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Is there a scope for exploiting the interplay between physical and financial electricity markets?*

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Abstract

The characteristics of electricity production and consumption make electricity markets highly susceptible to the exercise of unilateral market power. However, it is a recognized view that a well-functioning financial power market will contribute to a competitive price level in the associated physical market. But if producers are permitted to acquire so-called long positions, i.e. buy contracts for future purchases – as is the case at Nord Pool, the Nordic Power Exchange – the last argument may no longer be valid, and the market outcome could in stead be anti-competitive. By means of a simple two-period model, we find that a dominant hydro producer with storage capacity and superior private information has incentives to manipulate expectations about future electricity prices via strategic hydro scheduling, and thus gain an extra profit in the corresponding financial market.

Key words: Deregulated Electricity Markets, Futures Market Manipulation, Asymmetric Information, Hydro Power Scheduling

JEL Classification: D82; G13; G14; L94

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1. Introduction

More efficient use of resources and competitive prices to consumers have been important motivations for the deregulation of electricity sectors, which have taken place around the world during the last decades. Although so far the deregulated markets are not typically characterized by perfect competition, for some time the potential problems of strategic behavior among liberalized electricity generators were overlooked both in real world markets and in the bulk of academic analyses. After the issue was raised and the potential for strategic behavior was discovered, a number of analyses of actual restructuring processes have found proof of imperfect competition, c.f. for example Tennbakk (2000), Hogan (2002) and Woo et al. (2003). The main focus of such analyses up until now has been possible manipulations of spot markets, see Kumar (2001) and Chung et al. (2004) for reviews of analyzes of market power in deregulated electricity markets.

Another strand of the literature focuses on how the availability of long-term contracts and derivatives markets may mitigate strategic spot market behavior. Broadly speaking the established view among economists is that the derivatives market increases welfare, both by means of risk sharing (see e.g., Anderson, 1984), and by yielding fiercer price competition in a market characterized by imperfect competition. Under given assumptions Allaz (1991), Allaz and Vila (1993) and Huges and Kao (1997) among others, show that the derivates market has a disciplining effect on strategic behavior in spot markets. These results have also been supported by analyses with application to deregulated electricity markets, primarily with reference to the British (England/Wales) electricity market, which was one of the first to be deregulated. Well-known references are Green (1992), von der Fehr and Harbord (1993), Newbery (1998), Green (1999) and Wolfram (1999), the results of which are generalized in Anderson and Xu (2005). Equivalent conclusions, which have originated from studies of other electricity markets, are found in Wolak (2000) for the Australian market, Borenstein (2002) for the Californian market, Garcia and Arbeláez (2002) for the Colombian market and Herguera (2000), who compare the British and the Nordic market. Recent extensions of this literature include Chung et al. (2003), Chung et al. (2004) and Kamat and Oren (2004). However, Kamat and Oren (2004) show that the beneficial effect of derivates markets on the exemption of market power, as predicted in Allaz and Vila (1993), to a large extent will be reduced in the presence of congested transmission lines.

A common feature of the above mentioned electricity market analyses is the assumption that the only motivation for producers to enter the contract market is risk aversion and the need for risk management due to uncertainty about future price levels. Therefore, the analyses include only short positions, i.e. contracts for future *sales*. If a large share of a producer's production is tied to contracts for future sales, the potential profit from forcing prices up in the spot market is significantly reduced. Allowing producers to acquire contracts for future *purchase* can, however, have the adverse effect, as shown in Kyle (1984), Ferreira (2003), Thille (2003) and Mahenc and Salanié (2004). High spot prices at the time of settlement will then increase the value of the financial position, implying that the existence of financial markets where producers can hold long positions may in fact reduce competition in the physical markets. To our knowledge this issue has received limited attention in the electricity market literature although the anti-competitive effects of producers' long positions in the delivery period is a result of fairly long standing in the economics literature, cf. Kumar and Seppi (1992).

The objective of the present paper is to study the possible anti-competitive effects of allowing electricity producers to acquire long positions and to study analytically the presentiment that large hydro producers may have incentives to exploit private market information to manipulate futures prices during the trading period. Analyzes of market power exploitation in deregulated electricity markets characterized by large hydro power recourses have mainly focused on spot market earnings related to strategic hydro scheduling in a Cournot setting, c.f. Scott and Read (1996) with reference to the New Zealand market, Fleten and Lie (2000) to the Nordic market, Kelman et al. (2001) to the Brazilian market, Garcia and Arbeláez (2002) to the Colombian market and Bushnell (2003) to the Western United States. We have not come across studies that reveal hydro power producer's incentives to manipulate financial electricity markets. Financial electricity markets are, however, quite novel institutions in electricity markets in general. In order to cultivate our main objective of analyzing potential financial market manipulations, the empirical and analytical scope of our model is rather modest. Our analysis shows that under the assumption of asymmetric information a dominant hydro power producer may find it profitable to manipulate financial prices by allocating hydro resources in ways that contradict least-cost production. This result is our main contribution.

The topic of the paper is motivated by the Nordic electricity market which has a large share of hydro generation with storage. In a hydrological normal year, the total hydro power production amounts to almost 50 percent of the gross consumption in the Nordic area. The hydro power is mainly concentrated in Norway (close to 100 percent of production capacity) and Sweden (approximately 50 percent of production capacity).[1] Although the Nordic electricity market is generally perceived to exhibit well-functioning competition (Amundsen and Bergman, 2006), having a joint market place does not imply that a common Nordic spot price always prevails, see e.g. von der Fehr et al. (2006). The market situation may change

[1] The remaining production capacity is primarily nuclear in Sweden, thermal in Finland, and thermal with a considerable share of wind in Denmark.

every hour and, consequently, capacity utilization and flows on the transmission lines. Moreover, the menu of anti-competitive strategies available to large hydro power producers with reservoirs differs quite substantially from that of owners of other types of generation technologies, c.f. Bushnell (2003). This may have significant consequences when it comes to the potential for exploiting the interplay between spot market prices and financial market prices during the trading period of a financial contract. Also, the inherited pre-deregulation structure of the Nordic Exchange Area means that market concentration is high in submarkets, e.g., Norwegian Statkraft has an overall market share of about 35 percent of Norwegian generation capacity and Swedish Vattenfall controls about 50 percent of Swedish generation capacity. Considering the decision to investigate a possible manipulation of the financial market at Nord Pool, the first international power exchange, during the spring 2002 (Nord Pool, 2002), the empirical relevance of our topic is evident.

The paper is organized as follows. For readers not familiar with strategic hydro scheduling, we present in Section 2 the chief characteristics of hydro power production and discuss the basis for assuming asymmetric information underlying firm's expectation formation in such environments. In Section 3 briefly presents risk management with reference to the Nordic Power Market and Nord Pool. Our formal analysis and results are presented in Section 4. First, we analyze strategic behavior during the trading period, then we include the delivery period. We describe in Section 4 a simplified model of a deregulated electricity market consisting of one large risk neutral hydro power producer owning a reservoir and a fringe of (small) risk adverse producers. Studying the problem in a Cournot-setting is left for a subsequent paper, although some preliminary results are suggested in Section 5. In this subsection we discuss potential impacts of our findings on market competitiveness and economic welfare, and evaluate possible preventive measures. The appendix contains the proof of Proposition 1.

2. Hydro power production and price expectations

Optimal production planning varies between technologies. Operating a hydro power station with a reservoir differs significantly from the operation of a thermal plant, for example. A thermal generator has a flexible (at least deterministic) capacity constraint as more or less fuel can be bought in the market, whereas a hydropower producer's capacity is given – although it varies with inflows (stochastic). For a hydro power producer the production level in one period will affect the potential production level in later periods. Therefore, a hydropower generator with reservoirs store water and, at any given time, supply according to own current reservoir level and expectations about future inflow and prices. A price-taking generator will allocate water such that the value of the marginal unit produced today (given by the market price) is equal to the expected price in a future period (adjusted for risk and interest rate). The value of the alternative use of a unit of water in a given hour is defined as the *water value*. Consequently, if reservoirs are sufficiently large there will be relatively small price variations in a hydro dominated electricity system.

It is important to note that the water value may vary between generation plants and firms, i.e. the characteristic of a production facility determines a firm specific water value. Typically, a generator with little ability to regulate its production, for example, will have a lower water value than a generator with high flexibility. Flexibility depends on the size of the reservoir (ability to wait longer for prices to increase) and the effect capacity (ability to produce more during hours with high prices). Moreover, the water value depends on own reservoir level, the competitors' reservoir levels, snow levels in the mountains, transmission capacity and fuel prices, in other words expectations about future market prices, and, consequently, also prospects of market power abuse. Therefore, the firm specific water value depends on incomplete information, which may also be asymmetric.

Although information on average reservoir fillings are published on Nord Pool's web pages and weather reports are easily accessible, obtaining the basically private information on snow reservoirs in the mountains can be crucial for predicting the future spot prices in the Nordic hydro system. It is reasonable to assume that large producers have an advantage in collecting accurate snow reservoir data or to interpret the information optimally, implying that there is asymmetric information regarding important market information. More specifically, large producers often operate power plants located in various geographical regions, and thus have access to more complete information. Further, water values are calculated by large and complex models which are costly to maintain and even to run. If the large producers do not have incentives to behave strategically, their market bidding will reveal information to the other market participants. If prices and volumes change, it is reasonable to assume that it is based on some relevant market information. It can hence be efficient for small producers to have adaptive expectations to some degree.

3. Risk management

Electricity producers are exposed to different types of risks; the most common are price risk and volume risk. A number of factors influence future prices, both with reference to the supply side and the demand side. Uncertainty on the demand side is mostly associated with temperature and seasonal variations, in addition to variations in production in the Nordic electricity industry which accounts for about one third of total consumption. On the supply side, uncertainty is linked to availability of nuclear power and technical outages. Particular to hydro power is the volume risk associated with variations in seasonal inflow to reservoirs, which depends on precipitation and snow melt. In the utmost consequence a supply deficit may be covered by purchases in the physical market, and the volume risk is then coupled to the price uncertainty of physical delivery. There is no volume risk in the financial market. There are different opportunities for risk handling in electricity markets. Most common are physical and financial contracts that increase the predictability of income/expenses for electricity suppliers/buyers during the contract period. Financial and physical contracts have exactly the same price hedging characteristics. If all participants in the electricity market are risk-neutral, the price on a financial contract will be equal to the expected future spot price.[2] More commonly, prices on financial contracts are assumed to include a positive or negative risk premium.

There are four different categories of financial instruments at Nord Pool: forward contracts, futures contracts, options and contracts for difference, which hedge against the exchange area price risk. Forward contracts are divided into months, quarters and years, six years ahead. Futures contracts are divided into days and weeks, six weeks ahead. Settlement of futures contracts involves both a daily mark-to-market settlement, that covers gains or losses from day-to-day changes in the market price of each contract, and a final spot reference cash settlement which begins at maturity and covers the difference between the final closing price of the futures contract and the system price in the delivery period. Market prices of futures contracts are also more closely linked to the spot price than market prices of forward contracts, as physical conditions play a greater role in the short term. The total financial

[2] Anderson and Hu (2007) present a model in which there is a contract premium even when electricity market participants are risk neutral.

volume traded at Nord Pools's financial market in 2005 was 786 TWh. For comparison the annual generating capacity in the Nordic Exchange Area is approximately 370 TWh. The behavior of electricity prices at Nord Pool is studied in Lucia and Schwartz (2002) and Koekebakker and Ollmar (2005). The latter find that only 75 percent of the price variation can be explained using a two-factor model, compared to 95 percent in most other markets. Moreover, correlation between short- and long term forward prices is lower than in other markets.

4. Futures market manipulation – the model

Assume that we have one large risk neutral hydro power producer owning a reservoir and that there is a fringe of (small) risk adverse producers. By assumption, the large producer has no motive for hedge selling. Further, each producer has private information about its reservoir content. The large producer is assumed to have a dominant position so that strategic hydro scheduling is possible – at least in periods. In other words, the large producer is able to deliberately change the spot price, whereas the small producers constitute a so-called price-taking fringe with adaptive expectations about future spot prices. More specifically, we have argued that since small producers lack information about crucial market data such as snow reservoirs, they will assume that changes in the spot price reveal private information that the large (dominant) producer possesses. Then naturally, they will adjust their expectations accordingly.

To keep the analysis simple we assume there are two identical periods, i.e. the dominant producer's residual demand elasticity is equal during these two periods. The large hydro power producer can generate a total volume $2X$, and there is no restriction on the production pattern between the periods. Let $P_S(X,\overline{Z}_S)$ denote the spot price in one particular period (day-ahead price), implying that the spot price is dependent on the volume produced by the large hydro power producer in that period, and a vector $\overline{Z}_S$ of other parameters influencing the spot price, including possibly the aggregate fringe supply. For easy reading we ignore this vector in the following. Further, the spot price is assumed to decrease with increased production, so that $\partial P_S / \partial X < 0$. Since the two production periods are identical, we do not need to separate between the spot price in each of the two periods. We also ignore discounting, the possibility of spilling water and the short term marginal cost of hydro power production.

4.1 The spot market

Under the above simplifying assumptions the dominant producer's maximum spot market profit, Π_S^*, is defined by

$$\Pi_S^* = P_S(X)X + P_S(X)X = 2P_S(X)X \tag{1}$$

Lemma 1 *In a spot market with two periods and a dominant hydro power producer with equal residual demand elasticity in each period, the profit maximizing allocation of total production volume 2X is to have an equal amount of water produced in each period with corresponding maximum profit given by equation (1).*

Proof: Consider the opposite alternative where a production volume Δ is shifted from the first period to the second. This yield alternative spot market profit

$$\hat{\Pi}_S = \left[P_S(X) - \frac{\partial P_S}{\partial X}\Delta\right](X - \Delta) + \left[P_S(X) + \frac{\partial P_S}{\partial X}\Delta\right](X + \Delta) = 2P_S(X)X + 2\frac{\partial P_S}{\partial X}\Delta^2,$$

where the terms in brackets indicate the change in prices due to, respectively, a decrease and an increase in production levels. Since $\frac{\partial P_S}{\partial X} < 0$, we can easily see that

$$2P_S(X)X + 2\frac{\partial P_S}{\partial X}\Delta^2 \leq 2P_S(X)X \text{, which implies that } \hat{\Pi}_S \leq \Pi_S^* . \ \square$$

Considering only spot market income, distributing hydrological resources unevenly between periods is not profitable under the above assumptions.

4.2 Introducing a financial market

We now include a financial market with a futures contract assumed to be of a relatively limited time span, as physical market conditions have a larger impact on contract prices in the short term, as noted in Section 3. Let P_f denote the market price of the financial contract and *V* the volume held by the dominant hydro power producer. The price of the futures contract is assumed to be influenced by the prevailing spot market price P_S, implying that there is some presence of adaptive expectations, the contract volume *V* and a vector of parameters $\overline{Z}_f$ so that $P_f = P_f(P_S, V, \overline{Z}_f)$. To ease reading, we omit $\overline{Z}_f$ in the following. Further, we define *V* to be positive when the dominant hydro power producer is selling futures contracts (hold a short position). Then we have

$$\frac{\partial P_f}{\partial P_S} > 0 \text{ and } \frac{\partial P_f}{\partial V} \leq 0 .$$

It is assumed that other market participants always are willing to take the opposite position.

4.2.1 The trading period (mark-to-market settlement)

The large hydro power producer can now choose to exploit its dominant position by manipulating the spot market price to attempt to gain excess profit in the financial market during the trading period of the financial contract by the following behavior: First, hold back an amount Δ of hydro power resources in the first period. As we have $\partial P_S / \partial X < 0$ and $\partial P_f / \partial P_S > 0$, this behavior increases the spot price and subsequently the price of the futures contract in the first period. Then, sell a volume *V* of the futures contract. In the next period, the producer must supply the rest of the water in the spot market, including the previously withheld volume Δ, which decreases both the spot and the futures prices. Then, buy the same volume *V* of the futures contract. The profit from this joint spot and financial market operation, Π_{SF}, can be expressed

$$\begin{aligned}\Pi_{SF} &= \left[P_S(X) - \frac{\partial P_S}{\partial X}\Delta\right](X-\Delta) + \left[P_f(P_S(X)) - \frac{\partial P_f}{\partial P_S}\frac{\partial P_S}{\partial X}\Delta + \frac{\partial P_f}{\partial V}V\right]V \\ &+ \left[P_S(X) + \frac{\partial P_S}{\partial X}\Delta\right](X+\Delta) - \left[P_f(P_S(X)) + \frac{\partial P_f}{\partial P_S}\frac{\partial P_S}{\partial X}\Delta - \frac{\partial P_f}{\partial V}V\right]V \\ &= 2P_S(X)X + 2\frac{\partial P_S}{\partial X}\Delta^2 - 2\frac{\partial P_f}{\partial P_S}\frac{\partial P_S}{\partial X}\Delta V + 2\frac{\partial P_f}{\partial V}V^2\end{aligned} \qquad (2)$$

where $\frac{\partial P_f}{\partial P_S}\frac{\partial P_S}{\partial X}$ captures the *interplay effect* which reflects the core assumption of our main result.

To study if such behavior yield any extra profit compared to single market profit maximizing behavior stated in Lemma 1, we define by $\Delta_{\Pi_1} = \Pi_{SF} - \Pi_S^*$ the extra profit that the dominant hydro power producer achieves when exploiting the potential interplay between the physical and the financial market. Inserting equation (2) for Π_{SF} and equation (1) for Π_S^* and introducing a parameter $\theta = \frac{V}{\Delta}$, we can write

$$\Delta_{\Pi_1} = 2\Delta^2 \left(\frac{\partial P_f}{\partial V}\theta^2 - \frac{\partial P_f}{\partial P_S}\frac{\partial P_S}{\partial X}\theta + \frac{\partial P_S}{\partial X} \right). \tag{3}$$

Now, recall that we have assumed that $\frac{\partial P_f}{\partial V} \leq 0$. Therefore, we need to pursue the implications of equation (3) for two cases:

Case 1. Fully liquid financial market

If the price of the futures contract is totally independent of the volumes traded, i.e.

$$\frac{\partial P_f}{\partial V} = 0,$$

it is easy to see from equation (3) that the profits can be increased infinitely, simply by increasing the volumes traded in this contract. This situation is unrealistic and of no interest for further analyzes.

Case 2. Price effect in the financial market

If, on the other hand, the volumes traded have some effect on the contract price, i.e.

$$\frac{\partial P_f}{\partial V} < 0,$$

we can see from equation (3) that the extra profit gained when exploiting the interplay between the physical and financial market has the functional form of a parabola with a maximum value, since

$$\frac{\partial^2 \Delta_{\Pi_1}}{\partial \theta^2} = 2\frac{\partial P_f}{\partial V} < 0.$$

To find an expression for the maximum extra profit we first study the optimal relationship between the deviation from least-cost hydro power production Δ and the financial contact volume *V* by differentiating equation (3) by θ

$$\frac{\partial \Delta_{\Pi 1}(\theta^*)}{\partial \theta} = \left(2\frac{\partial P_f}{\partial V}\theta^* - \frac{\partial P_f}{\partial P_S}\frac{\partial P_S}{\partial X} \right) 2\Delta^2 = 0$$

and solve for θ^*, which yields

$$\theta^* = \frac{\frac{\partial P_f}{\partial P_S}\frac{\partial P_S}{\partial X}}{2\frac{\partial P_f}{\partial V}} \tag{4}$$

We can see that both the nominator and the denominator are negative, and hence that θ^* is positive. This simply implies that the signs of *V* and Δ should be equal. That is, when hydro resources are withheld, i.e. Δ is positive, selling financial contacts is the optimal action, i.e. holding a positive *V*. Admittedly, the opposite would be surprising: buying contracts when prices are high due to withheld hydrological resources, and sold when prices are low due to increased hydro power production.

Now, by inserting the optimal ratio θ^* of equation (4) into equation (3) and rearranging, it is possible to derive an expression for the maximum extra profit that the dominant hydro power producer can achieve by exploiting the interplay between the spot and financial market:

$$\Delta^*_{\Pi_1} = 2\Delta^2 \left[\frac{\partial P_S}{\partial X} - \frac{\left(\frac{\partial P_f}{\partial P_S}\frac{\partial P_S}{\partial X} \right)^2}{4\frac{\partial P_f}{\partial V}} \right] \tag{5}$$

We can now state our main result:

Proposition 1 *Suppose there is an electricity market which consists of a spot market and a financial market with two periods of trading, a fringe of price-taking producers, a dominant hydro power producer with equal residual demand elasticity in each period and an interplay effect* $(\partial P_f / \partial P_S)/(\partial P_S / \partial X) < 0$. *Then the dominant producer has an incentive to exploit its position in the spot market to manipulate futures prices to achieve a maximum positive extra profit given by equation (5).*

Proof: See the Appendix.

To characterize the dominant producer's optimal solution we can rearrange equation (5) for the case when $\Delta^*_{\Pi_1} > 0$, which yields

$$4\frac{\dfrac{\partial P_f}{\partial V}}{\dfrac{\partial P_f}{\partial P_S}} > \frac{\partial P_f}{\partial P_S}\frac{\partial P_S}{\partial X} \ , \tag{6}$$

where both sides of the inequality sign are negative and the term to the right of the inequality sign is the interplay effect.

Corollary 1 *From inequality (6) we see that exploiting the interplay between the physical and financial market is facilitated*

(i) the more liquid the financial market is, i.e. the smaller $\left|\partial P_f / \partial V\right|$

(ii) the more adaptive expectations are, i.e. the larger $\left|\partial P_f / \partial P_S\right|$ *and*

(iii) the more market power the large producer has, i.e. the larger $\left|\partial P_S / \partial P_X\right|$. □

4.2.2 Introducing the delivery period (cash settlement)

To complete our study of financial market manipulations, we include here the possibility that the second period is the delivery period of the financial contract. In this period the contract price is fixed, whereas gains or losses are calculated using the prevailing spot price, spot prices therefore influence the value of producers' financial portfolios.[3] We assume that producers are allowed to hold both short and long positions in the financial market. Long positions give the producers incentives to increase spot prices during the delivering period, while short positions give incentives to lower the spot price. The latter strategy may be particularly attractive to large hydro power producers, since there is a potential to gain profits in the financial market in periods where excess water from previous withholding is produced. Looking strictly at strategic possibilities in the spot market, one will fail to see the possible profits to producers from low spot prices.

As in the previous subsection, we assume here two identical periods with respect to the dominant producer's residual demand elasticity, but now the second period represents the financial contract's delivery period. In order to model a possible exploitation by the dominant producer in this setting, we assume the large hydro power producer holds back an amount Δ of hydro power resources in the first period, which, as $\partial P_S / \partial X < 0$ and $\partial P_f / \partial P_S > 0$, increases the spot price and subsequently the price of the futures contract in this period. Then the producer sells a volume *V* of the futures contract with delivery in the second period. In the second period the producer must supply the rest of the water in the spot market, including the previously withheld volume Δ, which decreases the spot price, but receives the difference between the contract price and the second period spot price for the financial volume *V*.

[3] In the Nordic Exchange Area the system price, which is the unconstrained equilibrium price, usually serves as the reference price during the delivery period of financial contracts at Nord Pool.

Ignoring interest rates and short term marginal costs, the profit from the joint spot and two-stage financial market operation, Π_{SF}^{D}, can be expressed:

$$\begin{aligned}\Pi_{SF}^{D} &= \left[P_S(X) - \frac{\partial P_S}{\partial X}\Delta\right](X-\Delta) + \left[P_S(X) + \frac{\partial P_S}{\partial X}\Delta\right](X+\Delta) \\ &\quad + \left[P_f(P_S(X)) - \frac{\partial P_f}{\partial P_S}\frac{\partial P_S}{\partial X}\Delta + \frac{\partial P_f}{\partial V}V - \left(P_S(X) + \frac{\partial P_S}{\partial X}\Delta\right)\right]V \qquad (7) \\ &= 2P_S(X)X + 2\frac{\partial P_S}{\partial X}\Delta^2 + \left(P_f(P_S(X)) - P_S(X)\right)V - \frac{\partial P_f}{\partial P_S}\frac{\partial P_S}{\partial X}\Delta V + \frac{\partial P_f}{\partial V}V^2 - \frac{\partial P_S}{\partial X}\Delta V\end{aligned}$$

To study if such behavior yield any extra profit compared to single market profit maximizing behavior stated in Lemma 1, we define by $\Delta_{\Pi_2} = \Pi_{SF}^{D} - \Pi_S^{*}$ the extra profit that the dominant hydro power producer can achieve when exploiting the potential interplay between the physical and financial market during the trading period with a subsequent delivery period. Inserting equation (7) for Π_{SF}^{D} and equation (1) for Π_S^{*}, we get

$$\Delta_{\Pi 2} = 2\frac{\partial P_S}{\partial X}\Delta^2 + \left(P_f(P_S(X)) - P_S(X)\right)V - \frac{\partial P_f}{\partial P_S}\frac{\partial P_S}{\partial X}\Delta V + \frac{\partial P_f}{\partial V}V^2 - \frac{\partial P_S}{\partial X}\Delta V \,.$$

To simplify this expression, consider the following standard realization of the futures contract price:

$$P_f = E(P_S^T) + RP \,,$$

where $E\left(P_S^T\right)$ is the expected value of the spot price in the second period and *RP* is the risk premium. Assume now that we have a probability function that is 'symmetric' around $P_S(X)$ in the relevant area for Δ, in the sense that

$$P_S(X) - P_S(X+\Delta) = P_S(X-\Delta) - P_S(X) \,.$$

Then if p is the probability that the price will be $P_S^T(X-\Delta)$ and $(1-p)$ is the probability that the price will be $P_S^T(X+\Delta)$ we have $E(P_S^T(X)) = P_S(X)$. Assume furthermore that $RP = 0$. Then we can write $P_f(P_S(X)) = P_S(X)$, and by applying the parameter $\theta = \frac{V}{\Delta}$ and rearranging, we have the following expression for the extra profit stemming from the joint spot and two-stage financial market operation:

$$\Delta_{\Pi 2} = \Delta^2 \left[\frac{\partial P_f}{\partial V}\theta^2 - \left(\frac{\partial P_f}{\partial P_S}\frac{\partial P_S}{\partial X} + \frac{\partial P_S}{\partial X} \right)\theta + 2\frac{\partial P_S}{\partial X} \right]. \tag{8}$$

Lemma 2 *Suppose* $\partial P_f / \partial P_S < 1$ *and* $\theta > 0$*, then the extra profit to the dominant hydro power producer is larger when exploiting the interplay between the spot and financial market that includes the delivery period than without, that is*

$$\Delta_{\Pi_2} > \Delta_{\Pi_1}.$$

Proof: For $\Delta_{\Pi_2} > \Delta_{\Pi_1}$ to be true, it is necessary to show that $\Delta_{\Pi_2} = \Delta_{\Pi_1} + \alpha$, for $\alpha > 0$. Inserting equation (8) for Δ_{Π_2} and equation (3) for Δ_{Π_1}, and rearranging, we get

$$\alpha = \Delta^2 \left[\left(\frac{\partial P_f}{\partial P_S} - 1 \right)\frac{\partial P_S}{\partial X}\theta - \frac{\partial P_f}{\partial V}\theta^2 \right].$$

It is easy now to see that when $\partial P_f / \partial P_S < 1$ and $\theta > 0$, α is positive, i.e. the extra profit is always larger when both the trading period and the delivery period is included in the dominant producer's manipulation strategy. □

We shall now study another implication of the extra profit defined in equation (8). As we can see, it has the functional form of a parabola with a maximum. Differentiating by θ and rearranging, we get the optimal volume ratio θ_D^*:

$$\theta_D^* = \frac{\left(\frac{\partial P_f}{\partial P_S}\frac{\partial P_S}{\partial X} + \frac{\partial P_S}{\partial X}\right)}{2\frac{\partial P_f}{\partial V}}, \tag{9}$$

where we use the subscript D to distinguish it from the optimal value of equation (4) in the previous subsection that only includes the trading period of the financial contract. By inserting θ_D^* from equation (9) into equation (8) and rearranging, we find an expression for the maximum extra profit that the dominant hydro power producer can achieve by exploiting the interplay between the physical and the financial market that includes the delivery period:

$$\Delta_{\Pi_2}^* = \Delta^2 \left[2\frac{\partial P_S}{\partial X} - \frac{\left(\frac{\partial P_f}{\partial P_S}\frac{\partial P_S}{\partial X} + \frac{\partial P_S}{\partial X}\right)^2}{4\frac{\partial P_f}{\partial V}} \right] \tag{10}$$

Proposition 2 *Suppose there is an electricity market which consists of a spot market and a financial market with one trading period and a delivery period, a fringe of price-taking producers, a dominant hydro power producer with residual demand elasticity in each period and an interplay effect* $(\partial P_f / \partial P_S)/(\partial P_S / \partial X) < 0$. *Then the dominant producer has an incentive to manipulate the price of the futures contract in the first period to achieve a maximum positive extra profit given by equation (10).*

Proof: From Proposition 1 we know that there is an interval of θ's where $\Delta_{\Pi 1}(\theta) > 0$ and from Lemma 2 we have $\Delta_{\Pi_2} > \Delta_{\Pi_1}$, then the maximum value $\Delta_{\Pi_2}^* > 0$, which is both necessary and sufficient for establishing an incentive to manipulate the price of the futures contract. □

To characterize the dominant producer's optimal solution when the delivery period of the financial contract is included in the manipulation strategy, we rearrange equation (10) for the case when $\Delta^*_{\Pi_1} > 0$, that is, when

$$2\frac{\partial P_S}{\partial X} > \frac{\left(\frac{\partial P_f}{\partial P_S}\frac{\partial P_S}{\partial X}+\frac{\partial P_S}{\partial X}\right)^2}{4\frac{\partial P_f}{\partial V}} .$$

Then, with a bit of manipulations, we arrive at

$$\frac{4\frac{\partial P_f}{\partial V}}{\left(\frac{1}{2}\frac{\partial P_f}{\partial P_S}+\frac{1}{2}\right)} - \frac{\partial P_S}{\partial X} > \frac{\partial P_f}{\partial P_S}\frac{\partial P_S}{\partial X}. \tag{11}$$

If we compare inequality (11) with inequality (6),

$$4\left(\frac{\partial P_f}{\partial V}\bigg/\frac{\partial P_f}{\partial P_S}\right) > \frac{\partial P_f}{\partial P_S}\frac{\partial P_S}{\partial X} ,$$

we see that both have the interplay effect to the right of the inequality sign. Further, if we assume that $\frac{\partial P_f}{\partial P_S} \le 1$, which is quite reasonable, we see that the left side of inequality (11) is larger, which implies that it is easier to fulfill inequality (11) than inequality (6).

Corollary 2 *If it is possible for the dominant hydro power producer to benefit from manipulating the futures price via the spot market during the trading period, it is always possible to benefit from futures market manipulations during the delivery period.* □

5. Concluding Remarks

Market power in power markets is typically exercised by holding back capacity and thereby inducing a higher market price. This has been thought to be more costly for a hydro power producer than for thermal producers since the withheld water must be spilled or produced later. Depending on the hydrological situation, reservoir fillings and the season, the withheld water may be produced the same night, during the following week or in later periods. Hence, the producer runs the risk that the market price will fall when the extra water is produced. Thus, to profit from such a strategy the extra profit earned in the period with a higher price must normally be larger than the loss incurred as the price potentially falls during hours with increased production (or the water is spilled). In other words, the producer must take advantage of the fact that the price elasticity and/or the total supply level differ in different load periods. For example, the price may be increased in high load when capacity utilization is generally high and most competitors are prevented from increasing their production in response to higher prices. The extra water may then be produced in a low load period when base to medium load thermal production is easily reduced if prices fall only slightly. For a hydro producer, the possibility to gain from changing the production pattern hence typically relies on the asymmetries between different time segments.

In this paper, we find that a large hydro power producer may be able to benefit from market power even without asymmetries between the time segments. This possibility is introduced by the access to a financial market where the prices of future or forward contracts are influenced by the spot market price, and the possibility of acquiring contracts for future purchase. Our results are, however, crucially dependent on the assumption that the dominant hydro producer has private information about one or more of the uncertain factors that form other players' expectations on future spot prices.

It is evident that the sort of manipulation we describe will be easier to perform in certain periods of the year and in certain years. For example, snow reservoirs are a more important price driver in the spring and in years when the reservoir filling is low during winter.

Also, a more realistic market approach would be to model a market with several dominant producers, i.e. with Cournot strategies. This is, left for a subsequent paper. However, back-of-the-envelope calculations suggest that a static Cournot game would weaken the incentives for dominant producers to exercise market power, whereas introducing a dynamic setting would probably facilitate tacit collusion with results close to those in the present paper.

Anyhow, the main policy recommendation to be gleaned from our analysis is to be reluctant with establishing financial electricity markets where producers are allowed to acquire long positions, particularly in electricity markets characterized by large hydro power resources. If long positions are already introduced, as in the Nordic electricity market, authorities are advised to reduce the degree of private information in the market to a minimum. This can be done by improving the public availability of relevant market data. But probably more important, more symmetric information can be achieved by lowering market concentration, both vertically and horizontally. If the relevant information is distributed among several producers, the possibility of manipulating price expectations are lower and the price signals will be more correct. Also, since detecting and proving anti-competitive behavior in spot markets are known to be complicated, the results in the present paper suggest that authorities take up an even more precautionary attitude towards threshold values when considering files for mergers in the electricity industry.

Finally, market concentration is a result of the investment rate of the industry and supply adequacy is crucial to competitiveness in the long run. Therefore, deregulated electricity markets must provide sufficient incentives for investments in new production capacity. A liquid financial electricity market is an important institution in this respect, and the mere rumor of market power abuse can reduce the attractiveness of trading in a financial market. Generally speaking, only dominant producers benefit from illiquid financial markets.

6. Appendix

6.1 Proof of Proposition 1

The idea of this poof is to show that the dominant hydro power producer has an incentive to exploit the assumed interplay between the spot and the financial market. As noted previously, the functional form of the extra profit $\Delta_{\Pi 1}(\theta)$, defined in equation (3), is a parabola with a maximum. Therefore, our task is to find an interval of values for θ which yields a positive extra profit. In other words, we must show that the values of θ where $\Delta_{\Pi 1}(\theta) = 0$ are both positive.

Applying the Quadratic Formula to equation (3), it is straight forward to show that the extra profit is zero at:

$$\theta = \frac{\frac{\partial P_f}{\partial P_S}\frac{\partial P_S}{\partial X}}{2\frac{\partial P_f}{\partial V}} \pm \frac{\sqrt{\left(\frac{\partial P_f}{\partial P_S}\frac{\partial P_S}{\partial X}\right)^2 - 4\frac{\partial P_f}{\partial V}\frac{\partial P_S}{\partial X}}}{2\frac{\partial P_f}{\partial V}}$$

Since both the nominator and the denominator of the first term are negative, this term is positive. Then, for both values of θ to be positive, the following inequality must hold:

$$\left|\frac{\partial P_f}{\partial P_S}\frac{\partial P_S}{\partial X}\right| > \sqrt{\left(\frac{\partial P_f}{\partial P_S}\frac{\partial P_S}{\partial X}\right)^2 - 4\frac{\partial P_f}{\partial V}\frac{\partial P_S}{\partial X}}$$

Rearranging we get

$$\left(\frac{\partial P_f}{\partial P_S}\frac{\partial P_S}{\partial X}\right)^2 > \left(\frac{\partial P_f}{\partial P_S}\frac{\partial P_S}{\partial X}\right)^2 - 4\frac{\partial P_f}{\partial V}\frac{\partial P_S}{\partial X}$$

and, finally,

$$0 > -4\frac{\partial P_f}{\partial V}\frac{\partial P_S}{\partial X},$$

which is always true since both $\frac{\partial P_f}{\partial V} < 0$ and $\frac{\partial P_S}{\partial X} < 0$. □

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