X_{fi} is equal to K_{fi} . For Peak load units the marginal cost function is

$$\frac{\partial C_{jf}}{\partial X_{jf}} = a_j + b_j \left(\frac{X_{jf}}{K_{jf}} \right)^\phi; \quad f=1,2,\dots,F. \quad (10)$$

where a_j is the fuel and other operating costs per unit of output in the cheapest type of combined heat and power production units and $a_j + b_j$ is the corresponding cost in oil fired condensing power plants. The parameter ϕ is a positive number greater than unity. Thus the second term on the right hand side grows rapidly as X_{jf} exceeds K_{jf} . This construction is intended to approximate the considerably higher production cost in gas turbines which have to be taken into operation when all other capacity at the disposal of the firm's is already fully utilized.

As was mentioned above cost minimization considerations determine a firm's utilization of its available capacity as well as the marginal cost of production, $\partial C_f / \partial X_f$, of the firm. The following equations and inequalities, where X_i and X_j are assumed to be non-negative, define the relevant decision rule of the firm.

$$\frac{\partial C_f}{\partial X_f} - \frac{\partial C_{f'}}{\partial X_{f'}} \leq 0; \quad i=1,2; f=1,2,\dots,F. \quad (11)$$

$$X_f \left(\frac{\partial C_f}{\partial X_f} - \frac{\partial C_{f'}}{\partial X_{f'}} \right) = 0; \quad i=1,2; f=1,2,\dots,F. \quad (12)$$

$$\frac{\partial C_f}{\partial X_f} - \frac{\partial C_{f'}}{\partial X_{f'}} \leq 0; \quad f=1,2,\dots,f. \quad (13)$$

$$X_j \left(\frac{\partial C_f}{\partial X_f} - \frac{\partial C_{f'}}{\partial X_{f'}} \right) = 0; \quad f=1,2,\dots,F. \quad (14)$$

Total production, and thus the price level, is determined by profit maximization behaviour on the part of the producers as well as the competitive environment. Concerning the competitive environment several possibilities are conceivable. One, rather unlikely, possibility is that all firms behave as price takers on a competitive market. Then the model is closed by the standard price-equal-to-marginal-cost condition, i.e.

$$P_E = \frac{\partial C_f}{\partial X_f}; \quad f=1,2,\dots,F. \quad (15')$$

This condition also summarizes the outcome of Bertrand competition in prices. The competitive price level can be used as a norm for evaluating the equilibrium price level emerging with other assumptions about the competitive environment. Apart from outright collusion the most extreme outcome in terms of monopolistic pricing is a Nash-Cournot equilibrium, i.e. an equilibrium in a situation when each firm knows the market demand and takes the output of the other firms as given. This type of producer behaviour is defined by the following set of equations.

$$P_E + X_f \frac{\partial P_E}{\partial X_f} = \frac{\partial C_f}{\partial X_f}; \quad f=1,2,\dots,F. \quad (15'')$$

This completes the description of the model. It is empirically implemented by means of production cost and capacity distribution data from the Swedish power industry, and calibrated to the actual situation in 1991. The model is solved by means of GAMS (see Brooke et.al. (1988)), and a solution is obtained in less than 30 seconds on a 486 PC.

3. Empirical data and the Base case.

In the model the nine largest electricity producing firms are treated as active players, while the remaining power producers are aggregated into one group which is assumed to adapt passively to the prevalent market price of high voltage electric power. The real world firms, and their behavior, are represented by simplified "cousins" in the model. Thus, VAT is a stylized firm with the same portfolio of production units as Vattenfall. Like Vattenfall VAT has an initial market share of approximately 50 % and an even larger share of the joint production capacity. The firms in the model and their respective production capacities are presented in Table 1.

Concerning the calculations of the firms production capacity it should be pointed out that the supply of hydro power can vary up to +/- 16 TWh between years depending on actual precipitation. This implies that the annual production capacity of the power producing firms vary between approximately 156 TWh and 188 TWh. Unexpected production halts can of course lead to additional variations. The data in Table 1 are based on the situation in 1991 when total domestic power production was 142.5 TWh.

Three different categories of power generation plants are identified: hydro power, nuclear power, and an aggregate of CHP and condense power fired by fossil fuel or biomass. Each firm's variable cost is a function of the variable costs associated with the different sources of power generation, and of the structure and mix of each individual firms production facilities. Estimates of the variable costs associated with the different sources of power generation used in the model are shown in Table 1.

Table 1 Electricity producing firms, production capacity and variable costs.

| Firms in the model | Hydro power 1 Öre/kWh | Nuclear Power 5 Öre/kWh | Other Power 7-20 Öre/kWh | Capacity TWh/year |
|--------------------|--------------------------|----------------------------|-----------------------------|----------------------|
| VAT | 35.7 | 40.4 | 15.0 | 91.1 |
| SYD | 6.9 | 17.1 | 10.6 | 34.6 |
| STOCK | 3.2 | 4.8 | 4.0 | 12.0 |
| GULL | 3.9 | 3.6 | 1.6 | 9.1 |
| STOR | 3.9 | 2.1 | 1.2 | 7.2 |
| SKAND | 1.6 | 1.2 | 0.8 | 3.6 |
| SKELL | 2.6 | 0.4 | - | 3.0 |
| GRAN | 2.4 | - | - | 2.4 |
| KORS | 0.9 | 0.3 | 0.3 | 1.5 |
| Fringe | 5.1 | - | 2.6 | 7.7 |

In the numerical examples that follow a reference scenario, or a "Base case", is established. The Base case is used to describe the situation on the "old" Swedish electricity market, prior to the reform. This means that VAT is assumed to be the price leader on the market and to apply marginal-cost-pricing subject to a rate of return constraint. Thus the Bas case equilibrium price is equal to VAT's marginal cost of production plus a mark-up based on the fixed costs and the required rate of return.

The model has then been calibrated to the 1991 level of electricity production, both in total and for individual firms, and the market price on high voltage electricity 1991. Like the endogenously determined equilibrium prices discussed in the sequel the Base case price should be interpreted as a weighted average of both energy and capacity fees during one whole year. Put differently one can say that the model describes the price formation ofn a market for one-year contracts for customers with a representative time-of-use profile of their electricity use over the year.

4. Nash-Cournot equilibrium and the structure of the market.

4.1 Price formation on a deregulated electricity market

In the Base case the production of electricity is 142.5 TWh and the equilibrium price is 18 öre/kWh. Obviously the Base case is one natural norm of comparison. Another interesting

norm of comparison is a hypothetical competitive equilibrium on the market for high voltage electricity. Thus in the first scenario generated by the model pure competition is assumed. As can be seen in Table 2 the competitive equilibrium price, which is equal to the common marginal cost of production, is 84 % of the the Base case price. Thus the potential reduction of the price due to increased competition is quite significant.² But pure competition is not a very likely outcome, and in the following we instead focus on Nash-Cournot equilibria under various assumptions about the structure of the market.

If the model is solved for a Cournot equilibrium, allowing the firms to maximize their profits and take advantage of their possibilities to influence the market price given their market share, the result is a significantly higher price level and a considerably lower level of electricity production. The reason for this is the high degree of concentration on the seller side of the market. The Cournot equilibrium at the initially given firm structure is summarized in Table 2.

Table 2 Production and equilibrium prices for competitive and cournot equilibrium on the electricity market.

| | Production TWh | Equilibrium price Öre/kWh | Equilibrium price in % of Base case |
|-------------------------|-------------------|------------------------------|--|
| Base case | 142.5 | 18.0 | 100 |
| Competitive equilibrium | 155.7 | 15.1 | 84 |
| Cournot equilibrium | 122.5 | 24.4 | 136 |

A closer analysis of the model results reveals that it is primarily VAT that cuts back production and thus influences the price level. To be precise VAT reduces nuclear power production from 40 TWh/year in the competitive case to only 13 TWh/year in the Cournot case. An alternative interpretation of this result is that VAT exports the power or sell it to selected customers on the basis of special contracts. The important factor for the outcome is that the power is kept away from the regular electricity market.

4.2 Policies to promote competition

The results presented so far indicates that due to the concentration on the supply side deregulation of the Swedish electricity market may in fact lead to higher rather than lower prices. However, such an outcome can be prevented in several different ways. One possibility is simply to use the measures made available by the new legislation aimed at promoting

² Under certain conditions the competitive solution can also be interpreted as a Bertrand equilibrium.

competition. According to the new rules it is illegal for a firm with a large market share to "mis-use its dominant position" on the market.

One crucial question then is whether the authorities can manage to, first of all, detect that a firm is mis-using its dominant position on the market, and then stop it from continuing to do so. It is obviously easy for the authorities to spot that a firm closes down part of its operations for a prolonged time. It might be more difficult, however, to prove that the reason for the stop is an attempt to manipulate the market price. The fact that power is sold on the side of the regular electricity market might be very difficult for the authorities to reveal, and even more problematic to prove that the large firm is mis-using its dominant position. In view of these difficulties it is interesting to investigate alternative measures that can be undertaken in order to prevent monopolistic pricing and to promote competition on the electricity market.

One measure that is often discussed is to divide Vattenfall into two separate and independently managed firms. Those two firms will then be of approximately the same size as Sydkraft. In the model this amounts to splitting VAT in half and solve for a new Nash-Cournot equilibrium. Under the new conditions the Cournot equilibrium electricity price is 17.0 öre/kWh. This is a considerably lower than the initial Cournot equilibrium price, and it is 94 % of the price in the Base case. In other words deregulation in combination with a split of VAT would reduce the market price of electricity. The results are summarized as "Case 1" in Table 3.

Table 3 Production and equilibrium prices for different structures of the electricity producing firms.

| | Production TWh | Equilibrium price Öre/kWh | Equilibrium price in % of Base case |
|---------------------|-------------------|------------------------------|--|
| Cournot equilibrium | 122.5 | 24.4 | 136 |
| Case 1 | 146.7 | 17.0 | 94 |
| Case 2 | 145.6 | 17.4 | 97 |

Case 1 VAT is divided in half resulting in two firms of equal size to SYD
Case 2 VAT is not divided but is forced to set price equal to marginal cost

Another policy measure that could be implemented is to let VAT remain intact, but to force it to set its price equal to marginal cost. This can be done by the state since it owns 100 % of VAT. The model results obtained in this case are presented as "Case 2" in Table 3. As can be

seen in the table the equilibrium price and production level are not very different from the situation in Case 1 where VAT is split in half.

The results from the Cournot equilibrium and Case 1 show that the size of the biggest firm on the market is very important for the outcome in terms of total production and the price level. But in a new, deregulated environment the firm structure in electricity generation is a policy variable only to a very small extent. A possible "endogenous" reaction among the smaller firms is to merge with each other in order to accommodate the dominance of VAT. Assuming, for instance, that VAT is split in half and that the smaller firms grouped as one firm implies an electricity market with seven relatively big generating firms. In the model the Cournot equilibrium corresponding to this structure implies 146.6 TWh electricity production and a price level of 17.2 öre/kWh. That is, this case is very similar to Case 1, i.e. the case where VAT is divided in half and the remaining firms are left intact.

Another possible "endogenous" change in the structure of the market is increased concentration on the demand side. Such a development can take the form of organized cooperation among consumers or the development of large whole-sale firms. Increased concentration on the demand side might in the end lead to an electricity market where bilateral monopolies trade with each other. However, this scenario has not yet been incorporated in the model.

Two main conclusions can be drawn from these results: First, the relative size and market share of the largest firm on the market is of great importance for the equilibrium price and production level. Second, the number of small firms, given the size of the largest firms, is not very essential for the outcome.

4.3 Market structure and price responsiveness

The deregulation of the electricity market is expected to be followed by privatization of the major power producing companies as well as relaxation of various restrictions on international trade in electricity. In order to shed some light on the effects of possible major structural changes on the electricity market resulting from these changes in the institutional framework we combine assumptions about changes in the firm structure and increased price responsiveness of demand.

To begin with we reallocate the existing production capacity at given demand conditions and consider an electricity market where the producing firms have identical production

possibilities and marginal costs. If there are four identical firms the equilibrium price turns out to be 25.8 öre/kWh and with six identical firms the equilibrium price is 17.9 öre/kWh. Thus, going from four to six firms reduces the equilibrium price by approximately 30 %. In other words the number of firms is very important for the price level when there are only a few firms on the market.

The next step is to consider the demand side responsiveness to price changes. The price elasticity of electricity demand is obviously of great importance for the firms possibilities to capture monopoly rents. So far we have assumed the price elasticity to be -0.3. As the demand function in the model includes export demand, this number is well in line with the wide-spread perception that electricity demand, at least in the short term, is not very sensitive to price changes. However, if the borders are opened up for trade Swedish producers can gain market shares in particularly the other Nordic countries. This phenomenon can be represented as an increase of the price elasticity of demand experienced by the Swedish producers. In the long run natural gas may also prove to be a good substitute to electricity and thereby increase the price elasticity of electricity demand even further.

One way of indicating the effect of increasing price responsiveness is to calculate the equilibrium (uniform) mark-up of the firms at different price elasticities of demand and a constant number of competing firms. This is done for a case with four firms and a case with six firms. Table 4 summarizes the results in the case with four identical firms, while Table 6 gives the corresponding results for the case with six identical, firms.

Table 4 Production and equilibrium prices for different price elasticities of electricity demand and four identical electricity producing firms.

| Price elasticity of electricity demand | Production TWh | Equilibrium price Öre/kWh | Mark-up p/mc |
|--|----------------|---------------------------|--------------|
| -0.3 | 127.4 | 25.8 | 5.2 |
| -0.6 | 144.6 | 17.6 | 1.7 |
| -0.9 | 145.6 | 17.5 | 1.4 |
| -1.1 | 146.0 | 17.4 | 1.3 |

Table 5 Production and equilibrium prices for different price elasticities of electricity demand and six identical electricity producing firms.

| Price elasticity of electricity demand | Production TWh | Equilibrium price Öre/kWh | Mark-up p/mc |
|--|----------------|---------------------------|--------------|
| -0.3 | 142.6 | 17.9 | 2.2 |
| -0.6 | 145.6 | 17.4 | 1.4 |
| -0.9 | 146.2 | 17.3 | 1.2 |
| -1.1 | 146.4 | 17.3 | 1.2 |

Two conclusions can be drawn from the tables: First, the possibility for firms to capture monopoly rents is strongly related both to the price elasticity of demand and the number of competing firms on the market. Second, with six or more identical firms the mark-up is not very sensitive to the numerical value of the price elasticity.

The relationship between the number of firms on the market, the price elasticity and the realized mark-up is illustrated by Figure 1. In the figure mark-up is plotted for different levels of price elasticity η , ranging from -0.2 to -1.1, and for 2 to 10 identical firms n . For simplicity the marginal cost is kept at a constant level for all combinations of price elasticity and number of firms.

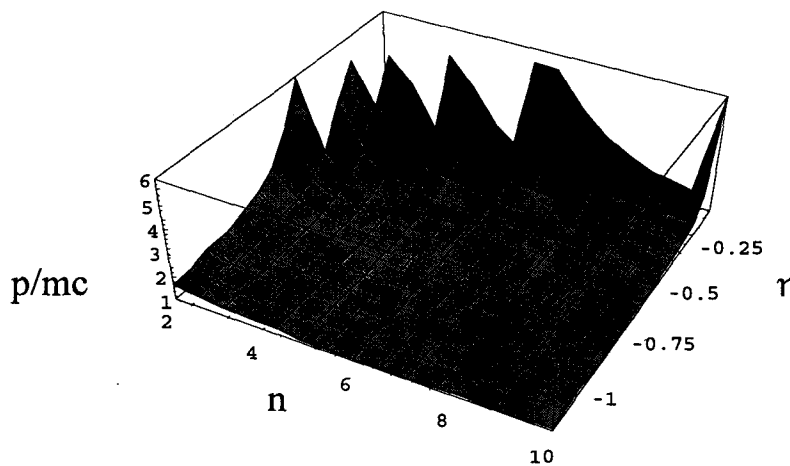


Figure 1 Mark-up as function of price elasticity and number of firms

5. Concluding remarks.

The results in the preceding sections mainly speak for themselves. The bottom line is that, given the current firm structure on the supply side of the Swedish electricity market, deregulation is not a sufficient condition for equilibrium prices close to marginal costs. What is perhaps even more important is that individual producers are able to influence the market price. This has implications for the functioning and the role of a future spot market for electricity in Sweden. In particular, if spot market prices can be influenced by individual producers, it is not likely that markets for futures and options in electricity will develop. And if such markets do not develop, the agents on the electricity market have to find other, and possibly less efficient, ways of hedging against price uncertainty. Thus, the high degree of concentration seems to produce two types of efficiency losses. The first is the loss of efficiency which is due to monopolistic pricing. The second is the loss of efficiency due to an incomplete set of markets.

References.

Brooke, A., D. Kendrick and A. Meeraus (1988), GAMS. A User's Guide, Redwood City Ca.: Scientific Press.