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Electricity Market Design and the Impact of Supply and Demand Shocks: Experiences from the Nord Pool System

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ABSTRACT

During the 1990's the electricity markets in Norway, Sweden, Finland and Denmark were deregulated and integrated into a single Nordic market for electricity. A common power exchange, Nord Pool, was established and an essentially common design of the wholesale electricity market, "the Nord Pool system", was implemented. Important market design features are full market opening and point-of-connection transmission tariffs. The annual consumption of electricity in the area is close to 400 TWh per annum, which is comparable to the largest national electricity markets in Europe. Hydropower accounts for around of total generation, while the corresponding figure for nuclear power is .

The purpose of this paper is to explore to what extent recently experienced supply and demand shocks have revealed serious design deficiencies in the Nord Pool system. The major supply shock was an unusually low level of precipitation in the autumn of 2002, leading to very low levels of hydropower generation in the winter 2003. The major demand shock came in the winter of 2001, when peak loads reached unprecedented levels. The main conclusions of the analysis are that the new market institutions handled the large variations in hydropower supply quite efficiently, while the provision of peak capacity is an emerging problem unless new market institutions are established.

1. INTRODUCTION

1.1 Purpose and Scope

Like in most European countries the national electricity markets in the Nordic countries (Denmark, Finland, Norway and Sweden) used to be protected from foreign competition, tightly regulated and dominated by vertically integrated publicly owned[1] power companies. In the 1990 s, however, far-reaching reforms were implemented. The aim of the reforms was to create an integrated Nordic electricity market and a more efficient electricity supply industry. In addition the Nordic countries had to comply with the EU electricity market directive that was worked out during the 1990:s and finally implemented in 1999.

By the turn of the century the four national markets had been transformed into a (close to) fully integrated electricity market with competition in generation and supply[2]. A common power

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[1] In Denmark, however, the power companies have been and still are owned primarily by municipalities and consumer cooperatives.

[2] The electricity supply industry is a network industry in which generation is the "upstream" activity. The network infrastructure consists of transmission grids and local distribution networks, while "supply" (or retailing), i.e. metering and billing of final consumers, is the "downstream" activity.

exchange, Nord Pool, had been created and an essentially common design of wholesale electricity market had been implemented. In addition to the "physical" markets for spot and balancing power, there are markets for standardized financial instruments (futures, forwards and options) where market participants can hedge spot market price risks. Important design features are full market opening and point-of-connection transmission tariffs. Moreover the cross-border tariffs and other barriers to electricity trade between the Nordic countries that existed in the past have been eliminated.

Electricity market reform in some sense is an experiment. As generation and load have to continuously balance, there has to be a system operator with the mandate of controlling the system in real time. Consequently the scope for ordinary market forces is somewhat limited. Thus "electricity market reform" amounts to opening up for competition before "gate closure", i.e. before the point in time when the system operator takes over. In terms of old time terminology this means that regular market forces determine "merit order dispatch", while the system operator remains in charge of the fine-tuning in real time.

There are two basic questions in relation to electricity market reform. The first is whether supply secu-rity can be maintained when part of the operation of the electricity supply system is left to market forces. The second is whether competition on day-ahead and bilateral markets that are open before "gate closure" will produce efficiency gains, in the short term and in the long term, that are sufficient to cover the costs[3] of associated with a reformed electricity market. The Californian electricity crisis in 2001 (see [1] and [2]) clearly showed that the answer to these questions to a large extent depend on the design of the relevant market institutions and regulations.

The purpose of this paper is to tentatively evaluate the electricity market reforms that were implemented during the 1990's. In particular the aim is to explore to what extent recently experienced supply and demand shocks have revealed serious design deficiencies in the Nord Pool system. The major supply shock was an unusually low level of precipitation in the autumn of 2002, leading to very low levels of hydropower generation and soaring spot market prices in the winter 2003. The major demand shock came in the winter of 2001, when peak loads reached unprecedented levels. To begin with, however, some background information about the Nordic electricity market is provided.

1.2 Consumption and Production of Electricity in the Nordic Countries

The Nordic countries, i.e. Denmark, Finland, Norway and Sweden, are small in terms of population but the level of per capita electricity consumption is quite high, particularly in Norway and Sweden. Thus the total consumption of electricity is quite high. To mention some figures the total consumption of electricity in the Nordic countries was 393 TWh in 2001. This is less than the corresponding figures for Germany (550 TWh) and France (450 TWh), roughly equal to the electricity consumption in UK (360 TWh) and considerably more than the consumption of electricity in Italy (300 TWh) and Spain (200 TWh)[4]. In other words the Nordic electricity market is one of the major electricity markets in Europe.

From a technological and fuel point of view the power generation system is fairly mixed in the Nordic area as a whole, although hydropower accounts for around ½ and nuclear power for around ¼ of total generation. At the national level, however, the systems differ significantly. Thus in Norway essentially all power is generated by hydropower, while the share of hydropower generation is around 45 percent in Sweden, around 20 percent in Finland and zero in Denmark. The corresponding figures for nuclear power are 45 percent in Sweden, 33 percent in Finland and zero in Denmark and Norway.

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[3] These include the costs of operating the new market institutions, the marketing costs of the competing firms and the loss of the economies of vertical integration between transmission and generation.

[4] The numbers refer to the situation in 1999.

Power generation based on fossil fuels is quite significant in Denmark and Finland, but close to zero in Norway and Sweden. As hydropower production differs between individual years, the gross trade in electricity is sometimes quite high but goes in different directions in different years. Thus Norway is a net exporter in "wet" years, and a net importer in "dry" years.

1.3 Market Structure

The functioning and efficiency of an electricity market clearly depends on the regulatory framework and the design of market institutions, but it also depends on the structure of the industry. Table 1 depicts the production of electricity by major power companies in 2002. It should be mentioned that Fortum owns generation assets both in Finland and Sweden. Thus Fortum is not only the largest generator in Finland, but also the third largest generator in Sweden.

As can be seen in the table Vattenfall has a dominating position on the national market in Sweden, while Fortum and Statkraft are major electricity market players Finland, and Norway, respectively. This suggests that market power could be a serious problem, particularly as entry barriers in the form of high investment costs and environmental and other regulations are significant. However, if the Nordic electricity market is considered as an integrated market the situation is quite different. Thus, in terms of standard concentration measures such as C4 and HHI[5] the degree of concentration on the Nordic market as a whole is rather low.

Table 1 Production by major power companies 2002

Company	Generation (TWh)	Share of national generation (%)	Share of Nordic generation (%)
Vattenfall (Sweden)	70.3	49	18
Fortum (Finland)	46.5		12
- in Finland	19.0	26	
Statkraft (Norway)	40.4	31	11
Sydkraft (Sweden)	28.5	20	7
Pohjolan Voima (Finland)	16.6	23	4
Total	*202.3*		*53*

Source: Elmarknaden 2002 (The electricity market 2002). National Swedish Energy Administration.

2. WHOLESALE AND RETAIL MARKET PERFORMANCE

2.1 Market Integration

One of the aims of electricity market reforms in the Nordic countries was to create an efficient integrated Nordic market for electricity. From an institutional point of view this objective was fulfilled when the common power exchange was created, and the border tariffs between the countries were removed. However, from an economic point of view a market is well integrated only if there is a single price of the product that is traded on the market in question. Moreover, the impact of supply and demand shocks to a large extent depend on whether the Nordic electricity market in effect is a single well-integrated market or four national markets.

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[5] C4 is the sum of the market shares of the four biggest firms, while the Herfindahl-Hirschman index (HHI) is a weighted average of the market shares of all firms on the market, using the market share of each individual firm as weight.

The extent of cross-border trade that is feasible depends on the relevant inter-connector capacities. Whenever the inter-connector capacity between two areas becomes binding, there is one market-clearing price at each side of the border. Thus, at Elspot, the day-ahead market of Nord Pool, there is a distinction between the *system* price and the *area* prices. For each hour a market-clearing price is computed on the basis of the bids made by sellers and buyers. The system price is determined on the assumption that inter-connector capacities are sufficient. If one or several inter-connectors become congested, however, equilibrium area prices are determined using information about the location of the bidding units.

Inter-connector capacities that are sufficient for all patterns of trade would clearly be a waste of resources. On the other hand the market would not be reasonably well integrated if inter-connector capacities were binding and area prices different most of the time. Table 2 summarizes the development of Elspot system and area prices between 1996 and 2002, as well as the ratio between the Norwegian and the Swedish area prices. As Denmark did not enter the common Nordic market until 2000 data for that country is left out. It should be mentioned that Norway is divided into several price areas, but for the purposes of this discussion it is sufficient to incorporate only the Oslo price area in the table. Finally it should be noted that Nord Pool prices are quoted in NOK (1 € is approximately 8 NOK).

As can be seen in the table the system and area prices do differ, but in several years the differences are quite small. This suggests that inter-connector capacity was scarce only during a relatively small number of hours. The biggest deviation appeared in 2000 when the net export from Norway, due to unusually high precipitation, was exceptionally high (19 TWh). As a result the Norway-Sweden inter-connector was congested a significant part of the time and the Norwegian area price was well below the system price as well as the area prices in Sweden and Finland. A similar situation prevailed in 2002 when the net export from Norway, for slightly different reasons, also was high.

Table 2 Elspot system and area prices 1996-2002. Annual averages. NOK/MWh

	1996	1997	1998	1999	2000	2001	2002
System	253.6	135.0	116.4	112.1	103.4	186.5	201.0
Oslo (N)	256.7	137.5	115.7	109.2	97.7	186.0	198.5
Stockholm (S)	250.6	135.0	114.3	113.1	115.5	184.1	206.3
Helsinki (F)	-	-	116.3	113.7	120.7	184.0	203.4
"Oslo":"Stockholm"	1.024	1.019	1.012	0.966	0.846	1.010	0.962

Source: Nord Pool

In the other years precipitation was close to the long-term average (for some reason called "normal"), and the differences between system and area prices were quite small. The annual averages may of course hide significant variations in different directions, but a closer inspection of hourly price data conveys the same general picture as Table 2[6]. In other words, under "normal" precipitation conditions the Nordic wholesale electricity market is a reasonably well-integrated "single" market.

It is interesting to relate this conclusion to the physical realities of the Nordic power system. The inter-connector capacity between Norway and Sweden is around 4 000 MW, which corresponds to around 15 percent of peak demand in Sweden and around 18 percent of peak demand in Norway. Between Finland and Sweden, Sweden and Denmark, and Norway and Denmark the inter-connector capacities are in the range 1 000 – 2 500 MW. These numbers suggest that inter-connector capacities in the range 15-20 percent of peak demand are sufficient to allow market integration as long as the variations in hydropower supply are moderate.

[6] This is hardly surprising. The availability of hydropower resources in Norway is the main determinant of the direction of cross-border trade flows, and rarely happens that Norway is a big net exporter one part of the year and a big net importer another part of the same year.

2.2 Market Power

There is obviously a close connection between the degree of market integration and the possibilities to exercise market power. When inter-connector capacities are sufficient to equalize prices across the national borders, the major power companies can only serve a relatively small share of the "relevant market" (see Table 1). When inter-connector capacities are binding, however, the "relevant" markets are smaller and the possibilities for the biggest producers to exercise market power are higher (see [3]).

This connection between the geographical extent of the market and the degree of competition was one of the reasons for the early (1996) integration of the Norwegian and Swedish electricity markets. As Vattenfall produced more than ½ of the electricity consumed in Sweden there was a widespread concern that the "new" electricity market would lead to monopolistic rather than competitive pricing. The strategy to solve this problem was to integrate the Swedish and Norwegian electricity markets (see [4]) and thus dilute the market power of Vattenfall.

So far the adopted strategy seems to have been successful. The annual averages of area prices have not significantly exceeded the relevant marginal costs. Thus in terms of the Lerner index[7] the degree of market power is small. However, due to significant entry barriers and increasing demand the situation may change in the not so distant future. Moreover, the analysis presented in [5] suggests that additional mergers and increased cross-ownership between Nordic power companies may re-establish the market power that was diluted by the integration of the national electricity markets.

2.3 Retail Competition

The design of retail electricity markets affects the overall performance of the electricity market. In particular the design of retail electricity contracts, in terms the connection between the spot and retail electricity price has a significant impact on the short-term price sensitivity of electricity demand. However, a detailed treatment of the Nordic retail electricity markets is beyond the scope of this paper[8].

Traditionally the major generating companies in Sweden, i.e. Vattenfall, Sydkraft and (the Swedish part of) Fortum, have had rather small shares of the retail market. In the last few years, however, they have bought majority or minority shares of a number of small and medium sized retailing companies. As a result of these developments the number of retailing companies has been reduced, and the "big three" have become dominating players in the retail market. Thus around 70 percent of the market is served by the "big three" if retailing companies in which minority shares are owned are included.

In Norway, by contrast, electricity retailing is less concentrated than in Sweden. Moreover, while a very large share of households in Sweden buy electricity on the basis of fixed-price contracts, most households in Norway have variable-price contracts with the retail price directly linked to the spot market price. Thus the immediate impact of spot price variations on household electricity prices is much stronger in Sweden than in Norway.

In Table 3 the annual averages of Norwegian and Swedish household prices 1996-2001 are displayed. The numbers reflect averages of all household and contract types. It is immediately clear from the table that Norwegian and Swedish retail prices differ significantly. No "law of one price" is visible. Thus, from the point of view of the households there seems to be two national rather than an integrated Nordic electricity market.

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[7] The Lerner index is defined as the sum over all firms of $s_i(p- c_i)/p$, where p is the market price, while s_i is the market share and c_i is the marginal cost of firm i.

[8] For a thorough analysis of the retail market, see [6].

Table 3 Household prices (annual averages) net of taxes 1996-2001 (NOK/MWh)

	1996	1997	1998	1999	2000	2001
Norway	198	210	162	152	141	206
Sweden	249	256	254	245	219	211

Source: Statistics Norway, Statistics Sweden.

As can be seen in the table the annual variations of the Norwegian retail prices are quite significant, but also relatively well correlated with the annual variations in Elspot prices (see Table 2). Thus the retail prices fell during the "wet" period 1997-2000, but increased in 2001 when precipitation was "normal". The time lag between the change in the Elspot price level and the resulting change in retail prices reflects the fact that some customers have contracts in which the price is fixed for some time.

In the case of Sweden, however, the correlation between Elspot and retail prices was rather weak during the period 1996-1999. Instead average retail prices remained high in 1998 and fell only marginally in 1999, while a quite significant reduction took place in 2000 and 2001. The main reason for this is that until November 1999 electricity consumers were not allowed to change supplier, or change contract with the old supplier, unless a costly real-time metering and reporting system was installed. In other words effective retail competition was prevented by significant switching costs.

3. THE IMPACT OF SUPPLY SHOCKS

As was mentioned above hydropower accounts for around 50 percent of total generation in the Nordic countries. Thus under "normal" precipitation conditions the total annual hydropower production in Finland, Norway and Sweden is around 200 TWh. However, precipitation conditions vary significantly between different years, and although the water reservoirs serve as buffers the annual hydropower production varies between 165 and 235 TWh. The year 2000 was an unusually "wet" year and total hydropower production was 234 TWh. As a result spot market prices were extremely low (see Table 2). In 2001 precipitation and hydropower production was close to normal, and average spot market prices were significantly higher than the year before.

In the first part of 2002 precipitation was above normal, and spot market prices started to decline as hydropower production increased significantly. Then the situation changed quite dramatically. Both the summer and autumn of 2002 turned out to be extremely dry, and while the water reservoir filling was above normal in July it reached its lowest level in fifty years by the end of the autumn. In view of this and the uncertainty about temperatures and snowfall during the coming winter hydropower production was significantly reduced. In other words the Nordic electricity market experienced a "supply shock".

Any electricity supply system may of course experience and unexpected reductions of production capacity for some period of time. The key issue is whether the adjustment mechanisms embedded in the market institutions are sufficiently efficient to prevent problems such as load shedding and financially disruptive windfall gains and losses. In other words, well-designed market institutions should help to maintain both the physical stability of the electricity supply system (security of supply) and the financial stability of the electricity supply industry and its customers when electricity production capacity is unexpectedly reduced.

In order to maintain security of supply the electricity supply system has to balance in real time, which essentially means that the spot market has to constantly clear. If demand is elastic in the very short term a given supply reduction leads to a relatively modest increase of the market-clearing price. But if demand is inelastic in the short term the same supply reduction may induce the market-clearing price to increase very significantly. From the security of supply point of view, however, the key issue is whether a market-clearing price will be established at all.

However, electricity supply systems based on hydropower usually are energy constrained rather than capacity constrained. Thus shortage of water in the reservoirs should not lead to instantaneous security of supply problems. Instead there is an issue about security of supply during a longer period, typically the winter period when the precipitation comes in the form of snow. Consequently the analysis of the impact of the unusually low precipitation in 2002 and 2003 can focus on monthly rather than hourly market conditions and spot market prices.

As can be seen in Table 4 spot market prices started to rise in October 2002 and reached unprecedented levels in December and January. During these months the Nordic market disintegrated into four national markets with rather different prices[9]. Yet the market continuously cleared throughout this period, i.e. there was all the time a market price at which electricity could be bought. Thus, although the demand for electricity is quite inelastic in the short run the demand response to the higher prices was sufficient to bring about equality between supply and demand. In other words the new market institutions passed the fundamental test.

However, there is also a political aspect of higher electricity prices, particularly if the recently implemented reforms are expected to produce lower electricity prices. One can say that the electricity market design should be politically stable in the sense that the market outcomes should not induce political intervention and re-regulation of the market. The experience in California, where soaring electricity prices and load shedding induced massive political intervention, is a case in point. In the case of the Nordic countries, however, there was no political intervention in the market in spite of serious public concern, particularly in Norway, about the high electricity prices.

The primary reason for the more pronounced public concerns in Norway is that, as was mentioned above, that retail prices in Norway to a large extent are directly linked to spot market prices, while most households in Sweden have retail electricity contracts in which prices are fixed for 1-3 years. In other words a spot price increase has an almost immediate effect on Norwegian households, while the Swedish households are not affected until their current contract expires.

Table 4 Elspot system and area prices, September 2002 – August 2003. NOK/MWh

Month	System	Oslo	Stockholm	Helsinki
September	181.7	178.0	190.3	190.2
October	230.4	230.0	232.5	231.9
November	316.9	316.3	317.2	317.2
December	544.4	550.1	536.9	494.9
January	523.7	532.6	513.7	510.3
February	363.6	365.3	363.1	354.3
March	310.2	318.2	302.2	294.9
April	247.4	256.9	236.2	232.3
May	232.6	234.2	232.2	221.2
June	202.5	196.0	217.8	213.5
July	229.6	228.4	233.8	233.7
August	272.5	274.4	274.9	258.0

Source: Nord Pool

[9] The lower prices in Finland reflect the access to imports from Russia in combination with insufficient inter-connector capacity between Finland and Sweden.

Another aspect of the dramatically increased spot market prices is related to the financial consequences for generators and retailers (and major customers who buy electricity directly at the spot market). Without possibilities to hedge spot market price risks the developments in late 2002 and early 2003 would lead to very significant windfall gains for the generators and damaging losses for the retailers, particularly for retailers selling electricity at fixed retail prices. This was, by the way, the situation in California where the utilities were fully exposed to the spot market price risks.

In the case of the Nordic countries the profit of the generators did increase significantly, and some retailers did run into financial difficulties. But there was no wave of retail company bankruptcies, and generator profits did not skyrocket. The reason for this is that Nord Pool's financial markets in effect managed to redistribute windfall gains from the generators to the retailers. In other words, the portfolios of futures and forwards held by the generators and retailers as a result of previous trading at Nord Pool's markets for financial instruments effectively locked the prices of very significant quantities to predetermined levels.

It seems correct to conclude that the new market institutions handled the hydropower supply shock in 2002-2003 in a rather efficient manner. Physical stability, in the sense that "the lights stayed on", was maintained. Financial stability, in the sense that the retailing segment of the industry avoided large-scale bankruptcies, was also maintained. In addition political stability, in the sense that the market outcomes did not induce political intervention and re-regulation, was maintained. In spite of these conclusions the performance of the Nord Pool system could be improved. In particular a stronger connection between spot at retail prices, and thus an increased short term price sensitivity of demand, could be established.

4. THE IMPACT OF DEMAND SHOCKS

During a few days in the winter of 2001 the load was close to full capacity. One day in February the expected load in Sweden was 29 GW, while the available capacity was 30 GW. Due to transmission constraints this margin was to small, and serious security of supply problems were envisaged. Svenska Kraftnät, the system operator in Sweden, made public announcements about the situation and asked the public to cut back on electricity consumption, particularly during a few critical hours in the morning that day. As a result the actual load was only 27 GW and supply security was maintained. However, the incident suggested that the new market institutions were not efficient in terms of securing sufficient peak load capacity.

One particular feature of the design of the Swedish electricity market institutions is that there are no capacity payments, i.e. generators are not paid to keep capacity available. The underlying idea is that the spot market prices during peak load periods will be sufficiently high to motivate generators to keep peak capacity available. In theory this line of reasoning is correct. However, in reality it seems that generators are risk averse, i.e. they prefer a certain stream of annual capacity payments to possibly very high but uncertain revenues during a few short periods some time in the future. This is a "market failure" in the sense that existing market institutions are not able to induce market participants to behave in a socially efficient manner.

As a result of this market failure only generating capacity that is frequently used has been kept available, while 3.8 GW of peak capacity has been mothballed in Sweden after 1996. Thus the margin between the expected maximum load and available installed capacity has been decreasing. The developments during the critical days in February 2001 have induced several investigations aimed at, in one way or another, introducing capacity payments. The system operator (Svenska Kraftnät) and power industry representatives have recently agreed on a temporary system in which Svenska Kraftnät pays some generators for keeping a certain amount of peak capacity available.

However, a quite interesting and seemingly efficient system for capacity payments has been implemented in Norway (see [7]). The key idea is that the system operator buys options to use generating capacity and to shed load in peak load periods. The options are bought at an auction where generators and major customers (with interruptible use of electricity) make bids. A seller of an option is committed to make generating capacity available, or shed load, on short notice. In exchange a fixed, market determined, payment is received. The Norwegian system has so far worked quite efficiently, and may be copied in Sweden. In particular it has made it possible to use low-cost load shedding options instead of costly installations of reserve generating capacity.

5. CONCLUDING REMARKS

On the basis of the experiences so far the Nordic electricity market institutions work quite well. Although customers may not like the high prices in "dry" years, and producers may not like the low prices in "wet" years, the market has turned out to be quite resilient to supply shocks. Demand shock in the form of infrequent but very high peak loads is less well handled by the current market institutions, and an additional market in which some kind of capacity payments can be determined seems to be needed.

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