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The regulating power market on the Nordic power exchange Nord Pool: an econometric analysis

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Abstract

What differentiates the structure of Nord Pool from other power exchanges around the world is the way the balance from the spot market is maintained until the actual, physical delivery takes place, via the regulating power market in Norway. This paper reveals the pattern of the prices on the regulating power market, by analysing the cost of being unable to fulfil the commitments made on the spot market. Some power producers with unpredictable fluctuations (e.g. wind) will need to buy regulation services. The disclosed pattern implies that these producers must pay a limited premium of readiness in addition to the spot price; this premium is independent of the amount of regulation. The level of the premium of readiness for down-regulation is shown to be strongly influenced by the level of the spot price. On the other hand, it is demonstrated that the premium for up-regulation is less correlated to the spot price. Furthermore, it is found that the amount of regulation affects the price of regulating power for up-regulation more strongly than it does for down-regulation. The disclosed cost of using the regulating power market is a quadratic function of the amount of regulation. This asymmetric cost may encourage bidders with fluctuating production to be more strategic in their way of bidding on the spot market. By using such strategies the extra costs (for example wind power) needed to counter unpredictable fluctuations may be limited. © 1999 Elsevier Science B.V. All rights reserved.

JEL classifications: C50; L94

Keywords: Norwegian regulating power market; Price and cost of regulation; Premium of readiness; Bidding strategy; Fluctuating production

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1. Introduction

Norway, together with England and Wales, are among the first countries in the world to liberalise the electricity market and introduced power exchanges (see Newbery and Pollitt, 1996; Skytte and Grohnheit, 1997). Even though the power exchange in Norway (Nord Pool) and the one in England and Wales (The Pool) were launched almost simultaneously, they were built up independently of each other and therefore have different structures (see Skytte, 1999; Knivsflå and Rud, 1995; Grohnheit and Olsen, 1995). Unlike the British structure where the balance is centrally controlled, Norway has a *regulating power market* where supply and demand bids determine the price for regulation, i.e. supply of up- and down-regulation services are cleared against the need for these services in order to create a market balance (see homepage of Nord Pool ASA — Nordic Power Exchange; A Northern European power exchange).

From being a national Norwegian power exchange, the Nordic power exchange Nord Pool was extended in 1996 to cover both the Swedish and Norwegian electricity markets. The Danish and Finnish utilities are active buyers and sellers at Nord Pool as well. Nord Pool is composed of a common Norwegian and Swedish spot market for physical trade and a common financial futures market. Regulation of deviations from the spot market balance is made individually in each of the participating countries. Sweden uses a regulation system almost similar to the British one, whereas Norway has kept the original regulation system derived from its national power exchange with a regulating power market.

The Nordic spot market closes at noon every day. At closing time the supply and demand bids are cleared against each other (balanced) and commitments are made for delivery the following day on an hourly basis. The interval between the time the bids are made and when the actual trades take place is at least 12 h. Some fluctuations in the actual supply and demand are therefore unavoidable compared with the commitments made on the spot market.

Analyses have been made on the spot markets (see, e.g. Johnsen, 1996; Skytte and Wolffsen, 1997) but almost none have looked at the regulation of the market balance. This paper focuses on the Norwegian method of regulating deviations from the spot market balance.

The relationship between the different prices on the spot and regulating power markets is of particular interest to those traders on the spot market who have unpredictable, fluctuating demand or supply, e.g. wind power generation, and suppliers of regulation services. In this paper we will try to reveal the patterns of the regulating power prices by analysing the costs involved in being unable to fulfil the commitments made on the spot market. We set up a hypothetical model to determine the regulating power price, and thereby the extra costs of using the regulating power market instead of the spot market to fulfil a commitment. We estimate the coefficients of the model and give a discussion of the finding and applications of the findings.

2. Fluctuating energy and balance regulation

Electricity generation from some technologies may be more predictable than others in an electricity market with mixed production technologies. Wind power is one of the technologies where the electricity supply is difficult to predict. Research projects (see, e.g. Landberg et al., 1997) have showed that wind power predictions made from meteorological forecasts at best can have an accuracy of approximately 90% (up until 36 h of prediction).

On one hand, should technologies with fluctuating power production account for a large market share, the market balance could be displaced. Both the system operator and power generators have therefore a common wish that fluctuations on the power deliveries are small. On the other hand, many technologies can adjust their power generations in order to re-establish the market balance. This regulation possibility especially matches power plants with rapid regulation properties, e.g. hydropower plants, gas turbines and combined heat and power (CHP) plants where in the latter case heat storage facilities can be used as short-term buffers for regulating the electricity generation. This is especially true in the case of extraction CHP plants where the proportion between heat and power production is variable (see Grohnheit, 1993).

A power exchange is an organised marketplace for wholesale purchasers and sellers of electricity. The primary function of the power exchange is to mediate electricity trades and prices. The prices on the power exchange reflect the marginal electricity prices on the market if all the actors on the market have free access to the power exchange. The concentration of power dealers on the power exchange implies that power can be offered little by little. This means that generators of fluctuating power can incorporate their production offers on the daily spot market on the power exchange at the same prices as other generators.

The only extra expenses for fluctuating power is if the generators are unable to fulfil the commitments made on the spot market when the actual deliveries take place. These expenses come from the regulation expenses the system operator has by keeping the total balance between supply and demand on the spot market.

The regulating power market on the Norwegian market plays an important role in keeping the balance between the supply and demand found at the spot market. If a power supplier delivers less or a buyer uses more than the amount agreed upon on the spot market (excess demand), then the supplier has to pay for up-regulating power in order to be able to fulfil his agreement on the spot market. Other suppliers get paid to deliver the lack of supply or some buyers get paid to decrease their demand for power.

If an amount is supplied more or used less than that agreed upon on the spot market (excess supply), then *down-regulating power* is implemented to keep the balance in the market. The excess supply is sold to buyers who then increase their purchases, or suppliers buy the excess supply in order to decrease their own supply.

The regulating power market closes 2 h before the actual trades take place, but the clearing does not take place until 15 min before the trades takes place. The

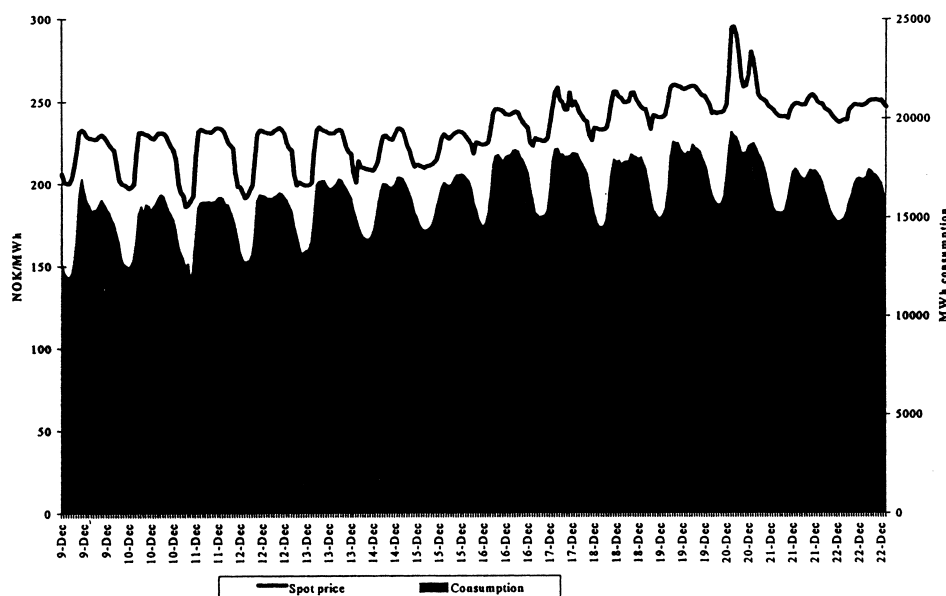


Fig. 1. Spot price and consumption in December 1996.

suppliers of regulating services on the regulating power market therefore have to be able to fulfil their bids within 15 min of notice.

Payments on the spot and regulating power markets are made separately, i.e. a payment for a commitment on the spot market is made with no attention paid to the actual trade. Any deviations are then paid on the regulating power market via the balance price between supply and demand for regulating power.

3. Analysis

The price level on the spot market reflects the total demand (consumption) strongly in winter, where the inter-median power plants are price setters. The spot price reflects the total demand weekly in the early summer, when the demand is low and there is usually plenty of water in the reservoirs. Fig. 1 illustrates the correlation between the spot prices and consumption in a 2-week period in December 1996. The spot price in NOK/MWh² is represented by the left axis and the consumption by the right axis. The consumption pattern is clearly reflected in the prices; however other physical and economic variables may influence the spot price (see Johnsen, 1996).

²1 NOK \approx 0.12 ECU.

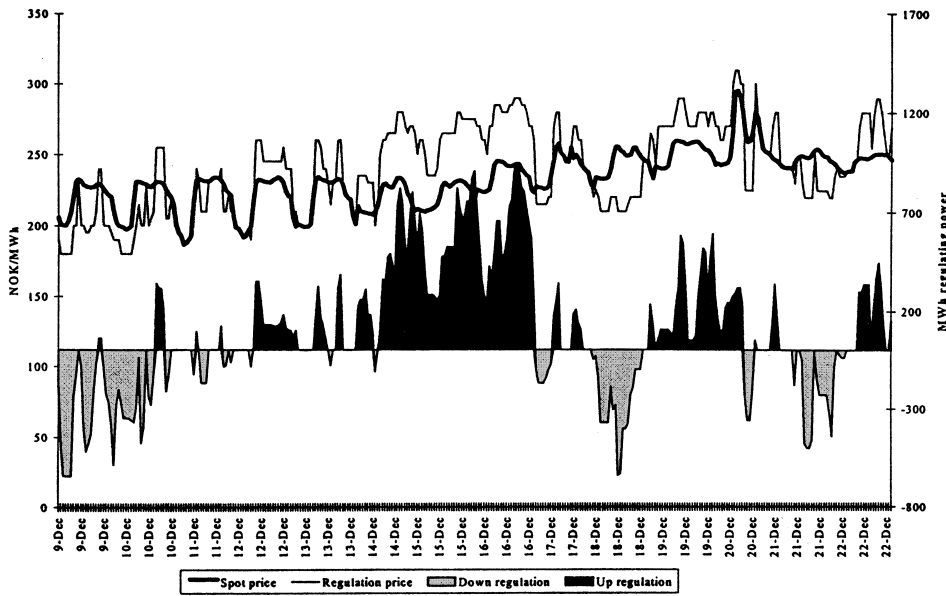


Fig. 2. Regulating power in December 1996.

The regulating power price follows the spot price and thereby indirectly reflects the price setters through the spot price.

From Fig. 2 it is seen that the difference between the spot and regulating power prices depends on the amount of regulation. It cannot be stated whether the connections between the spot price and the up- and down-regulating power prices are the same or not. Since it might be different buyers and sellers who bid for up- and down-regulation, the regulating power prices may be more sensitive to the amount of either up- or down-regulation. In addition, the dependence of the spot price may also be different for up- and down-regulation.

It seems therefore reasonable to set up a hypothetical relation as follows:

$$\begin{aligned}
 PR(P_t, S_t, D_t) = & \varphi \cdot P_t \\
 & + 1_{S_t < D_t} \cdot [\lambda \cdot P_t + \mu \cdot (S_t - D_t) + \eta]. \\
 & + 1_{S_t > D_t} \cdot [\alpha \cdot P_t + \gamma \cdot (S_t - D_t) + \beta].
 \end{aligned} \quad (1)$$

where PR_t is the price of regulating power, P_t the spot price, S_t the amount announced at the spot market and D_t the actual delivery. $(S_t - D_t)$ is the amount of regulation. The values of P_t and S_t are known when the regulating power price is determined, since the spot market closes before the regulating power market starts. The only unknown variable is therefore the actual delivery, D_t .

There is an excess demand for power when $S_t > D_t$. This is for example the case, when some producer has delivered less than promised on the spot market. He therefore has to buy up-regulating power in order to fulfil his promise. Likewise, there is an excess supply of power when $S_t < D_t$, which means that the producer buys down-regulating power, i.e. he sells the excess power at the price for down-regulation, which is lower than the spot price.

The 1 in relation (1) is an indicator function, i.e., equal to 1 when the substatement is true, and equal to 0 elsewhere. Relation (1) therefore says: When there is neither any up- nor any down-regulation, then the regulating power price equals the spot price scaled by a factor. We will see below that this factor is estimated to be equal to 1.

The indicator functions are included in order to accentuate more voluminous oscillations in regulating power prices for either up- or down-regulation. The indicator function will be superfluous if the coefficients in the brackets are estimated to be statistically identical.

The coefficients μ and γ can be interpreted as the marginal regulating power prices per unit of regulated power. The other coefficients, λ and η (as well as α and β), are independent of the amount of regulation. These coefficients can be interpreted as determining a *premium of readiness* paid to the suppliers of regulation services. This may be an important factor, since the suppliers have to be able to regulate within 15 min of notice, compared to the spot market where the time period between the acceptance of the bids and the time of the physical trades is at least 12 h (Fig. 3).

The premiums of readiness for, respectively, up- and down-regulation services consist of a constant term and a term connected to the spot price. This means that part of the premium is common to all suppliers of regulation services, and another

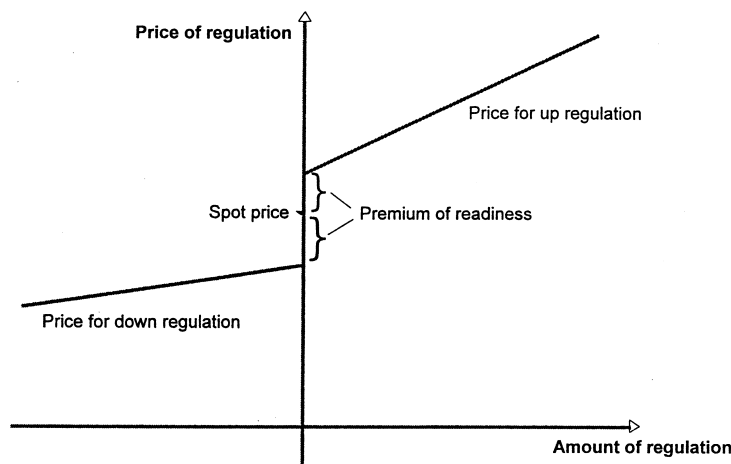


Fig. 3. Price of regulating power.

part depends on the price level on the spot market. The making of a separate analysis of each part and an analysis of the relationship between the parts of the premium are two of the goals in this paper.

3.1. Data

The time series used for the estimates given in this paper runs from the beginning of week 50 in 1996 until the end of week 21 in 1997. The data were given on an hourly basis in the Oslo area. Additional time series have been used to examine the robustness of the results but are not shown in this paper.

The magnitude of the regulation amounts is shown in Fig. 4. The figures show data from 1 year (8760 h), where the data have been sorted after their size. Positive numbers represent up-regulation and negative numbers down-regulation.

The figure can for example be used to state that in more than 300 h of the year; there was a down-regulation need for more than 500 MWh/h. Note that there was no need for regulating power in approximately 40% of the hours of the year. There was a need for up- or down-regulating power in approximately 60% of the hours.

3.2. Findings

The coefficients in relation (1) were estimated by the use of the econometric modelling system PcGive Professional 9.0 (see Doornik and Hendy, 1996). The findings are shown in Table 1. Additional stationary tests and tests of robustness of the findings were made, but are not indicated in this paper.

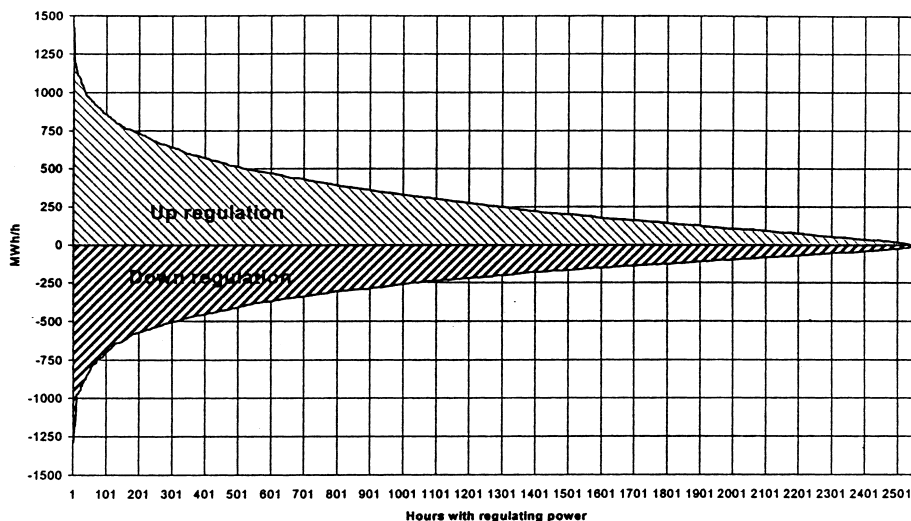


Fig. 4. Load duration curve for regulation power 1996/1997 in the Oslo area.

Table 1
Estimated coefficients

Coefficient	Value	S.E.	<i>t</i> -value
φ	1.000	0.00096	1e + 3
λ	−0.06924	0.00547	−12.65
μ	0.02316	0.00103	22.39
η	−4.3298	0.90180	−4.80
α	0.02750	0.00524	5.25
β	13.071	0.98455	13.28
γ	0.0417	0.00130	31.98
R^2	0.998		

Relation (1) was estimated to explain more than 99% ($R^2 = 0.998$) of the fluctuation in the regulating power prices. The estimated relation is shown in relation (2).

$$\begin{aligned}
 PR(P_t, S_t, D_t) = P_t & \\
 & + 1_{(S_t < D_t)} \cdot [-0.069 \cdot P_t + 0.023 \cdot (S_t - D_t) - 4.3] \\
 & + 1_{(S_t > D_t)} \cdot [0.028 \cdot P_t + 0.042 \cdot (S_t - D_t) + 13.07]. \quad (2)
 \end{aligned}$$

First of all, it is seen that η in relation (1) is estimated to be equal to 1 (t -value = 1000). This means that the regulating power price equals the spot price when the amount of regulation is zero.

Secondly, it is seen that the use of indicator functions is justified, since the coefficients in the brackets are significantly different. Note that down-regulation is represented by a negative amount of regulation, which means that the down-regulating power price is always less than or equal to the spot price which is less than or equal to the up-regulating power price (see Fig. 3 for an illustration). The regulating power price is seen to be twice as sensitive to the amount of up-regulation compared to the amount of down-regulation.

Thirdly, the premiums of readiness are seen to be different for up- and down-regulation. The premiums were estimated (in NOK/MWh) to be

$$\text{Premium}_{\text{Down}} = 0.069 \cdot P_t + 4.3 \quad (3)$$

$$\text{Premium}_{\text{Up}} = 0.028 \cdot P_t + 13.07$$

4. Discussion of findings

Fig. 5 shows the estimated premiums as functions of the spot price. It is seen

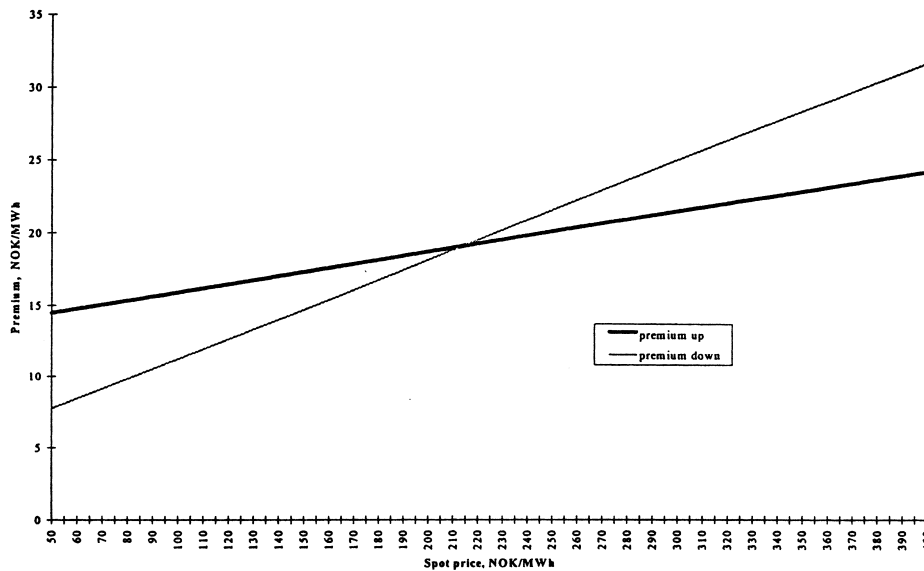


Fig. 5. Premium of readiness.

that the down-regulation premium is more sensitive to the spot price than the up-regulation premium.

With relation (3) and Fig. 5 it is seen that the level of the premium of readiness for down-regulation is strongly influenced by the level of the spot price. On the other hand, it is seen that the premium for up-regulation is less correlated to the spot price. When the spot price is lower than 215 NOK/MWh the down-regulation premium of readiness is lower than the premium for up-regulation. The opposite is true when the spot price is higher than 215 NOK/MWh.

The strong correlation between the spot and down-regulating power prices may derive from the use of electric boilers on the Norwegian power market. Electric boilers are used as a 'sink' for cheap hydro-based electricity that would otherwise be lost in the case of copious inflow to the water reservoirs. The boilers will be more active on the spot and regulating power markets when the spot price is low than when the spot price is high.

The different slopes of the price for up- and down-regulation get more distinct when we look at the costs, i.e. when we multiply the regulating power price found in relation (2) by the amount of regulation.

Since the regulating power price depends on the amount of regulation the costs (payments) of using the regulating power market for a certain amount (amount times price) is a quadratic function of the amount. If we use the estimated coefficients found in Table 1 we get Eqs. (4) and (5)

$$CS_t \equiv P_t \cdot (S_t - D_t), \quad (4)$$

$$\begin{aligned} \text{Cost}_{\text{Regulation}} = CS_t & \\ & + 1_{S_t < D_t} \cdot \{-0.069 \cdot CS_t + [-4.3 + 0.023 \cdot (S_t - D_t)] \cdot [S_t - D_t]\} \\ & + 1_{S_t > D_t} \cdot \{0.028 \cdot CS_t + [13.07 + 0.042 \cdot (S_t - D_t)] \cdot [S_t - D_t]\}. \end{aligned} \quad (5)$$

where CS_t in Eq. (4) is the payment for a similar amount of power on the spot market. The costs of regulation are negative when the amount of regulation is negative, i.e. a sale of excess power by buying a down-regulation service. A negative cost indicates sales revenue of excess power.

To illustrate the difference in the payment on the spot and regulating power markets we assume that the spot price = 125 NOK/MWh. Fig. 6 illustrates the costs as functions of the amount of regulating power.

The slanting fields in the figure indicate the gap between the costs on the spot and regulating power markets. If there is an excess of power supply compared with the balance on the spot market, the excess power can be sold only at a payment equal to the bending line in the left side of the figure. If the same amount of power was sold at the spot price it could realise a payment that equals the straight line. If there is an excess demand on the regulating power market then the lack of power must be bought at a payment equal to the bending line in the right side of the figure.

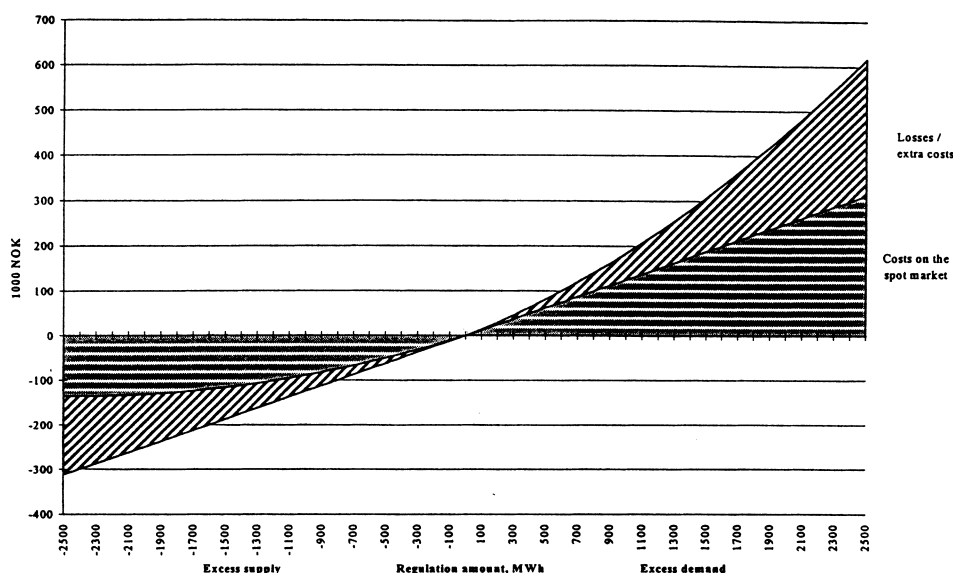


Fig. 6. Extra costs by using the regulating market.

The difference between payments on the spot and regulating power markets is greatest for up-regulation services in the above example. This means that the costs of using the regulating power market are not symmetric around zero, which may encourage a buyer or seller with fluctuating demand or supply to give bids in the spot market which are not equal to the expected actual trade. A power supplier may bid less or more than the expected production in order to maximise his expected profit.

5. Fitting the time series

In one of the first sections of this paper Fig. 2 shows a section of the used time series for the regressing and estimation of relation (1). If the estimated relation (2) is simulated in the same figure, we get a graphic fitting of the regulating power prices as shown in Fig. 7.

It is seen that the simulation of the estimated prices for regulating power describes the actual regulating power prices well. However, the flat peaks for the actual prices are not reflected completely in the fitted time series.

In other words, there are small deviations from the actual prices when peaks in the amount of regulating power are observed. These deviations are so small that they do not have any influence on the results of the paper. (Referring to Table 1,

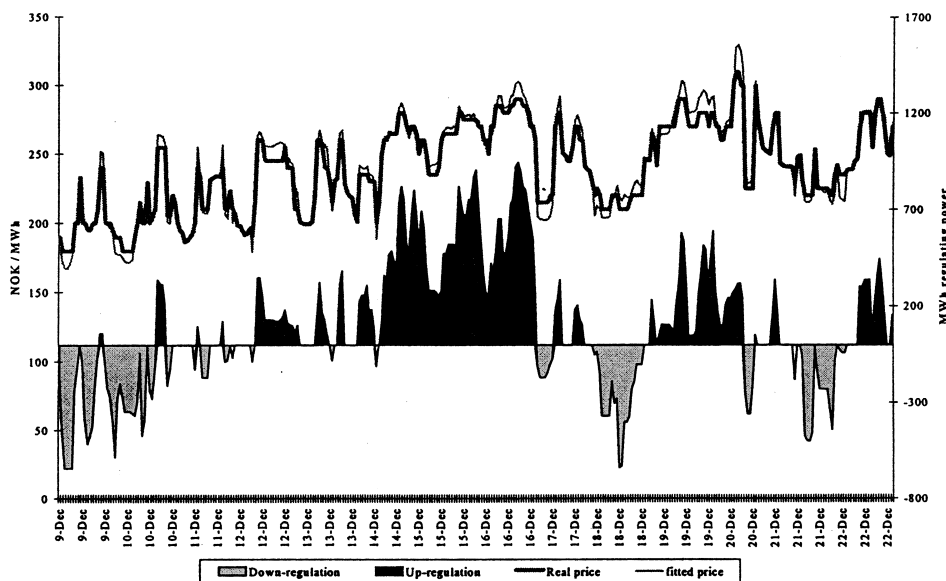


Fig. 7. Fitted and actual price for regulating power, 9–21 December 1996.

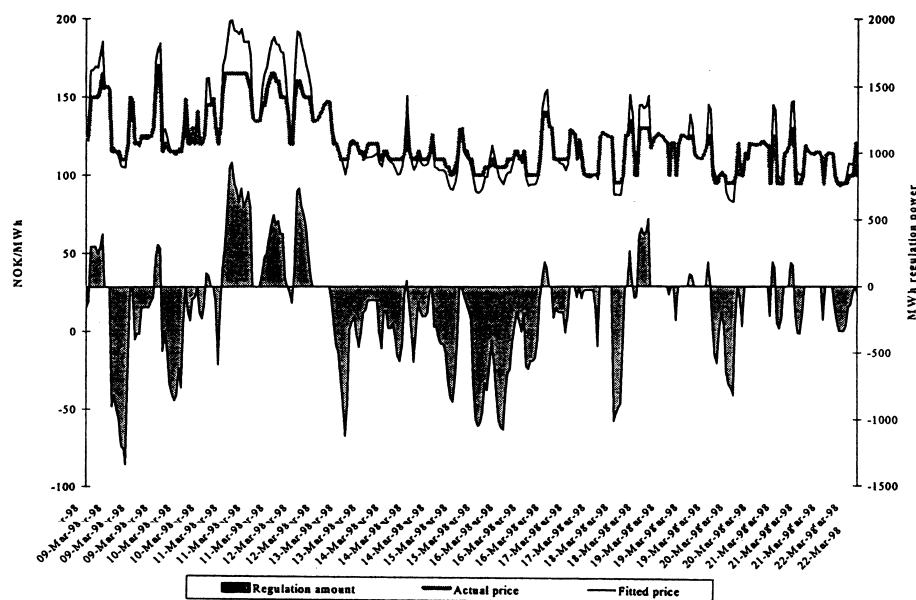


Fig. 8. Fitted and actual price for regulating power, March 1998.

the estimated relation describes 99% of the variation in the regulating power prices.)

To test the robustness of the results, the estimated relation has also been simulated over a time series which has not been used in the estimations. Also in this case the estimated relation describes the actual regulating power prices well. Fig. 8 shows 2 weeks from the time series (in March 1998) with simulated regulating power.

The 2 weeks in Fig. 8 are chosen because this section of the time series actually shows some major differences between the actual and simulated prices for regulating power. It is seen that the price level is lower than the other examples shown in this paper. Furthermore, it is even clearer that the flat peaks for the actual prices (e.g. 11 March) are not reflected completely in the fitted time series.

One reason for these flat peaks in March can be that the snow is starting to melt and thereby creates plenty of water in rivers and reservoirs. At the same time, the power consumption may be low. The hydropower stations may therefore offer regulating services at low prices. This is especially true for hydropower stations without reservoirs, since they otherwise will have to let the excess water run through the stations without any power production.

In general it can be assumed that when the prices are low, hydropower plays an active role as price setter. Since the hydropower stations are easy to regulate, it can be assumed that hydropower stations can offer large amounts of regulating power at low prices.

6. Applications of the findings

The relationship between the different prices on the spot and regulating power markets is of particular interest to those traders on the spot market who have unpredictable, fluctuating demand or supply, e.g. wind power generation, and suppliers of regulation services.

At the time a producer announces his production on the spot market he does not know his actual delivery if his production fluctuates. A producer may have revenues from his sale on the spot market as well as costs from regulating his delivery in order to fulfil his promises (bids) on the spot market. If the producer looks separately at the spot and regulating power markets (partial optimisation) he will seek to maximise his surplus of power on the spot market and minimise his use of regulating services on the regulating power market.

If the producer looks at the spot and regulating power markets at the same time (joint optimisation) he will seek to optimise his total revenue from the spot and regulating power markets by considering the revenue on the spot market against the expected regulation costs on the regulating power market. This means that the producer has to make his bids on the spot market in order to maximise his expected total profit from the power exchange, which is given by

$$E[\pi(P_t, S_t, D_t)] = P_t \cdot S_t - E[\text{Cost}(P_t, S_t, D_t)] \quad (6)$$

It is reasonable to assume that the producer is relatively small on the market, i.e. he has no market power. In effect, the producer is a price-taker on the spot market, i.e. $\partial P / \partial S_t = 0$. He must maximise his expected revenue with respect to his announcement on the spot market. From Eq. (1) we get, that the optimal announcement on the spot market depends linearly on the price level on the spot market and the expected delivery.

The same observations can be done for suppliers of regulation services, e.g. hydropower plants, gas turbines, or heat pumps.

With the estimated relation a buyer or seller of electricity is able to optimise both his total bids on the spot and regulating power markets within his expectations of fluctuations of demand and supply. The disclosed cost of using the regulating power market is a quadratic function of the amount of regulation. This asymmetric cost may encourage bidders with fluctuating production to be more strategic in their way of bidding on the spot market. By using such strategies the extra costs (for e.g. wind power) needed to counter unpredictable fluctuations may be limited.

7. Summary

We have seen that in order to buy regulating power one must pay a premium of readiness in addition to the spot price that is independent of the amount of regulation. For down-regulation the level of the premium of readiness was seen to

be strongly influenced by the level of the spot price. On the other hand, the premium for up-regulation was less correlated to the spot price. Furthermore, we have seen that the amount of regulation more strongly affects the price of regulating power for up-regulation than for down-regulation. The disclosed cost of using the regulating power market is a quadratic function of the amount of regulation. This asymmetric cost may encourage bidders to be more aggressive in their bidding strategy on the spot market. The flat peaks for the actual prices where seen not to be reflected completely in the fitted time series. With the estimated relation a buyer or seller of electricity is able to optimise both his total bids on the spot and regulating power markets within his expectations of fluctuations of demand and supply.

Acknowledgements

The Nordic Energy Research Programme, for which the author is grateful, finances this paper. The author is grateful to Hans F. Ravn at Elkraft Power Company and to Poul Erik Grohnheit, and Frits M. Andersen at Risø National Laboratory for their helpful comments and discussions.

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