

Did hydropower generators in Nord Pool exercise market power during 2006? – A simulation analysis of hydro production in Norway and Sweden

Abstract

This thesis analyzes whether the production allocation strategy of hydro producers in Norway and Sweden during 2006 was consistent with market power behaviour.

To attain a measure for a competitive hydro allocation, the simulation model PoMo (Power Model) was used. The simulation model takes current market conditions into account (for e.g. water inflow and store level) and assumes that hydro producers act as price takers. Consequently, PoMo predicts competitive hydro output levels. The observed hydro production in Norway and Sweden during 2006 was then related to the production levels predicted by the simulation model.

Two types of allocation strategies were identified and tested for; direct and indirect withholding of output. The former strategy refers to a situation where the hydro producer directly constrains its production during the high demand period. The latter refers to a situation where the hydro producer withholds output from the high demand period by overproducing during the low demand period.

The results of this thesis indicate that hydro producers in Sweden and Norway were exercising market power by indirectly withholding output during 2006. The finding suggests that the risk of detection could be an important factor for a hydro firm's choice between direct or indirect withholding.

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1. Introduction

During the 1990's the Nordic countries (Norway, Sweden, Finland and Denmark) deregulated their electricity markets and Nord Pool, the world's first multinational exchange for trade in electric power, was created¹. The purpose of opening up the markets for competition was to make the electric power sector function in a more efficient manner and to provide customers with low electricity prices (Deng, 2005).

The system price² level since the official formation of Nord Pool has varied significantly and no trend of lower prices can be observed (Elåret 2006). For these reasons, the level of competition in the electricity power market has been repeatedly questioned. In its latest report, the Swedish Competition Authority claims that the electricity market has considerable competition problems. According to Swedish Competition Authority, new investments in electric resources and more producers of electricity are needed in the Nordic electricity market (Konkurrensen i Sverige 2006). One of the problems discussed in the report is the degree of co-ownership that exists in Swedish nuclear plants. This widespread co-ownership increases the risks that the nuclear generators can either restrict output or jointly raise the minimum price at which they are willing to sell, i.e. exercise market power³. Even though the issue of co owned nuclear plants may be a potential problem for the competition in the Nordic electricity market, one may argue that hydro generators are more capable of exercising market power.

Hjalmarsson (2000) claims that nuclear power generators, compared to hydro, are much less flexible and considerably more expensive to use for strategic purposes. This is because a hydro resource can, by adjusting the rate at which water is released from the reservoir, move energy between different time periods. Due to the high speed at which water in a reservoir can be converted into electricity and the very low variable production cost, one can claim that hydro resources are able to store electric power (Borenstein et al, 1999). The ability to "store" power enables the hydro resource controlling firm to exercise market power in a different way compared to firms who own other types of electric resources.

Bushnell (1998) and Arrelano (2004) study how hydro generators⁴ can exercise market power in the Western U.S. and Chile. They find that hydro generators can profitably exercise market

¹ The startup of Nord Pool was in 1996 when Sweden and Norway created the joint power exchange.

² The system price is the price for the whole Nord Pool area given no transmission constraints exist.

³ Borenstein et al. defines market power as the ability of a firm to change the market price by reducing its output or raising the minimum price at which it is willing to sell output.

⁴ Hereafter, hydro producer or hydro generator refers to a power producer who owns a hydro reservoir.

power through allocating relatively less production to high demand periods (peak periods) and relatively more production to low demand periods (off peak) compared to the scheduling strategy of a price taking firm⁵.

Since hydro plants generate about 50% of the electricity in the Nordic power market, the previous discussion ought to be relevant when evaluating the level of competition on Nord Pool. Against this background, I find it interesting to study to what degree hydro generators can exercise market power on the Nordic power market. The aim of this thesis is to answer the following question:

Did hydropower generators in Nord Pool exercise market power during 2006?

The research question will be studied by using the simulation model PoMo⁶ to make forecasts of how competitive hydro generators would optimally schedule their production during 2006. The competitive hydro scheduling will then be compared to the weekly observed hydro production in Sweden and Norway and weekly output gaps will be computed. By analyzing the output gap, one can evaluate whether the scheduling strategy of the hydro generators is consistent to how a generator with market power would allocate its production over time. The analysis of the output gap will be based on descriptive findings and computed correlations. The thesis is organized as follows: In section 2 the Nordic power market and the role hydro power plays are described. Section 3 explains the notion of strategic hydro scheduling and the concept of withholding analysis. In section 4 the PoMo model is described and the hypotheses are formulated. In section 5 the results are presented where the output gap is analyzed both descriptively and by computing different correlations. Section 6 examines the limitations of the study. Section 7 concludes the thesis.

⁵ A price taking firm is a firm unable to influence the market price, i.e. a firm without market power.

⁶ PoMo is a simulation model that can be used to forecast hydro production given a perfectly competitive power market. The model was developed by the energy consulting companies EME analys and Tentum.

2. The Nordic power market

2.1 Hydro power and the Nordic power industry

The power production within the Nord Pool area was 395 TWh during 2006 while the consumption was 383 TWh (Kraftläget i Norden , 2007). The overall trade balance depends largely on the weather conditions, which can cause large variations between years in both consumption and production (SOU 2004:129). About 50% of the electricity production comes normally from hydro resources. The water inflow and precipitation have therefore a large impact on the size of the yearly power production. The variation in consumption can be explained by that electric heating constitutes a large fraction of demand. Since the temperature, particularly during winter, can vary between years the consumption also fluctuates (Amundsen et al, 2005).

The share of hydro resources differs considerably between the individual countries in the Nord Pool area. Norway's electric generation consist to 99% of hydro power while Denmark does not have any hydro power resources at all. Hydro power constitutes about 20% of Finland's production and around 50% in Sweden.

The supply side in the Nordic electricity market is characterized by a rather high market concentration in the respective national markets but a low market concentration in the Nordic market. None of the major power producers have a market share that exceeds 20% of the Nordic market (Amundsen et al, 2005). This fact implies that the competition in the electricity industry is quite dependent on the degree of integration between the four national markets (Amundsen et al, 2005). An institution that plays a vital role in the integration of these markets is Nord Pool.

2.1.1 Nord Pool

Nord Pool is a common marketplace for trade with electricity in Norway, Sweden, Finland and Denmark. Nord Pool provides a spot market for physical trade in power and a financial market with trade in futures, forwards and options (SOU 2004:129).

The prices at the spot market are determined in single price auctions on an hourly basis. If transmission constraints are binding the spot market is divided into different bidding or price areas. In such a case, Sweden, Finland, East and West Denmark are divided into one price area respectively while Norway can be divided into several (three during the 2006/2007

winter). The theoretical price that would exist on the market if no transmission constraints⁷ are binding is called the system price (Hjalmarsson, 2000).

2.1.2 Price formation

The spot price is formed in the following way. First the participants submit their bid curves to Nord Pool, which shows how much power they are willing to sell or buy at different prices. Then, the price is calculated by grouping all bids and offers together on a sale curve and purchase curve. The curves represent the aggregated supply and demand at Nord Pool and their intersection point is the system price (Hjalmarsson, 2000). The price should correspond to the marginal cost for the most expensive production unit used and all producers receive the same price.

The demand for electricity is relatively inelastic. This can be explained by the strong household/industry dependency of electricity and the lack of substitutes. The power producing firms are much more able to adjust their production to the prevailing price level (SOU 2004:129).

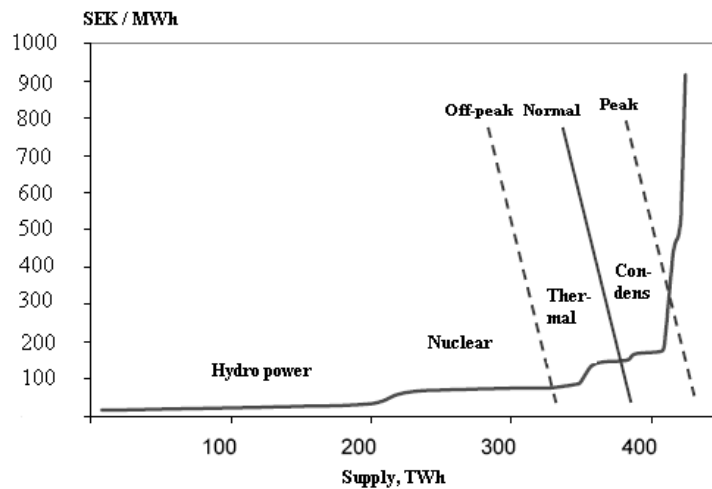
The supply curve for wholesale electricity markets tends to be rather flat for the majority of load levels but as quantity moves towards system capacity the slope increases rapidly. Wind and hydro power have the lowest production costs. Thereafter comes in order; thermal power used in the industry, nuclear power and other thermal power production. The most expensive production units are coal and oil condensing as well as gas turbines.

Since both demand and supply vary, the price will be set on different parts of the marginal cost curve during different seasons. During the summer season, when demand is low, the hydro and nuclear productions affect the spot price the most. During the winter season, production units with a higher variable cost will be needed to will be needed to meet the higher demand.

Figure 1 below illustrates the supply or marginal cost curve for a normal year in the Nordic power system.

Figure 1. The supply curve and demand levels in the Nordic power system

⁷ During most times of the year the limitations in the grid are very small or nonexistent. Hence, if the spot prices differ from the system price the deviation is usually small.



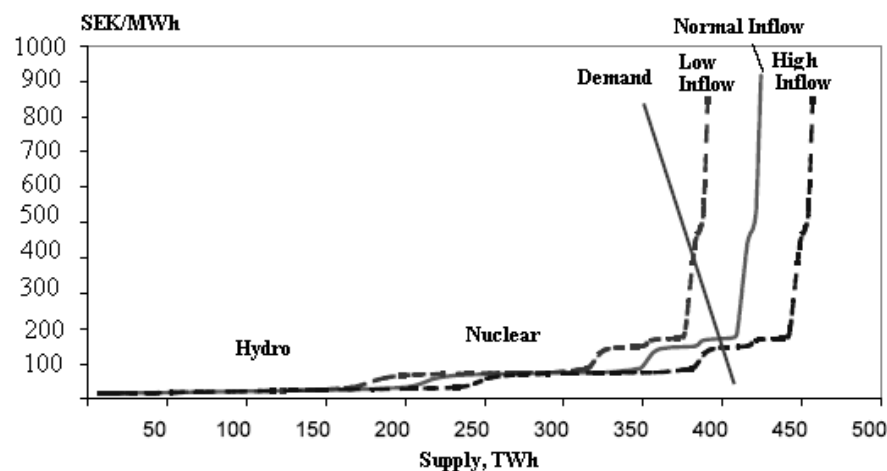
Source: SOU 2004:129

It is shown how the marginal cost increases relatively slowly during low demand periods when the majority of production comes from hydro and nuclear power. During high demand periods the slope is much steeper which means that each additional produced output is much more costly to produce than the previous produced output. A marginal increase in demand will during peak periods will have a much larger increasing effect on the spot price than during low demand periods (SOU 2004:129)..

2.2 Hydro power's role in the Nordic electricity market

The hydro production has the lowest variable production costs in the Nordic system and constitutes about 50% of the Nordic power production. The amount of available hydro determines the need to use other production units. Figure 2 illustrates how the access to hydro production affects the price level.

Figure 2. The effect of water inflow on power prices



Source: SOU 2004:129

During years of high water inflow the supply curve shifts to the right and prices fall, which means that the marginal cost of power production is reduced. During years of low water inflow the supply curve shifts to the left resulting in higher prices.

2.2.1 Water reservoir technology

The hydro power generation in the Nord Pool area consists almost exclusively on the use of water reservoir technology. This means that the hydro producer can save water in its reservoir for future generation. The storability of hydro power gives the producer the opportunity to time the market in order to maximize profits. For example, if the power price is expected to increase in the future it could be profitable for the hydro producer to hold back on production and instead produce more when price is higher (Deng, 2005).

The availability of water affects how each hydro generator values its water. When there are normal amounts of water stored in the reservoirs, the hydro generator will value its water according to the marginal cost structure, i.e. where demand meets supply from the most expensive unit in production. When there is a significant excess of water, the hydro producers are more or less forced to run production in order to minimize the risk of spilling water due to overfull stores. In such a situation the hydro generator will place a lower value at the water compared to what the marginal cost pricing structure would suggest. As a result the value of water would be very low and could be lower than the prevailing market price.

When there is a significant shortage of water, the value of the remaining water will be high. The hydro generator will in such a situation only run production when the market price is high. Even though the variable production cost of running production still is very low, the water will be bid at a much higher price. Hydro producers need to make an assessment of the risk that future precipitation becomes lower than expected, which affects their decision to run production at the present time or save production for a time when price may be higher (SOU 2004:129). In other words, the opportunity cost of producing today and not later in time needs to be taken into account.

3. Market power and hydro producers

This part of the thesis consists of two subsections. First, a literature review focusing on two studies about strategic⁸ hydro scheduling is highlighted. Next, a method of identifying and measuring market power is presented.

Previous research on market power behaviour in power markets has mainly focused on systems where the dominant share of production comes from thermal power. The general finding appears to be that the exercise of market power is most likely to occur in periods when the price taking fringe's capacity is exhausted and that usually happens when demand is at a high level. In such a situation the residual demand curve, which the strategic firm faces, becomes less elastic. Market power behaviour causes higher prices and that the overall production costs in the system increases compared to the case of perfect competition (Andersson et al, 1995, Wolak et al, 1997).

3.1 Strategic hydro scheduling

The rationale behind a firm exercising market power is to reduce produced output in order to increase the prevailing market price. The strategies available to a firm willing to exercise market power depend on what type of electric resources it controls.

In a system totally absent of hydro resources, the producers will only make decisions concerning when to run the plant and how much to produce at every moment in time. A producer acting in a purely thermal system is only able to exercise market power by restricting the total level of its production (Arrelano, 2004).⁹

In a system with hydro resources, the hydro producers are able to indirectly store power by saving water in the reservoir and then releasing the water at a time of the producer's choice. Hydro producers need to decide when to use their hydro resources over a specific period of time because an increase in the present production level will mean that less water is available for production in the future. Hence, the decision process for hydro producers is more dynamic. A hydro producer can therefore exercise market power not only by restricting the total level of its production level but also by scheduling/allocating its hydro production in a manner that has an increasing effect on the market price. To constrain total hydro production is a less subtle strategy since it can relatively easy be observed and consequently be accused

⁸ The term "strategic" refers to when a firm acts in a manner consistent with market power behaviour.

⁹ Given that transmission related strategies are not taken into account. This entails trying to raise prices in a local market by achieving transmission congestion.

as anti-competitive (Arrelano, 2004). For this reason, the focus of this thesis will be on hydro scheduling.

Arrelano (2004) and Bushnell (1998) examine the incentives hydro producers have to drive up market prices and how the producers would use its hydro resources to do so. They model the electricity markets of Chile and Western US respectively and solve for equilibrium of a multi period Cournot game between strategic producers. Focus is on the inter-temporal hydro scheduling strategy of the hydro producers. The analysis of market power is based on whether the allocation of hydro production across periods is consistent with what one would expect from a hydro firm exercising market power.

Arrelano and Bushnell use a Lagrange multiplier method and begin with solving for the marginal revenue of a hydro producer with market power in a two period setting. The Lagrange multiplier is denoted σ and represents the available hydro flows constraint.

The marginal revenue of the hydro producer is in each period (MR_t):

$$MR_t = MR_1 = MR_2 = \sigma \quad (1)$$

The σ multiplier is constant over time and corresponds to the marginal value of water (MVW), i.e. how large the profit increase is from an additional unit of water. One may also interpret MVW as the marginal cost of water, i.e. how much the firm is willing to pay for an additional unit of water.

3.1.1 Strategy of a firm with market power

As equation 1 illustrates, the hydro producer with market power will produce until the marginal revenue in both periods is equal to the marginal value of water. Consequently, the equations also imply that a hydro firm with market power will try to schedule its hydro production to equalize marginal revenue over time:

$$MR_1 = MR_2 = \sigma \quad (2)$$

As the producer uses an additional unit of water to produce, the profits will increase with MR_1 . As a result, there will be one water unit less that can be used in the next period and therefore the profits in period 2 will decrease with MR_2 . One can claim that the marginal cost of producing an additional unit in period 1 is represented by MR_2 . Hence, the hydro producer should schedule its production in a manner that equalizes marginal revenue over time. In reality, capacity constraints (maximum and minimum) will limit the strategic firm's ability to equalize marginal revenues. However, to the extent that it is possible the strategic firm will shift production from periods where it has low marginal revenue to periods where it has high marginal revenue (Arrelano, 2004, Bushnell, 1998).

3.1.2 Strategy of a price-taking firm

The strategy of a price-taking producer is different from a firm able to exercise market power. The price-taker, which by definition has no market power, will schedule its hydro production to equalise prices over time.

$$P_1(q_1) = P_2(q_2) = \sigma \quad (3)$$

It is important to point out that independent of the competitiveness of the market, a hydro producer will plan its production in order to equalize the *marginal profit*¹⁰ between periods. A hydro producer without market power will shave demand to achieve an equalisation of prices. while the producer with market power will aim at an equalisation of marginal revenues across time. Consequently, a hydro producer with market power will shave marginal revenues and not prices (Arellano, 2004).

3.1.3 Empirical results of the hydro scheduling studies

3.1.3.1 Arellano's study of Chile

Arellano (2004) investigates the hydro producer's ability to exercise market power in a mixed hydro- thermal system and focus on the case of Chile. Arrelano models the industry as a Cournot duopoly with a competitive fringe. He uses demand and cost data from the Chilean electricity industry and simulates a market equilibrium.

The hydro producer will face a residual demand curve which can be found by deducting the other generators' supply from the market demand. If the capacity constraints of other generators intermittently are binding and market demand fluctuates over time, differences in price elasticity will arise. In Arellano's model it is assumed that the residual demand, faced by the producer with potential market power, is less elastic in high demand periods than in low demand periods.

The hydro scheduling decision, both over a short and longer planning horizon, is studied.

The short horizon refers to how a hydro producer allocates its production over a one-month planning horizon while the long horizon refers to inter-month planning horizon. For both horizons Arrelano finds that a hydro firm that is exercising market power will exploit the differences in price elasticity of demand between periods. It will allocate too little production to the less elastic period and too much to the more elastic period compared to how a price taking producer would schedule its production. Arellano also finds that the smaller the

¹⁰ Marginal profit refers to the extra profit earned when an additional unit is produced.

difference is in elasticity between periods, the less will the firm with market power deviate from the strategy of a price taker¹¹.

3.1.3.2 Bushnell's study of Western U.S.

Bushnell models strategic behaviour of hydro controlling producers in the Western U.S. electricity market. Similar to Arrelano's approach, he does this by solving for a multi-period Cournot game between strategic producers and price taking fringe hydro producers. The strategic firms are assumed to be acting in two different forms of markets; the competitive off-peak (low demand) market and the on-peak (high demand) market where they have market power.

If a strategic firm reduces output on-peak the price may significantly increase. On the other hand, if the strategic firm produces additional output in off-peak hours the impact on the price will be small. Bushnell concludes that firms with market power can find it profitable to shift production away from high demand hours to low demand hours.

He also examines whether strategic behaviour has an impact on the redistribution of water between months, i.e. a reallocation of hydro production from high demand months to low demand months. In contrast to Arrelano's results, Bushnell found that the implications for market power are less dramatic when it comes to a long-run reallocation of hydro production. However, hydro power constitutes a much lower fraction of total generation in the Western U.S. power market compared to the Nordic market. In this sense, Arrelano's study appears more relevant to my research question because the Chilean electricity market is similar to the Nordic in the sense that a large fraction (47%) of generation capacity comes from hydro resources.

3.1.3.3 Central proposition

The hydro generator's ability to store and quickly adjust output levels is very useful, but the way this ability is used depends on if the generator can exercise market power. A hydro producer will allocate its production in a way that maximizes inter-temporal profits. Arrelano and Bushnell study this hydro scheduling decision and their studies suggest the following proposition. A strategic hydro generator, acting in a market with a capacity constrained price-taking fringe, will allocate relatively less production to high demand periods than to lower demand periods in comparison to the hydro scheduling of a price-taking firm (Arrelano, 2004,

¹¹ A price taker would aim at storing as much water as possible when it is abundant and price is low, and produce as much as possible when water is relatively scarce and price is high.

Bushnell,1998). The price-taking firms will, subject to the minimum and maximum flow constraints, allocate its hydro production in a manner that reduces or eliminates price peaks.

3.2 Withholding analysis

A supplier with no market power maximizes its profits by bidding output at marginal costs. Given profit maximizing behavior, it is reasonable to assume that a supplier is exercising market power if it chooses not to sell an additional unit at a price that exceeds its marginal cost. Stoft (2002) claims that the most straight-forward approach to identify market power is to identify “missed opportunities”. This is the focus of withholding analysis.

Consequently, a vitally important aspect of withholding analysis is estimating the competitive output, i.e. the generation capacity that should have been produced given a competitive market characterized by price taking behavior. To identify market power, one looks for deviations from this competitive output (Brennan, 2002, 2003).

3.2.1 Measuring withholding – the output gap

Output withholding is measured by the output gap. The output gap is defined as the difference between the economic unit capacity at the observed market price and the quantity actually produced. The term economic capacity refers to the output that is optimal for the unit to produce given the prevailing market price and price taking behavior. Thus, the output gap shows how much output that is withheld from the market as a result of uncompetitive behavior. The output gap can be expressed as the following:

$$\begin{aligned} \text{Output gap} &= Q_i^{\text{econ}} - Q_i^{\text{prod}} \\ Q_i^{\text{econ}} &= \text{Economic level of output for unit } i \\ Q_i^{\text{prod}} &= \text{Actual production of unit } i \end{aligned} \tag{4}$$

If the value of the output gap is positive the unit has withheld output and therefore exercised market power. However, one needs to adjust the actual production for factors that affect production but are not related to market power such as transmission constraints and forced outages.

3.2.2 Competitive benchmark

To measure the unit capacity that is economic, a proxy for the competitive bid of each unit is required, i.e. a competitive benchmark for each unit’s bids. Joskow et al (2002) and Patton et al (2002) use a reference price based on previously accepted bids of each unit from presumed competitive periods and also take into account estimated variable costs. In many studies of market power, the variable production costs solely have been used as a proxy for marginal

costs. This is a good estimation of marginal costs if the variable production costs are the most important costs. For hydro, the variable production costs are close to zero while the intertemporal opportunity costs are often very substantial. If only the variable production costs would be taken into account when estimating marginal costs, the output gap would most likely overestimate the withholding (Patton et.al., 2002).

Producers who lack market power in a competitive market will bid at their “true” marginal cost of production, i.e. including inter-temporal opportunity costs. Hence, the competitive benchmark that is used to compute the output gap should be an estimation of the “true” marginal costs of the supplier.

3.2.3 Analysis of the output gap

Even though it may be of interest to solely study the output gap, relating the gap to market conditions over time adds insight to the significance and validity of indications. Patton et al (2002) investigates how the output gap varies in relation to periods of high demand.

The incentive to withhold production and raise prices should be higher in periods of high demand compared to other periods. This is because prices are relatively more sensitive to changes in output when demand is high. It is important to point out that the incentive to withhold does not rise gradually as demand rises. In contrast, the incentive to withhold is linked to the slope of the supply curve, which is steep only at the higher levels of demand. Since the electricity market is associated with a relatively inelastic demand, one can expect that prices are more sensitive to withholding as the supply curve becomes steeper (Patton et.al. 2002). Hence, the output gap level should be positive during peak demand periods compared to other periods. Patton et.al. (2002) found in their study of the New England electricity market declining levels of the output gap as demand increased and therefore their hypothesis of market power was rejected.

3.2.4 Withholding analysis and hydro power

To arrive at a competitive output it is essential to estimate the marginal costs of suppliers. As previously implied, this is very difficult to do for hydro producers due to the intertemporal opportunity costs.

In Borenstein et al (1999) analysis of market power in the Californian electricity market, it is assumed that hydro resources are not used strategically. The primary reason for this assumption is the difficulty in estimating the opportunity cost of hydro. Hjalmarsson (2000) investigates the existence of market power on Nord Pool and also he sees difficulties in

estimating the opportunity cost of hydro. Joskow et.al. and Patton et al (2002) estimate the marginal cost of hydro based on previously accepted bids from presumed competitive periods. However, both studies acknowledge the difficulty and low reliability of their method of measuring the opportunity cost. They recognize how the opportunity costs of hydro can vary considerably in a way that is not reflected by the reference price they use as a competitive benchmark¹².

To sum up, one can conclude that estimating hydro's true marginal cost is a complex task. Consequently, it is also difficult to estimate the economic output Q_i^{econ} needed to calculate the output gap.

¹² For that reason, Patton et.al excludes hydro resources in part of their analysis of the output gap.

4. Method

The preceding section addressed the difficulty of directly estimating hydro's true marginal cost. For this reason, I choose to use a simulation model to obtain a proxy for the competitive bid/output.

PoMo is a simulation model of a perfectly competitive market (characterized by price-taking behaviour). The model calculates the optimal hydro production given information on marginal costs of thermal power producers, hydro power capacity, present reservoir level, statistical data on average and standard deviation for demand, water inflow and base load production.

By using a simulation model of this sort, the problem of directly estimating hydro's opportunity cost can be sidestepped. Since the model simulates a perfectly competitive market the resulting optimal hydro production corresponds to Q_i^{econ} , the economic output.

I perform a withholding analysis of the hydro production in Norway and Sweden¹³. To do this, I calculate the output gap of hydro producers and study how this measure is correlated to the level of demand. The economic/competitive level of hydro output will be estimated by the simulation model PoMo.

PoMo calculates the optimal weekly hydro production given a perfectly competitive market. Thus, the output gap that will be obtained and analyzed will represent the weekly gap.

Joskow et.al (2002) and Patton et.al. (2002) compute output gaps based on hourly data. Patton et.al. (2002) study the relation between hourly load levels and output gap by descriptive and econometric analysis. If market power is present, one would expect a positive relationship between the load level and output gap. This is because the incentive to exploit market power increases as demand increases. Hence, an indication of market power is larger output gaps during peak demand periods.

My approach is similar to Patton and Joskow's. However, instead of hourly estimates of the economic output PoMo will calculate weekly outputs. Consequently, I will arrive at a weekly estimate of the output gap (Q^{econ}) which I then will relate to weekly price and load levels.

I test the proposition that hydro moves production from high demand weeks to low demand weeks. In other words, I will examine whether hydro producers in the Nord Pool area schedule their weekly production in a way that indicates market power abuse.

¹³ The Finnish hydro production is treated as given in the PoMo model. This means that the Finnish hydro production is not included in the analysis of market power. See section 4.1.2 for a more detailed discussion.

4.1 PoMo – hydro-thermal power model

PoMo (Power Model) is a dynamic optimization model designed to make forecasts in a mixed hydro-thermal system. The aim of the model is to determine the optimal hydropower generation and then forecast future spot prices (PoMo Manual, 2007).

It is assumed that each producer or power plant tries to maximize the discounted value of future profits. Each producer offers its output at marginal costs and thus the market is assumed to be perfectly competitive. A power system characterized by perfect competition corresponds to a system where future cost of thermal production is minimized.

The goal function of the model is therefore to minimize thermal variable costs over time taking into account different levels of demand. To achieve this, PoMo allocates the hydro production in a way that makes the expected burden on the thermal system as even as possible¹⁴. Such an allocation of hydro production is consistent with competitive price-taking behaviour, i.e. allocating production to times when demand and price are high.

PoMo uses one single water store and one hydro power generator to represent all hydro production in the system. Further, the water inflow to the store is assumed to be stochastic with a log-normal distribution. The mean and standard deviation of inflow is calculated based on historical data for each week of year. PoMo assumes the operating cost associated with hydro production to be zero.

4.1.1 Input data

The smallest time unit in the model is a week, therefore all data is treated and used on a weekly basis. PoMo uses the following data as input to the model:

- Demand/consumption each week of the year (GW)
- Mean and standard deviation for water inflow each week of the year
- Water store capacity (assumed to be constant over time)
- Maximum available hydro power production capacity
- Thermal operating cost and available capacity each week of the year
- Discount rate factor/week. For Nord Pool, PoMo uses a discount rate of 6%, (which gives $r = 1 - (6\% / 52) = 0,9988$)

4.1.2 Assumptions related to Nord Pool

Finnish hydro production

¹⁴ The phenomenon of evened out costs between weeks is hindered by hydrological restrictions. These restrictions are: risk for empty water stores during spring, risk for overfull stores in autumn. Also, there may be restrictions related to the maximum capacity of hydro production during times of high demand.

The hydro power production in Finland is given in the model¹⁵. The reason for this is that the programmers of PoMo want to be able to model Finland as a separate price area¹⁶ and take into account the risks for transmission constraints between Sweden and Finland. The choice to assume the Finnish hydro production to be given does not significantly affect the model's accuracy. This is because the Finnish hydro production only corresponds to about 13 TWh per year while Sweden's and Norway's yearly hydro production is about 65 and 120 TWh respectively¹⁷.

Thermal power production

- The thermal power production is represented through data on operating cost and available capacity from about 200 thermal power plants. The operating costs are linked to fuel prices. Therefore, changes in fuel prices automatically transmit to the cost of the individual plants. Also fuel taxes are linked in this way. This information is used to calculate marginal costs for the thermal power plants.

Uncertainty

The uncertainty that a hydro producer faces is modelled by calculating the total variation of a number of variables. These are the water inflow, demand/consumption, nuclear production, Finnish hydro production, Swedish and Finnish thermal production¹⁸. All these factors are assumed to be independent from each other and lognormal. Consequently, the total uncertainty or variance can be calculated by the sum of each single variance. The water inflow represents by far the dominant uncertainty (or variance). The uncertainty is modelled for by adjusting the data for standard deviation.

Furthermore, generators are assumed to know the current stock of water in the reservoirs, demand, and the output of electricity from nuclear, fossil and wind power plants. They are also assumed to know the probability distribution for the future weekly inflow of water to the reservoirs, as well as for the future weekly demand and non-hydro generation.

Snow sub model

¹⁵ The Finnish hydro production is based on the weekly mean and standard deviation from data between 1980-1995.

¹⁶ If then the Finnish hydro production would be modelled in the same way as the Swedish and Norwegian hydro production, one would need to add an additional water reservoir for Finland. This would make the model much more complex and less user-friendly.

¹⁷ Denmark has no hydro production.

¹⁸ Weekly estimated means and standard deviations for demand/consumption and thermal production are based on data from 1980-1995. Norwegian and Swedish water inflow is based on data from 1931-1990 and 1950-1996 respectively.

The PoMo includes a model for snow melting. This sub-model functions as an intermediate water reservoir and it predicts at what rate the snow melts and can be used in hydro production.¹⁹

Nord Pool export and import

The model allows for import/export of power, and generally assumes 80 % availability. Import corresponds to regular production from a generator while export is modelled as negative production.

Price areas

PoMo models one price area for both Sweden and Norway, one for Finland, and two for Denmark (West and East).²⁰ One may argue that PoMo models the hydro production in a too simplistic manner since it uses only one single water reservoir for Sweden and Norway. This means that the model does not fully take into account potential transmission constraints between Norway and Sweden. For this reason, the model may not be able to accurately compute different prices for these areas.

4.2 Description of the data

The output-data of the PoMo model is the average weekly production level of Norwegian and Swedish hydro generators during 2006. The output data is measured in GWh.

Since PoMo models the Norwegian and Swedish hydro production on an aggregated level the data measures the total production level of Swedish and Norwegian hydro production.

The input-data²¹ is limited to the year 2006. PoMo calculates the production level on a weekly basis only and consequently the output-data consists of 52 observations.²²

4.3 Hypothesis

A hydro firm can exercise market power by shifting production away from high demand periods to low demand periods, in order to achieve an increasing effect on prices during peak demand periods. This reallocation of production can be achieved in different ways. I distinguish between *directly* and *indirectly* withholding output from high demand periods. The two terms refer to what method or strategy the hydro producer uses to limit its production

¹⁹ The snow sub model is based on a regression analysis of Norwegian inflow and snow store statistics between 1961-1990. The model has proven to work well for Sweden as well.

²⁰ There is also a function in PoMo which allow you to choose how many price areas to work with.

²¹ See section 4.1.1 for info on the input data.

²² EME analys provided me with the input data. Due to an upgrade of the PoMo software, I had only access to data from 2006. Since the required input data is highly detailed, I chose to limit my study to the year of 2006.

during the high demand periods. One can make a distinction between these two strategies based on to what degree the hydro firm is constrained by the current store level during high demand periods.

4.3.1 Potential strategies and expected signs of output gaps

If a firm produces more than what is economic during a low demand period, one can claim that it is indirectly withholding output by not saving the water for the high demand period. In such a case, PoMo predicts a competitive output which is lower than what is observed and consequently the output gap will be negative ($Output\ gap = Q_i^{PoMo} - Q_i^{obs\ prod}$). The hydro firm that is indirectly withholding output will have relatively lower store levels in the high demand period and is therefore more water constrained.

On the other hand, if the firm produces less than what is economic during high demand periods it is directly withholding output from high demand periods. In other words, this means that some water is “saved” during the high demand period and then released during low demand periods. In that case PoMo should predict higher production during the high demand period than what is observed and as a result the output gap will be positive. The hydro firm that is directly withholding output will have relatively higher store levels in the high demand period and is therefore less water constrained.

In both the described scenarios PoMo should predict a zero output gap in the time period where the firm is not directly or indirectly withholding output. Since PoMo’s forecast of competitive production is based on the current store levels, the output gap should have a positive or negative sign only if the actual (direct or indirect) withholding takes place during the corresponding period. For example, if a firm is indirectly withholding output the water store level will be relatively lower during high demand periods. Due to this lower store level, PoMo will predict that a relatively small hydro production is economic during the high demand period. Consequently, a zero output gap should be expected during the high demand period if the firm is indirectly withholding output. The same reasoning holds for the case of direct withholding.

However, this is not the case if a firm both directly and indirectly withholds output from high demand periods. This happens if the hydro firms produce less than what is competitive during high demand periods and more than the competitive output during low demand periods. In such occasion, one should expect to see positive output gaps during high demand periods and negative output gaps during low demand periods.

4.3.3 Three hypotheses

One can conclude that the hydro producer can exercise market power using three different strategies. These are direct withholding, indirect withholding and a combination of indirect and direct withholding. What is common for the three strategies is that output, in some manner, is withheld from peak demand periods.

The aim of this thesis is to examine if hydro firms exercise market power, i.e. to look for signs that any of these strategies are carried out. Hence, the following hypotheses are formed:

Hypothesis 1: The hydro firms are exercising market power through *indirectly* withholding output from high demand periods. Therefore, we expect to observe negative output gaps in low demand periods. Also, during low demand periods we expect a positive correlation between the output gap and demand.

Hypothesis 2: The hydro firms are exercising market power through *directly* withholding output from high demand periods. Therefore, we expect to observe positive output gaps in high demand periods. Also, during high demand periods we expect a positive correlation between the output gap and demand.

Hypothesis 3: The hydro firms are exercising market power both through indirectly and directly withholding output from high demand periods. Therefore, we expect to observe positive output gaps in high demand periods and negative output gaps in low demand periods. Also, we expect a positive correlation between the output gap and demand.

5. Results

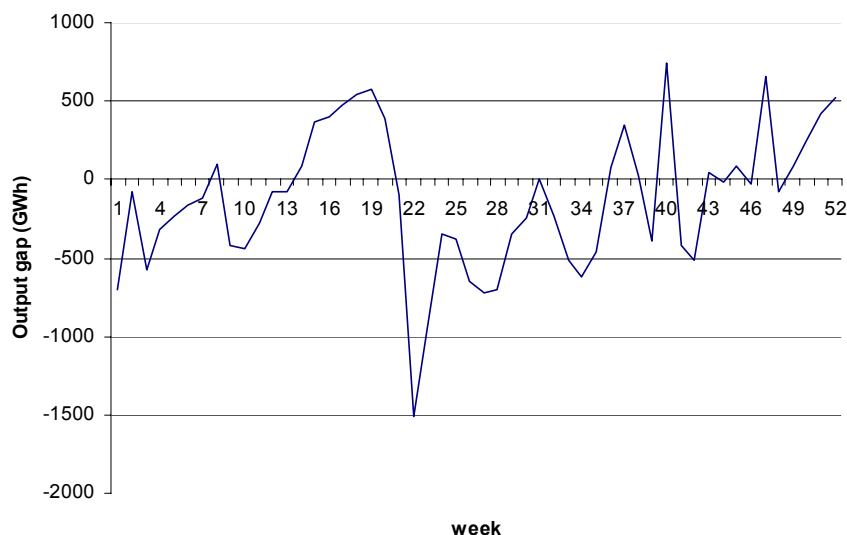
5.1 Descriptive analysis of the output gap

In this section I evaluate the output gap results in relation to the load level during 2006. The purpose is to decide whether the output gap's development during the year is consistent with what one would expect from hydro firms exercising market power, i.e. testing the hypotheses stated in the preceding section 4.3.3.

5.1.1 The output gap during 2006

The development of the output gap during 2006 is illustrated in the graph below. One can observe a negative output gap between week 1-13, indicating that the hydro generators produced more than the competitive output during this period. During week 14-20 the output gap was positive, representing a lower production than the economic level. Between week 22 and 35 the output gaps were negative and at times reached very low levels. Between, week 36 and 42 the output gap fluctuates around zero and shows both positive and negative values. The last weeks of the year, 46-52 the output gap was positive.

Figure 3. The output gap during 2006

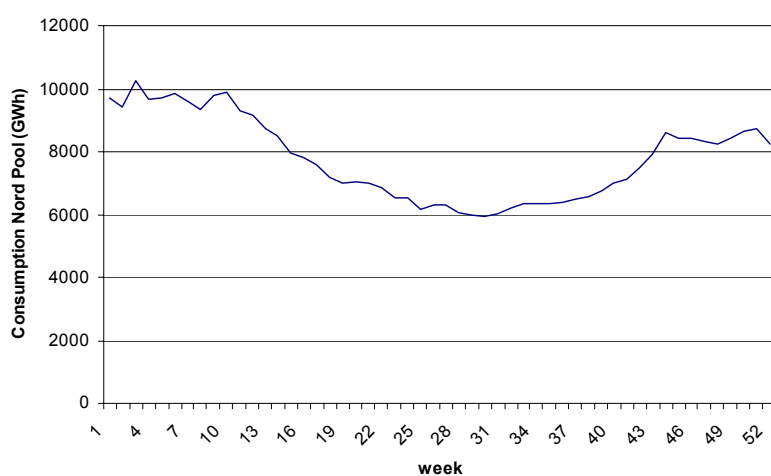


5.1.2 Demand level and the output gap

5.1.2.1 Demand level during 2006

In the graph below, the average weekly consumption during 2006 is illustrated. One can see a clear trend of high consumption during the colder winter weeks and low consumption during the warmer summer weeks. Unusually warm weather in the end of the year created a lower consumption than expected during November and December. The consumption during the winter weeks in the beginning and end are typically at similar levels (Elåret 2006).

Figure 4. Total consumption in Nord Pool during 2006



As previously argued the demand level varies during the year. The table below shows the distribution of weeks across different load levels during 2006.

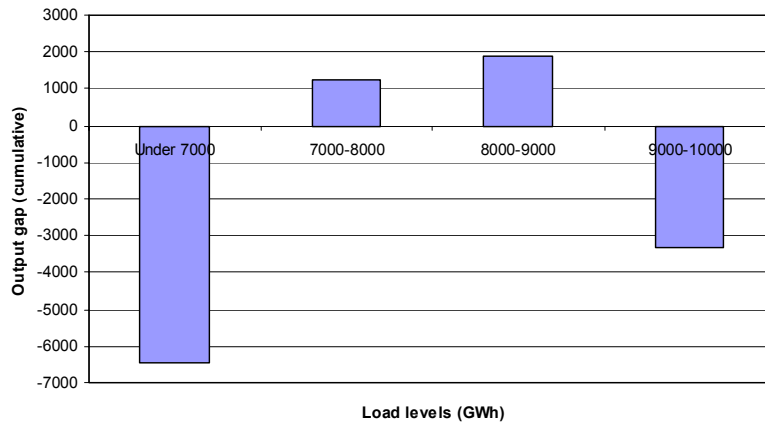
Table 1.

Load level (GWh)	Procent of weeks	Week number
< 7 000	40 %	19-40
7 000 - 8 000	15 %	15-18 and 41-43
8 000 - 9 000	21 %	13-14 and 44-52
9 000 - 10 000	23 %	1-12

5.1.2.2 Demand levels in relation to the output gap

Figure 5 shows the cumulative output gap (in GWh) related to different weekly load levels, i.e. a summation of the output gaps based on which load level category the weeks belong to.

Figure 5. Cumulative output gap during 2006



The output gap is highly negative for the lowest load level category (under 7000 GWh). This may be a sign of hydro production being shifted away from high demand weeks to low demand weeks. This indicates that hydro firms could have indirectly withheld output.

The figure also shows highly negative output gaps for the highest load category. Depending on which withholding strategy the hydro producer uses to exercise market power, one would expect either a positive output gap (if direct) or zero output gap (if indirect) during these weeks. Hence, these negative gaps during the highest load level category suggest that the hydro producers were not withholding output.

The two load categories ranging between 7000-9000 GWh show positive output gaps. Since the category 8000-9000 GWh corresponds to the weeks with the second highest consumption level one may expect that a hydro firm with market power could find it profitable to withhold production during such weeks. If this would be the case, one would expect positive or zero output gaps during this period.

Still, it would be more profitable for the hydro producer to withhold production from the highest demand weeks. One could argue that the hydro producer does not withhold production during this period due to the risk of that the market power behaviour will be detected. Since the consumption pattern during a year is relatively easy to predict, it would be hard for hydro producers to motivate low production levels during expected peak demand periods. Especially since the store levels are made public on a weekly basis. However, if hydro firms were exercising market power one would not expect a negative output gap during these weeks.

Next follows a section that looks at this category in more detail.

5.1.2.3 The peak demand period (week 1-12)

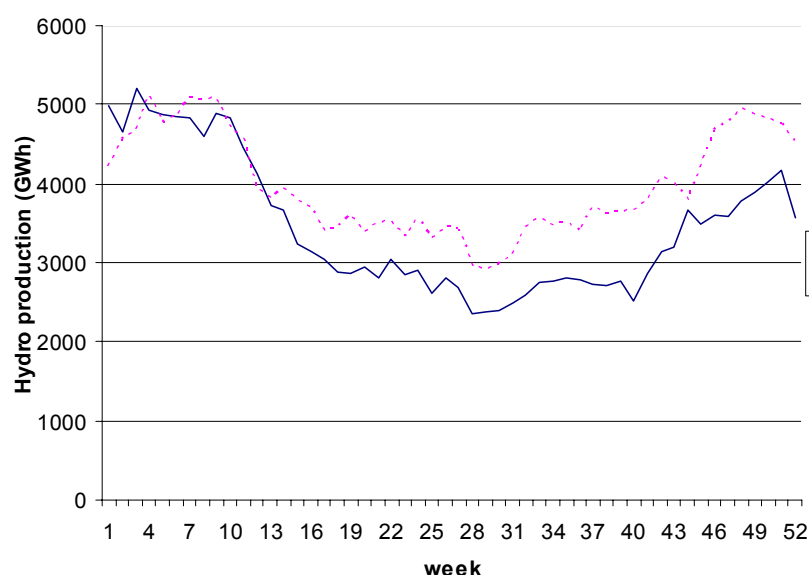
Consumption reaches the highest category/level of 9000-10 000 GWh²³ only during week 1-12. The water inflow and water reservoir levels were rather close to normal during week 1-12. However, the snow fall during the winter 2005/2006 was much smaller than normal.

Therefore, the snow stores were much thinner than normal and this caused the hydrological balance²⁴ to be much lower than 2005 during this period (See Figure 11 in section A.3). As a consequence of the thinner snow stores, one could expect a smaller and less persistent spring inflow (Energimarknadsinspektionen, 2006). Such circumstances should cause the hydro producers to be relatively more restrictive in their production. This is because one can expect a lower future inflow and the producers should therefore have saved more water than usual for future use.

Figure 6 below shows that the hydro production week 1-12 during 2006 was in level with the production from the same period during 2005. The inflow and store levels were normal during this period of 2005 (Elåret 2005). Also, the snow store levels were much higher during the winter 2004/2005 than 2005/2006 (Energimarknadsinspektionen, 2006).

Thus, even though the hydro producers knew that the snow stores were much lower than 2005 they did not decrease their production level during this period (week 1-12) compared to 2005. The hydro producers' behaviour during this period, i.e. the fact that water was not saved, contributed to the large water shortage later in 2006.

Figure 6. Hydro production 2005 compared to 2006



²³ The reason to that such levels were not reached at the end of the year was the unusually warm November and December.

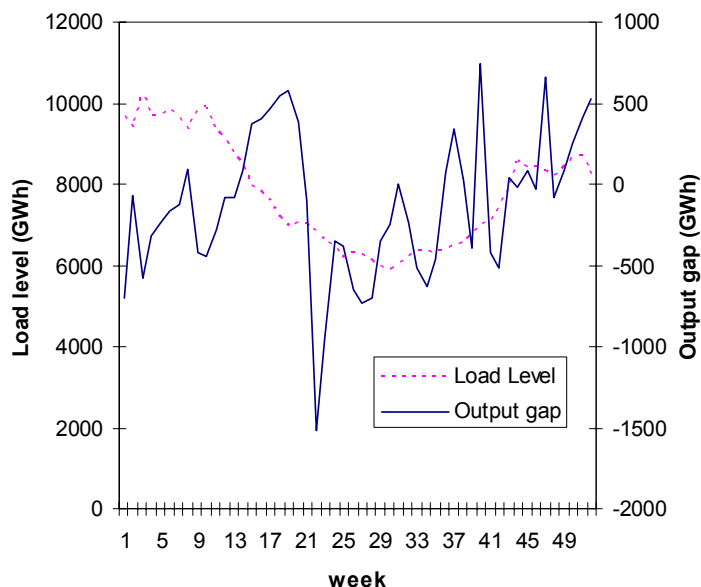
²⁴ The hydrological balance is defined as the amount of precipitation in all snow and water stores in Sweden and Norway.

In other words, hydro generators produced more than the economic quantity during week 1-12. One should therefore expect negative output gaps during this period. In figure 3 in section 5.1.1 one can indeed see that the output gap is negative during this period. If this negative output gap would be linked to a low demand period one may suspect the exercise of market power. However, this negative gap occurred during the peak demand period which is the opposite relationship one would expect to observe if market power is exercised. It is therefore unlikely that the hydro producers allocated their production in this manner with the intent to raise market price. It is possible that hydro producers forecasted the future precipitation to be much higher than the outcome was²⁵.

5.1.2.4 Trends

Hydro producers are able to shift production between periods. It is therefore important to study the inter-period differences in demand when looking for signs of market power. One needs to look at the change in output gaps between weeks, i.e. if the gaps become more/less negative or more/less positive. The larger the difference in demand between periods, the larger the incentive the hydro producer has to shift production between periods in a way that deviates from price taking behaviour. Figure 7 shows the output gap and the consumption of electricity in the Nord Pool area during 2006. The right axes shows the sign and size of the output gap and the left axes shows the load level.

Figure 7. The output gap related to the load level



²⁵ The hydrological balance between week 21 to 35 is much lower during 2006 than the corresponding period during 2005 (see Figure 11 in section A.3). As expected, the 2006 hydro production is lower than 2005 during this period.

One can observe a negative relationship between the output gap and demand / load level during week 1-19. Throughout this period there is a trend of increasing (more positive) output gap as demand falls in size. Such a relationship is opposite to what one would expect if hydro producers were exercising market power during that period. A similar relationship is observed during the peak load level period (week 1-12). Hence, one can argue that there are no signs of that the hydro producers directly withheld output during week 1-12.

One can observe a positive relationship between the output gap and demand during week 21 and 52. In other words, as time passes from low demand summer weeks to high demand winter weeks the output gap increases. The output gaps are the most negative in low demand periods and the most positive in high demand periods. This is an indication of that the incentive to reallocate production in a manner that deviates from price taking behaviour is the highest during high and low demand periods. Thus, the observed behaviour during week 21-52 could be an indication of market power.

Furthermore, one could argue that the sign and change in output gaps observed during this period (week 21-52) is consistent with indirect withholding. This is because during the lowest load level weeks the output gaps are highly negative and as the load level increases the output gaps becomes less negative. During the higher demand weeks at the end of the year (week 40-52) the output gaps are at times quite positive but the gaps still fluctuates rather close to zero. As previously stated, one would expect to observe negative output gaps during low demand periods and zero output gaps during high demand periods if hydro firms are indirectly withholding output.

5.2 Demand correlations to the output gap

In order to quantify the trend or relationship between the output gap and demand, the Pearson correlation coefficient has been used. To test the different hypotheses, the data has been divided into low and high demand periods respectively.

When testing for hypothesis 1 and 2, the high demand period was defined as the 26 weeks with the higher load levels and the low demand period was defined as the 26 weeks with the lower load levels²⁶. In other words, the hypothesis of direct withholding is tested by studying the relationship between demand and the output gap during the high demand period. While

²⁶ This rather rough division was due to the small number of observations (52). It would be preferable to look at perhaps the 10% highest and lowest demand/price periods because the incentive to withhold output is highest in these periods. However, since I only have 52 observations the number of the remaining sample would be very small.

the hypothesis of indirect withholding is tested by studying the relationship between load level and output gap during the low demand period.

In order to test hypothesis 3 of indirectly *and* directly withholding, two different ranges of data have been used. In the first correlation the same distinction as the hypotheses 1 and 2 was used, i.e. the high demand period is defined as the 26 weeks with the higher load levels and the low demand period as the 26 weeks with the lower load levels²⁷. In the second correlation, the high demand period was defined as the 13 weeks with the highest load level and the low demand period as the 13 weeks with the lowest load level. In the table presented in the following section, the former correlation is referred to as *Low/high* and the latter as *Lowest/highest*. Hence, when testing for hypothesis 3 two different correlations are computed and the correlation between the output gap and demand is studied during both the high and low demand periods.

The second column in the following table specifies what type of withholding the correlation tests for. If the hydro firms exercise market power, the expected sign for the correlation coefficients is *positive*. This holds for all correlations tested for.

5.2.1 Correlation between demand and output gap

Table 2 shows the correlation results for the relation between the output gap and load level.

The different hypotheses stated in section 4.3.3 are tested for.

Table 2. Correlation results

Correlation variables	Type of withholding	Correlation Coefficient	Significance ²⁸
<i>Low demand period output gap and Low demand period load level</i>	Indirect	+ 0,349	Significant at the 10% level
<i>High demand period output gap and High demand period load level</i>	Direct	- 0,777	Significant at the 1% level
<i>Low/high demand period output gap and Low/high demand period load level</i>	Both	+ 0,124	Not significant
<i>Lowest/highest demand period output gap and Lowest/highest demand period load level</i>	Both	+ 0,122	Not significant

²⁷ The 26 weeks defined as high demand weeks were week 1-16 and 43-52. The 26 low demand weeks were week 17-42.

²⁸ All significance tests are two-tailed.

As shown in the table, there is a positive correlation coefficient, +0,349, between the *Low demand period output gap* and the *Low demand period load level* (Hypothesis 1). The correlation is significant at a 10% level. As a result *Hypothesis 1* cannot be rejected at the 10% level. This is an indication of that hydro firms are indirectly withholding output. However, the correlation is not significant at a 5% level and therefore one should interpret the suggested relationship carefully.

The correlation coefficient between the *High demand period output gap* and *High demand period load level* is significant and the sign negative (Hypothesis 2). As previously stated, one would not expect a negative sign if market power is being exercised. Thus, this result indicates that the hydro firms are not directly withholding output and *Hypothesis 2* is rejected. The two last correlations test a combination of direct and indirect withholding (Hypothesis 3). The correlation coefficients have positive signs but are not significant and consequently *Hypothesis 3* must be rejected.

5.3 Output gap and price level

The aim of this thesis is to evaluate whether hydro producers exercise market power by moving production away from high to low demand periods. As the output gap was related to demand, the results indicated that hydro producers were indirectly withholding output and no evidence of direct withholding was found. However, the core incentive for a producer to withhold output is to increase the market price during the high demand period. For this reason, the withholding analysis could benefit from also relating the output gap to the price level during the low and high demand periods of 2006. The price level at Nord Pool varied more than normal during 2006, mostly due to the unusual hydrological development (Elåret 2006)²⁹.

5.3.1 Price level related to the output gap during high/low demand period

If hydro producers are exercising market power by strategic hydro scheduling the market prices will, in comparison to the scenario of price taking hydro scheduling, be higher during the high demand period and somewhat lower during the low demand period. As producers attempt to directly withhold output too little quantity is produced³⁰ in order to directly increase the market price. Such a strategy should, *ceteris paribus*, be the most profitable during high demand periods - when quantity (power) is relatively scarce and the withheld

²⁹ See A.4 in the Appendix for a more detailed description of the system price development during 2006.

³⁰ Compared to the competitive production level given the current conditions (water reservoir level, expected water inflow etc)

quantity has the strongest increasing effect on price³¹. As a result, one could argue that the relationship between the price during the *high* demand period and the output gap during the *high* demand period should be positive.

When a producer is indirectly withholding output, too much quantity is put on the market during the low demand period with the intent to increase the price during the high demand period. As a result, one should expect a negative relationship between the price during the high demand period and the output gap during the low demand period, i.e. the negative output gaps in the low demand period results in high(er) prices during the high demand period.

It is important to point out that both strategies, if there are effectively carried out, should result in higher prices during the high demand period and somewhat lower prices during the low demand period compared to the price taking scenario. The two strategies can be distinguished based on whether the hydro firms are relatively water constrained during the high demand period (indirect withholding) or if hydro producers hold back on production even though the current conditions suggest they should be producing more (direct withholding).

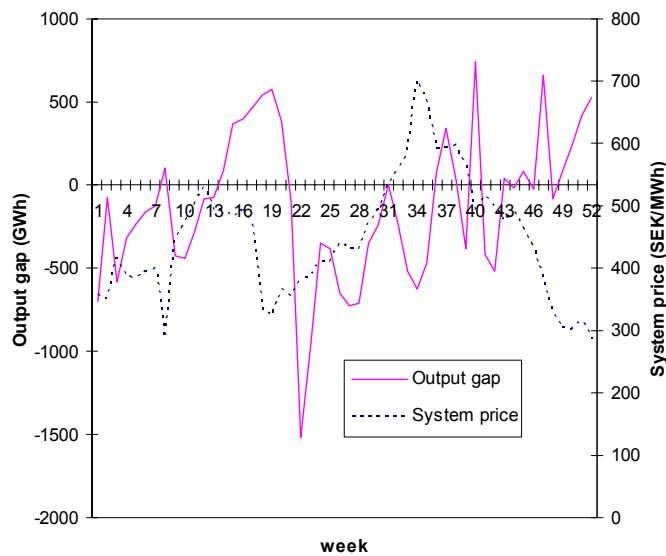
5.3.2 Direct withholding – price analysis

The demand analysis showed no indications of that hydro firms are directly withholding output. Figure 8 illustrates the output gap related to the price during 2006. The 26 weeks defined as high demand weeks were week 1-16 and 43-52³², i.e. the start and end of the year. As previously stated, one should expect a positive relationship between the price and output gap during high demand periods if firms are directly withholding output. As illustrated in the figure below, no such pattern can be observed.

³¹ As can be seen in figure 1 in section 2.1.2 the marginal cost (supply) curve becomes increasingly steep and if output is withheld even more expensive power producing units could be used.

³² The 26 weeks defined as low demand weeks are week 17-42.

Figure 9. The output gap and weekly system price



To further study the case of direct withholding, a correlation coefficient was computed to quantify the relationship between the output gap and system price level during the high demand period. As can be seen in Table 3 the sign of the coefficient is negative and not significant. This is contradictory to what one would expect if the hydro generators were directly withholding output.

Table 3.

Correlation variables	Type of withholding	Correlation coefficient	Significance
<i>High demand period³³ output gap and High demand period price level</i>	Direct	- 0,191	Not significant

Thus, the price analysis confirms the finding from the demand analysis that hydro firms were not directly withholding output during 2006

5.3.4 Indirect withholding – price analysis

To do a similar analysis on indirect withholding the price during the high demand period needs to be related to the output gap during the low demand period. In other words, one need to check whether the negative output gap during the low demand period can explain or is correlated to higher prices during the high demand period. There is a time-lag between when the actual withholding takes place and when the effects of higher prices are expected. Since I do not have access to lagged data I am unable to check for such correlation.

³³ The high demand period is defined as the 26 weeks with the highest demand.

6. Limitations

There are a number of limitations to the reliability of my data and analysis. First, the number of observations is only 52. It would have been preferable to study a longer time horizon than one year because a larger number of observations would add reliability to the results.

Second, all water reservoirs in Norway and Sweden are represented by one single large reservoir in PoMo. This means that the results are analyzed on an aggregated level and consequently plants' or firms' individual deviations can not be detected. Also, the single reservoir for Norway's and Sweden's hydro production implies that the model does not fully take into account the need of transmission between Norway and Sweden. As a result of this the model may not make accurate forecasts when there are price area differences.

A third weakness of my method is the rather rough division of weeks into high and low demand periods as the data was analyzed. The high demand period was the 26 weeks with the highest consumption and the low demand period was the 26 weeks with the lowest consumption. This means that I could only test for indirect withholding during the low demand periods. It could be possible that producers find it more profitable to over-produce (indirectly withhold) within the high demand period.

For instance during a week when the demand is not that high but still due to my division is defined as a high demand week. This division was made due to the small number of observations (52).

Fourth, since PoMo only can give an estimate of the economic output on a weekly basis the analysis will not be able to capture reallocation of production which takes place on an hourly basis. As a result of this, I will not be able to detect market power that is exercised on an hourly basis, i.e. when production is moved from high to low demand hours. Discussion concerning the latter limitation is developed in the following section.

6.1 Hourly versus weekly data

Hydro resources are different from other units withholding output in the sense that the withheld production can be used at another time. One may claim that the hydro generator has two choices; either move the withheld production to other hours or other weeks.

It is ambiguous whether this "extra" production is most valuable if used during low demand hours of the same day that it was withheld or if it is moved to low demand weeks. It is possible that all hydro generators do everything they can to save as much water as possible for the high demand weeks, i.e. acts as a price-taker on a weekly basis. And when the peak

demands periods arrive the strategic firm withholds during peak hours and uses the withheld production during lower demand hours of the same day. If this is the case, that the hydro producer does not move any production between weeks, I will not be able to detect market power behaviour (due to PoMo's weekly data).

A strategic firm may never find it profitable to allocate the extra production to weeks where demand is lower. This is because the firm may get a better price for the withheld production during the low demand hours of the high demand week than it would selling in low demand weeks. However, if the firm instead sells the extra output during peak hours of low demand weeks it may get a better price.

The strategic firm needs to consider how the extra production will affect the price for the quantity that it was already selling. In low demand weeks the negative effect on price is very small due to the flat supply curve. In contrast, in high demand weeks the price reaction will be strong due to the steeper supply curve. Therefore, an argument that speaks for weekly redistribution of output is that the negative price effect may be minimized if the extra production is moved to low demand weeks.

A second argument that speaks for weekly redistribution is that such a strategy has a lower risk of being detected. Wolfram (1999) claims that British generators did not exercise market power to the extent they could due to the threat of further entry or more restrictive regulations. Against this background, it is likely that hydro producers will employ a strategy of exercising market power which can be concealed as effectively as possible. It is difficult to judge whether a reduction in hydro production is a result of market power abuse or conservative expectations about future precipitation. A firm that reallocates production can make a more convincing argument that it held back on production due to expectations of low future water inflow.

One may argue that a firm who reallocates production between hours cannot blame its behaviour on the uncertainty of future inflow. It does not seem reasonable for a firm to claim that during the peak hours it expected a low inflow but under load hours it expected a high inflow. Even though, the forecast of future water inflow in the very short term may change quickly one could argue that the majority of the uncertainty lies in more long run forecasts, i.e. how the water inflow will change in the next weeks or months.

Hence, it is reasonable to assume that it is more difficult to mask a reallocation of production between hours than weeks. If the risk of detection is an important factor in hydro scheduling decision making one could expect that strategic hydro scheduling (market power behaviour) is captured by weekly data.

7. Conclusion

To identify and measure market power behaviour in the hydro power sector is difficult. A hydro producer can during high demand periods mask a withhold of production by claiming a low expectation of future water inflow and that it consequently exists a need to save water for future use. In the same manner, a hydro producer can motivate a relatively large production during a low demand period by an expectation of high water inflow. In this way it is possible for a market power exercising hydro producer to conceal that it deviates from the production allocation of a price taker. The element of discretion that characterizes hydro producers' decision making makes it important to study whether hydro producers transfer production from high demand to low demand periods.

However, how to identify market power when dealing with hydro is not evident. For an outsider it is difficult to judge whether the withheld production is a result of market power abuse or conservative expectations of precipitation.

To solve this problem, the PoMo model has been used because it takes the unpredictable variation of inflow of water into account when calculating the optimal production of a price taker. To evaluate whether hydro generators in Nord Pool exercised market power, a withholding analysis was performed. The output gap data was analyzed by using a descriptive method and computing correlations.

7.1 Main findings

The descriptive demand analysis showed that the cumulative output gap was highly negative during low load level weeks (under 7000 GWh). Also, one could observe a trend of less negative output gaps as the load level increased. These findings indicate that hydro producers shifted production away from high demand weeks to low demand weeks by indirectly withholding output. As the output gap was correlated with demand, the hypothesis of that hydro generators were indirectly withholding output could not be rejected at the 10 % level³⁴. However, the correlation was not significant at a 5% level and therefore one should interpret the suggested relationship carefully.

The descriptive demand analysis showed no evidence of direct withholding and the correlation analysis rejected the hypothesis of direct withholding. The hypothesis of a combination of directly and indirectly withholding was also rejected. In order to further

³⁴ To further investigate the presence of indirect withholding one could relate the output gaps during the low demand period to the system price during the high demand period. Since my data was not time-lagged, such an analysis could not be done.

examine whether hydro producers exercised market power by directly withholding output, the system price during the high demand period of 2006 was related to the output gap during the high demand period. Consistent to the previous findings, no signs of direct withholding were found. Hence, the results suggest that hydro firms were not exercising market power by directly withholding output.

To sum up, my results indicate that hydro producers were indirectly withholding output during 2006. As previously argued, the support found for indirect withholding was not clear-cut and there are many limitations related to my method. Still, my results suggest that it is more likely for hydro firms to indirectly withhold output than directly, i.e. it is more likely that hydro producers exercise market power by overproducing during off-peak periods than directly constraining output during on-peak periods. The rationale behind such a relationship could be that the risk of being detected is smaller for a firm that is indirectly withhold output.

7.2 Discussion

When a hydro firm with market power chooses hydro scheduling strategy, it is likely that the firm considers both the efficiency and potential risk of detection associated with the strategy. One can claim that direct withholding is a more efficient strategy to carry out because you can wait until the actual peak occurs. Indirect withholding is more complex and potentially less efficient. This is because the hydro firm needs to forecast when the demand peak will occur and based on this overproduce in a way that causes the hydro firm to be water constrained during the peak period. Since the hydro firms needs to take into account future uncertainty of inflow to achieve this, it is obvious that it is very hard to arrive at an optimally low store level during the high demand period.

However, the potential risk of detection may be a deciding factor as the hydro generators chooses strategy to withhold output. There are two factors indicating a lower risk of detection for indirectly withholding output.

First, it could be hard for hydro producers to explain directly withheld production during expected peak demand periods because one can argue that the consumption pattern during a year is relatively easy to predict with high demand during winter and low during summer. Also, since a dominant share of the water inflow occurs in the off peak period (between week 18 -30)³⁵, it is only during this time it is a real risk of overfilled reservoirs and a potential need of spilling water. A hydro producer who indirectly withholds output has therefore a possibility

³⁵ See Figure 10 in section A.2.

to mask its overproduction during the low demand period as a natural reaction to the risk of overfilled stores.

For these reasons, it may be easier for a hydro producer to mask and motivate an overproduction during the low demand summer weeks (indirect withholding) than an underproduction during the high demand winter weeks (direct withholding). As previously stated, the descriptive and correlation analysis of the demand level did indeed reject the hypothesis of direct withholding while the hypothesis of indirect withholding could not be rejected. This finding implies that it is important to study the hydro generator's behaviour in off-peak periods in order to be able to identify market power. As the level of competition is monitored, the focus is often on peak-demand periods because it is in those periods the higher prices are observed. Hence, it appears important to consider that it is possible for a hydro generator to behave like a price-taker in on-peak periods and still indirectly exercise market power by over-producing in low demand periods.

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9. Appendix

A.1 PoMo - Decisions under uncertainty

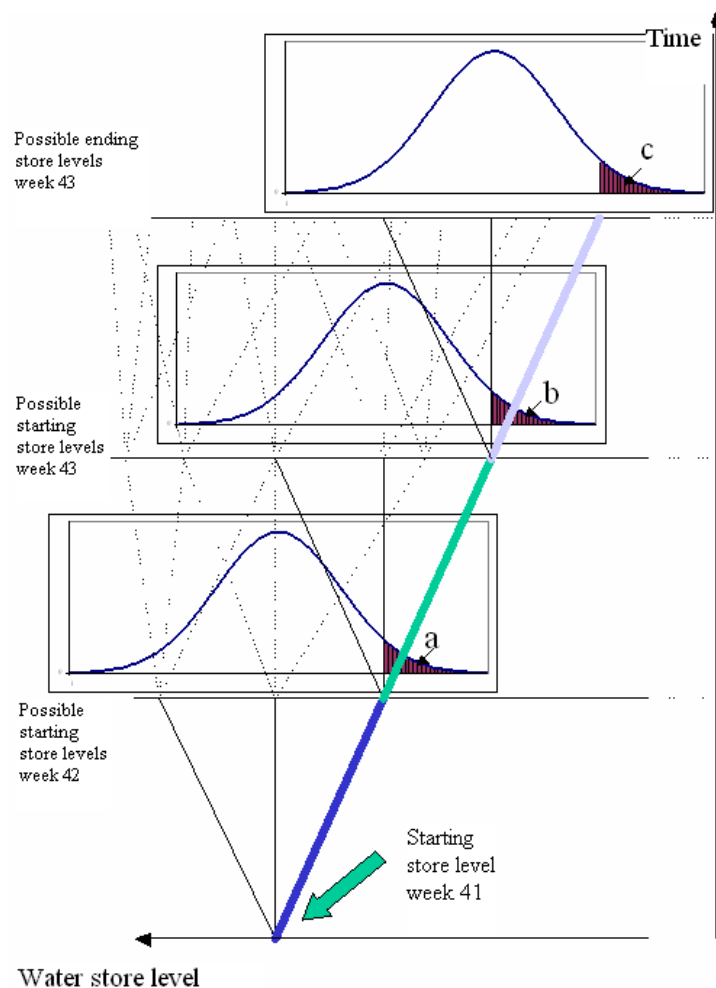
As previously argued, hydro power producers have a choice of deciding how much water that is to be used for generation at the present time and how much to use later when the price could be higher. PoMo computes the optimal hydro power production given information on marginal costs of thermal power producers, hydro power capacity, present reservoir level, and statistical data on average and standard deviation for demand, water inflow and base load production (PoMo Manual, 2007).

The calculation is done for all possible outcomes (different water inflows, demand etc) during a certain week. The model assigns a probability for each outcome. The result is a final optimal solution of production, which in turn gives us the ending reservoir level for the week. This ending reservoir level becomes the starting reservoir level for the next week and then the calculation is repeated.

PoMo optimizes the operation of the system subject to uncertainty, concerning for e.g. the weekly water inflow. For every possible future “water inflow case” a probability is assigned. Depending on each week’s possible store level, the PoMo cost minimization function will give the optimal hydro production over time. The remaining power production must come from thermal power in order to meet the total demand level. The marginal cost of the most expensive thermal plants used is what sets the PoMo prices.

In the figure below, it is illustrated how PoMo deals with the uncertainty related to water inflow during a week (week 41). The starting store levels for week 41 are given but the water inflow to the water stores during the week is uncertain. The probability that the water stores will decrease in alignment with the thick line is a during week 41. The parameter a is the area under the probability curve for week 41 and represents equally dry or drier outcomes than the thick line (up to a).

Figure 9. Treatment of water inflow uncertainty in PoMo



Source: PoMo Manual, 2007

Next, Pomo calculates the different water inflow scenarios for week 41 and assigns a probability to each outcome. To further illustrate, one may assume the dry scenario during week 41 (the thick line up to *a*), then PoMo calculates the different inflow scenarios for week 42 (represented by the thinly drawn lines). The probability of an equally dry scenario as in week 41 is represented by the parameter *b*.

One may also calculate the probability of that week 43 also would be dry (parameter *c*). The probability for that the dry scenario (or drier) will occur three weeks in a row, i.e. from week 41 to 43, is $a*b*c$. This is the case if one assumes that the water inflow in one week is statistically independent from other weeks.

Hence, PoMo takes into account that the water inflow can be very low during several weeks in a row but also that the probability for this is very low. Obviously, if the described scenario would occur the price of power would be very high. One can therefore argue that PoMo considers the uncertainty concerning prices and inflow of future weeks which determines the hydro producers' decisions.

The thinly dotted lines illustrate all other calculations performed by PoMo. At high inflows the cost minimization function will result in high levels of hydro production in order to reduce the risk of overfull reservoirs in autumn³⁶. In contrast, when the inflow is low water needs to be saved in order to fulfil the minimum level needed to handle the spring inflow.

The development of the store levels is not solely dependent on the different inflow scenarios.

The model also takes in to account thermal power production and changes in demand.

To sum up, one can conclude that PoMo's strength is its ability to compute an optimal level of production given the uncertainties that the hydro producer faces each week.

A.2 Hydrological development

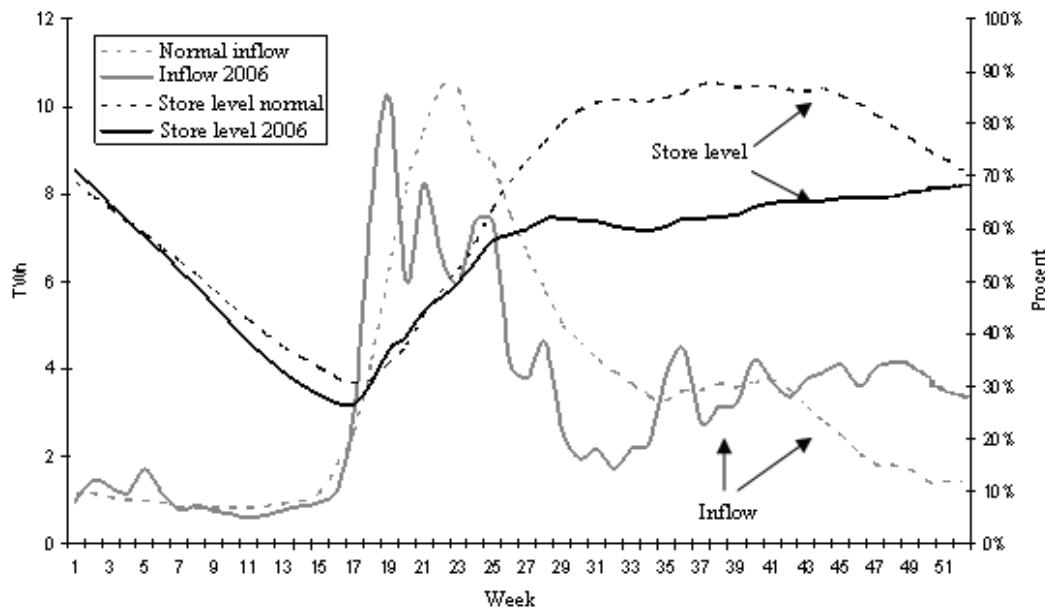
Since a large fraction of the Nordic electricity capacity consists of hydro resources, the hydrological development plays a vital role in the Nordic electricity market. The precipitation can vary a lot between years. Below, the hydrological development of 2006 is compared to a normal development based on historic statistic records from the 1950's to present.

The hydrological development during 2006 was very unusual (Elåret 2006 and Energimarknadsinspektionen, 2006). As one can see in the graph below, the water inflow was normal during the winter and up to the spring water inflow. This inflow started at a normal point in time but became more intensive and shorter than normal. This less persistent spring water inflow was to a large extent due to the much lower than normal snowfall during the winter 2005/2006. Next, the low summer precipitation resulted in a water inflow consistently below normal during the summer.

It was during this period the large deficit in the store levels was created. During mid September the total shortage in the Swedish and Norwegian water stores was 29 % of the normal level. A hydrological deficit of this size is very uncommon in the Nordic area and this was the largest observed deficit since the deregulation. However, during the last two months of the year the inflow was much larger than normal. Also, the weather was much warmer than normal during these months and therefore the demand for electricity became lower than normal. These two factors contributed to a quick recovery of the water store levels (Energimarknadsinspektionen, 2006).

Figure 10. Water inflow and store level, comparison to normal scenario

³⁶ The store levels are the highest during autumn.



Source: Energimarknadsinspektionen

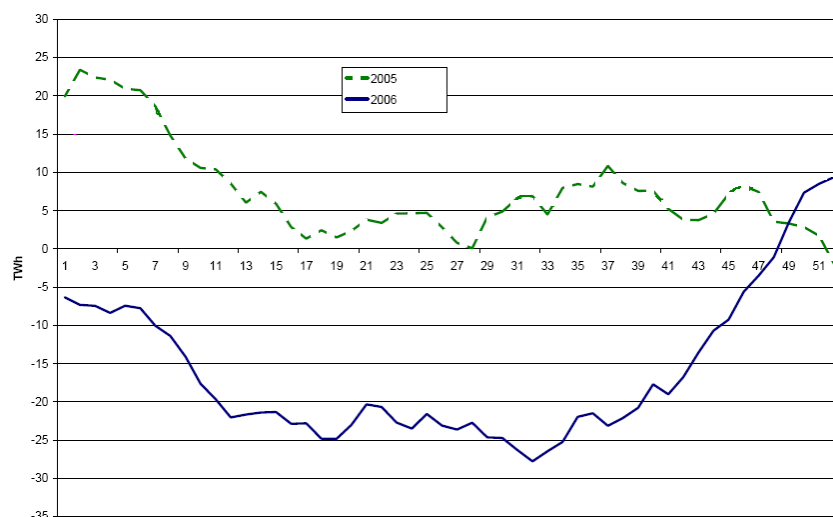
Figure 10 illustrates the water inflow and store level in Norway and Sweden for 2006 and for the normal case. The left axis measures the water inflow in terms of TWh and the right axis measures the store level in percent. The dotted lines refer to the normal development of the store level and inflow.

A.3 The hydrological balance 2006

The hydrological balance is defined as the amount of precipitation in all snow and water stores in Sweden and Norway. It is measured as the deviation from a normal value (+/- 0) based on statistics from 1961 to present (Fundamenta månadsrapport). If the deviation is negative the balance is lower than normal and vice versa. Figure x shows the hydrological balance in TWh during 2005 and 2006.

As illustrated in Figure 11 below, the hydrological balance during week 1-13 is much lower in 2006 compared to 2005. It is therefore surprising that the hydro production during the period is about the same.

Figure 11. Hydrological balance, comparison 2006 and 2005



Source: Fundamenta Månadsrapport

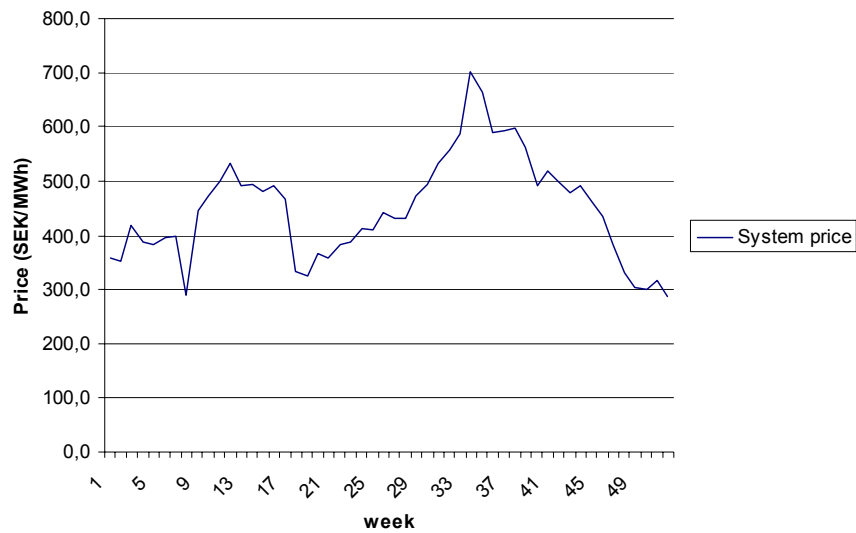
A.4 Price level during 2006

The prices at Nord Pool varied more than normal during 2006 (Elåret 2006). The system price was at its highest during August and at its lowest during December. The spring's low inflow and the increasing price of CO₂ emissions rights had an upward effect on prices in the beginning of the year. In the end of April the CO₂ emissions rights prices dropped with 50% which resulted in lower spot prices. Next, the dry summer in the Nord Pool area increased prices and production problems in Swedish nuclear plants enhanced this effect³⁷. The lack of water inflow and decreased nuclear production lead to increased import of power which drove up prices. The peak was reached in the end of August at about 700 SEK/MWh.

However, from August to the end of the year the spot price fell significantly. The most important factors to this development were the lower demand due to the mild weather and the higher than normal water inflow. Other factors were that the nuclear plants could be restarted and a continuing falling price of CO₂ emission rights (Elåret 2006). To sum up, the price development during 2006 exemplified how dependent the price formation is on underlying factors related to both production and demand. It is possible that if hydro firms attempted to exercise market power it may have been very difficult to time the price peaks in their production scheduling. Hence, it is likely that the unusual development of the price made it more difficult to effectively exercise market power.

Figure 12. The system price in Nord Pool during 2006

³⁷ The nuclear power produced 4,8 TWh less than 2005 most due to production problems in Forsmark 1 and other reactors during the summer and fall.



Source: Nord Pool

The table below shows the distribution of weeks across different price levels during 2006.

Table 4.

Price level (SEK/MWh)	Percent of weeks	Week number
< 400	37 %	1-2, 4-8, 18-23 and 47-52
400-500	40 %	3, 9-10, 13-17, 24-30, 40 and 42-46
> 500	23 %	11-12, 31-39 and 41