Market Liberalization and Market Integration

Essays on the Nordic Electricity Market

Jens Lundgren
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Jens Lundgren
To Jenny, Leo and Ida
Abstract

This thesis consists of four self-contained papers related to the Nordic electricity market.

Paper [I] examine how the reform of the Nordic electricity markets has affected competition in the electric power supply market, Nord Pool. The question is if the common power market has been competitive or if electric power generators have had market power during the period 1996 -2004. Moreover, since there was a stepwise evolution from national markets to a multinational power market, we also ask how the degree of market power has evolved during this integration process. The results show that electric power generators have had a small, but statistically significant, degree of market power during the whole period. However, studying the integration effect, i.e. how the market power has been affected by additional countries joining Nord Pool, it show that the degree of market power has been reduced and finally vanished as the market has expanded and more countries joined the collaboration.

Paper [II] analyse how the deregulation of the Swedish electricity market has affected the price of electric power and how the change in electric power price, in turn, has affected consumers’ welfare. The result shows that the change in pricing principle of electric power following the deregulation has increased consumer welfare over the period studied (1996-2006), with welfare gains about 100 SEK per customer per year, indicating a three per cent welfare gain for the average customer.

Paper [III] study whether (and to what extent) the multinational electricity market integration has affected the price dynamics at the Nordic power exchange. The results shows that a larger electricity market seems to reduce the probability of sudden price jumps, but also that the effect on volatility seem to depend on the characteristics, i.e. production structure, of the integrated markets.

In Paper [IV] a two-stage study is conducted to investigate the extent to which shocks in the demand and supply for electricity translate into price jumps, and the extent to which this process is affected by the prevailing market structure. The main findings from the study is that whether demand and supply shocks translate into price jumps largely depends on the prevailing market structure, i.e. on how far the market works from capacity constraints. A notable feature of the empirical analysis is also that the marginal effects from positive demand and negative supply shocks on the jump probabilities are mostly insignificant and of small magnitude.

Key words: Consumer welfare, Electricity price, Market integration, Market power, Price jump.
Acknowledgments

It was in June 2002 I got accepted to the PhD-programme at the Department of Economics at Umeå University. Actually it was on my birthday I got the letter that confirmed that I was accepted. Thinking back to that day makes me nostalgic. I still remember it as if it were yesterday when telling my girlfriend (today my wife) and the rest of the family the great news at the birthday dinner.

A lot of things have happened since that day, the journey of life with all its adventures has taken me to many places, however most certainly not straightforward towards finalising this thesis. Obviously, I got a job before having finished this thesis. Looking back one might think that I regret stepping out in the “real” world before the thesis was completed. This is not the case. Sure it would have been nice to have finished earlier, but the experience from working hands on with energy questions has been most valuable. I honestly think that this thesis has benefited from my “real” world experience.

Finalising this thesis has taken longer than I initially planned. However, now it is finished and for that I owe gratitude to so many people.

First of all, I wish to thank my supervisor Niklas Rudholm for taken his job more seriously than I ever could have asked for. Niklas has encouraging me and never given up on me. I am grateful for that and also for all the guidance and for all the good comments on my work, and for always taking time for my numerous questions. I have also enjoyed our “working camps”, first in Gävle and later on in Borlänge. Thank you Niklas!

I would also like to thank my co-supervisor, and co-author to two of the papers, Jörgen Hellström. Thank you for good collaboration and for always taken time discussing and explaining our econometric models. It has been a privilege working with you.

There are many more great persons at the Department of Economics that I would like to thank, too many to list them all here. However, there are some I like to give some extra credit. First I would like to thank Runar Brännlund for his magnificent support, especially in the final phase of completing this thesis. Without Runars support the last few months I doubt that I would have managed to finalise this thesis. I would also like to thank Marie Hammarstedt who has helped me with administrative issues from day one as a PhD-student. Eva Cederblad also deserves credit for being an excellent administrator always ready to step in with help in difficult matters. I would also like to thank my PhD-student classmates for five really interesting years at the department. Most of all I like to thank my old roommate Lars Persson,
both for interesting academic discussions but also for all the good times discussing various aspects of the life of snowmobiling.

As I said I started to work before finishing this thesis. I have now worked for five years at the Energy Markets Inspectorate. It is a great place to work at, with many talented people having an enormous knowledge of how the energy markets functions. I owe gratitude to my colleagues for good discussions and comments on my work. I also would like to thank my boss, Tony Rosten, for excellent guidance in combining theoretical framework with the reality of the electricity market.

Although the people mentioned above are very important in the process of finalising this thesis I am sure that I never would have been able to finish it without the support from family and friends. I wish to thank my family for always supporting and believing in me, especially mum and dad. To my brother, thank you for reminding me of what is important in life and for keeping me grounded. To my parants-in-law, thank you for your kindness and for all your help.

To my dear friends Fredrik, Johan, Robert and Anders, I really appreciate our friendship. I definitely have enjoyed our adventures together and I am looking forward to all the adventures that will come in the future.

To my children Leo and Ida, thank you for setting life in perspective and for giving true meaning to my life.

Last but not least, to Jenny, my wife and the love of my life. Thank you for choosing to spend your life with me. There are not words enough to express how much I appreciate your support!

Umeå, November 2012
Jens

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1 It might be a good idea to clarify that the views expressed in this thesis are solely the responsibilities of the authors and should not in any way be viewed as reflecting the opinion of the Energy Markets Inspectorate.
This thesis consists of a summary and the following four self-contained papers


1 Introduction

Traditionally, a single utility provider has supplied all electricity within a geographic area. The utility was most often vertically integrated and responsible for the whole chain, production, transportation and delivery to customers. This situation has changed in recent decades. Deregulations in the electricity sector began in the late seventies and since then the electricity sector in several countries around the world has experienced structural changes. Deregulation of electricity markets in Europe started in England and Wales in 1990, when the industry was privatized and competition between generators was introduced. The England and Wales deregulation was followed by the deregulation of the Norwegian market in 1991 and in Sweden in 1996.

The deregulation in Sweden introduced competition between power generating companies through vertical separation of distribution across power supply and retail, as well as induced stepwise market integration with other Nordic markets. Whereas power supply and retail were set out to competition, distribution was left as a monopoly due to its characteristics as a natural monopoly. The main question raised in this thesis is how this deregulation, in terms of competition and increased market integration, has worked and affected market prices for electricity. The development of the various components of the electricity price from 1970 up to 2012 is displayed in Figure 1.

Figure 1: Price decomposition of the Swedish electricity price

![Price decomposition of the Swedish electricity price](source: Swedenergy)

1 Price for a customer with 20 000 kWh yearly consumption, displayed in 2010 year prices.
Figure 1 reveals two interesting facts. The first is that the final consumer price (the sum of all components) has increased since 1996. The second is that the volatility in the price seems to have increased since 1996. Further inspection shows that taxes have gone up significantly while transmission costs have remained almost constant in real terms. Furthermore, additional environmental fees have been introduced during this period, e.g. green certificates in 2003 and the EU ETS in 2005. A tempting preliminary conclusion would then be that the main part of the increase in the consumer price level after the deregulation is due to increases in taxes and new environmental fees, whereas the increase in volatility seems to come from volatility in the power price itself. The main objective of this thesis is thus to further study the determinants and the development of the price level and price volatility, with a focus on the power price.

Following the market deregulation the market price of electric power is set in the Nordic multinational electric power exchange Nord Pool. This is combined with a shift from an average cost to a marginal cost pricing principle for wholesale electric power. With these changes in mind, one specific question posed is how the change of pricing principle has affected the price level and if this has changed the outcome in terms of market efficiency. A second specific question is raised by inspection of figure 1; can the new pricing principle explain the increase in price volatility with higher spikes and lower bottoms after 1996? In other words, has the change in the pricing scheme induced competition between electric power suppliers, and hence contributed to lower prices, and has it altered the price dynamics?

The papers in this thesis start with the change of pricing principles of electric power in the Nordic power exchange, Nord Pool, by addressing questions like the ones above. The papers cover three areas of the electricity market that all have the ability to cause market inefficiencies, and hence also lower customers welfare relative to what could be achieved in the best of circumstances. Although there exists a fairly extensive literature analysing electricity markets, the papers in this thesis contribute to the existing literature by addressing questions that have not previously been addressed.

First, with the new market setup determining prices at the power exchange, there are new ways of exploring market power. Previous literature, e.g. Green and Newbery (1992), Andersson and Bergman (1995) and Rudkevich et al (1998), concluded that electric power markets are vulnerable to market power. If this is also the case in Nord Pool, consumers will be charged market prices above marginal cost, which in turn will result in an inefficient allocation of resources. In the first paper in this thesis, the level of market power, i.e. the possibility for firms to charge a price above marginal

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2 The increase in price volatility becomes even more apparent if we look at daily, weekly or monthly electricity prices.
cost in the Nord Pool spot market, is analysed. This is interesting due to the fact that the new market structure introduced new conditions for competition in power generation and that over the years the size of the power market has expanded as more countries joined the Nord Pool collaboration. Previous literature, e.g. Johnsen et al (1999), Hjalmarsson (2000), Vassioupolus (2003), Steen (2003) and Damsgaard et al. (2007), studied market power in the Nordic power market. Fridolfsson and Tangerås (2009) reviews the efforts made in analysing the Nordic electric power market. However, neither of these nor any other previous papers evaluate the effects of the market integration process on market power in the Nordic power market. Amundsen and Bergman (2007) analysis the integration process but not the market power due to it.

There are studies of other power exchange markets besides the Nordic, e.g. Green and Newbery (1992), Wolfram (1999) and Wolak (2003). Although this thesis is a case study of the Nordic electricity market it has some bearing in a more general setting. That is, experience of the Nordic case can be of use in the integration process of electricity markets in other regions, especially within the European Union.

Secondly, even if the Nord Pool spot market is found to be competitive, the change in pricing principle for electric power to marginal cost pricing
d may have affected the level of the electricity price. Since this electricity power price level is the base of what consumers pay for electricity, it is interesting to study to what extent the change in pricing scheme has affected prices and also consumer welfare. Kwoka (2008) sets up 4 different approaches for analysing the effects of deregulations. The first approach is a direct comparison of the deregulated market with the underegulated market. This is also the approach in which paper II analyses the effect on consumers’ welfare through shift in the pricing principle of electric power. Existing literature analysing the effects of the deregulation in Sweden is not that extensive, but two articles on the matter are Bowitz et al (2000) and Damsgaard and Green (2005) which each use the first approach of Kwoka (2008). More recently Brännlund et al (2012) published a report analysing the effects regarding market efficiency and the price effects of the deregulation. Their approach is somewhat different as it is based on econometric modelling and falls under the fourth approach of Kwoka (2008).

3 Before the deregulation, the pricing principle on the Swedish high voltage electric power market was approximately average cost pricing. After the deregulation, the pricing principle changed to marginal cost pricing.

4 The other three approaches are 1; examine the effects of variations in the intensity of regulation across time and place, 2; controlled experiment, 3; econometric modelling based on underlying demand, costs, and other relevant behavioural relationships.
Thirdly, even if competition is working in the Nord Pool spot market, and the marginal cost pricing principle has increased consumer welfare, it’s likely (see the discussion regarding Figure 1) that marginal cost pricing has led to a higher volatility in the electricity power price than before the deregulation. Higher volatility creates uncertainty and possible disutility for consumers as well as producers. Consumers, assumed to be risk averse, are likely to prefer stable electricity prices rather than volatile, since it creates less uncertainty about future electricity costs. Producers, noting that on a deregulated market retailers can no longer pass cost through to customers without the risk of losing them, may end up with higher costs. For electric power producers the recovery of investments in, for example a new plant, is thus no longer guaranteed. Altogether, risk management has become a new and important part of the electricity business. In the third paper of the thesis the dynamics of electricity prices in the Nordic power exchange, Nord Pool, are empirically explored. More specifically the price dynamics are analysed in the context of the multinational Nordic market integration. Previous literature, e.g. Huisman and Mahieu (2003) and Bystöm (2005) has analysed electricity price dynamics, but to the author’s knowledge this is the first paper analyzing the effects of multinational power market integration on electricity price dynamics.

Paper IV continues where paper III ends. That is, one question left unanswered in paper III was the cause of electricity price jumps.\(^5\) In the previous literature on electricity price dynamics the occurrence of electricity price jumps is often loosely motivated by shocks to the electricity demand or to an inelastic electricity supply, e.g. Huisman and Mahieu (2003), Bystöm (2005), Gunthrie and Videback (2007) and paper III. As such, the purpose of paper IV is to empirically explore the possible causes behind electricity price jumps in the Nordic electricity market. To the author’s knowledge the possible causes for electricity price jumps have not previously been formally studied.

### The Swedish electricity market prior to the deregulation

Prior to the deregulation of the Swedish electricity market in 1996, the market in Sweden was characterized by vertically integrated monopolies, active in local or regional settings, producing electric power as well as selling electricity to customers and running the distribution network. An effect of the market rules was that there was no competition between the utilities at any level; generation, retail or distribution (SPK 1989:8). Thus, the incumbent retailer was the only firm selling electricity to customers in that area.

\(^5\) That is, relatively large sudden increases or decreases in the electricity price.
The electricity market before the deregulation was divided based on customer characteristics into a high and low voltage market. The high voltage market was a market for generators, large industries and retail distributors, while the low voltage market was a market for retail distributors and their consumers, mainly households (Bergman et al, 1994). As a customer in the low voltage market it was not possible to change supplier, the customer was stuck with the incumbent firm in the area where the customer lived. The vertical integration also meant that retailers to a large extent bought the electricity they sold to their customers from the vertically integrated power generator.

In addition to the high voltage market, there was a market handling short term energy exchange between generators. This market worked like an "electric power pool" and was characterized by extensive cooperation and information exchange between the participants. Generators, the members of the pool, with a shortage or surplus of power could buy or sell power from the "power pool", respectively. The exchange price was based on the so called split-savings principle, a method where the price was determined by the average of the buying firms’ marginal cost and the selling firms’ marginal cost (Hjalmarsson, 1996).

The high voltage market, where the state owned company Vattenfall was the dominating actor with 50 per cent of the generation capacity, was not directly regulated. Government regulation was instead implemented through the control of Vattenfall. Pricing was indirectly regulated through the state-ownership of Vattenfall and the requirements on the firm’s pricing formula. Vattenfall was required to apply pricing formulas that can be seen as marginal cost pricing subject to rate of return requirement and budget constraints, with a formal objective to break even. This established Vattenfall as the price leader on the high-voltage market and also worked to set a price ceiling. The generators' collaboration in the "power pool" resulted in a price floor which also prevented further entry to the market (Bergman et al, 1994).

More specifically, the pricing in the high voltage market was conducted through high voltage tariffs consisting of four elements: a fixed fee, a contractual demand charge, a peak load charge and an energy charge (SPK, 1989:8). The energy and the peak load charge were priced by marginal cost while the contractual charge and the fixed charge were determined by the rate of return requirements and budget constraints. The pricing method was rather efficient resulting in prices not much higher than marginal cost prices (Bergman et al, 1994). However, the pricing mechanism in the high voltage

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6 The required return was equal to the depreciation on replacement values and a rate of interest on loans from the government at the bond rate level.
market consisting of both marginal cost and fixed fees could be viewed as an approximation to average cost pricing.

This is also argued by Damsgaard and Green (2005) who say that the required rate of return restriction on state- and municipality-owned generators makes average cost pricing a reasonable approximation of the pricing principle on the high voltage market before deregulation. The split-saving principle used in the “power pool” before deregulation give further support that the price on electric power could be approximated by average cost pricing.

It should also be mentioned that the Nordic countries, Denmark, Finland, Norway and Sweden had started cooperation in electric power supply several years before the deregulation. That is, there were interconnectors between the countries which were used, as today, to transport electric power between countries when needed.

The Nordic electricity market after the deregulation

The political discussion to liberalize the Swedish electricity market began in the early 1990s. After a time of political controversies, new legislation was adopted and in 1996 the Swedish electricity market was deregulated. The process was the result of a combination of national initiatives and demands from the EU. The aim of deregulation was to create a well-functioning electricity market with competition in electric power production and retail. Distribution remained a monopoly market, but third party access was introduced. Legal unbundling between power production and distribution was also introduced to encourage competition. To invoke additional competition in the electric power market, collaboration with Norway in the Nord Pool market was introduced.

In 1996 the first directive concerning common rules for the internal market in electricity (96/92/EC) was presented. The enlargement of the Nordic electricity market is partly a result of this directive. The first directive is also the start of an era where the development in the electricity market is driven by the European Community, and national initiatives are becoming less important. The first directive has since been replaced by second and a third directives (2003/54/EC and 2009/72/EC respectively). These directives and the internal European electricity market are the primary driving forces for the electricity market, but the Renewable Directive (2009/28/EC) also plays a role as the issue of climate change in the last few years has become a challenge for the electricity markets.

The Nordic power exchange

At the time Sweden deregulated its electricity market, a similar process was ongoing in Denmark and Finland. In Norway, a deregulated market was already in place. When Sweden joined the Norwegian power exchange
market in 1996, the world’s first international power exchange, Nord Pool, was created. The power exchange market was expanded when Finland and Denmark entered Nord Pool in 1998 and 2000 respectively. Since then the Nord Pool area has continued to grow and today this includes collaboration with Germany, the Netherlands, Poland and the Baltic states.

The introduction of Nord Pool affected how the electric power market functions. Even if there were collaborations before the establishment of the Nord Pool power exchange, this new collaboration affected all participants in the market providing a formal market place where the price of power was determined. This meant that the participating countries’ electric power generators had to compete with generators from the whole Nord Pool area instead of acting as monopolists in their own local area. Secondly, as the market for electric power expanded, one consequence was that the large electric power generators in the individual countries got smaller market shares in the common market. For example in year 2004, the four largest electric power generators in Sweden covered 88 per cent of the Swedish market (with Vattenfall as largest firm covering 47 per cent), while in the Nord Pool area the four electric power generators covered only 48 per cent of the total market (with Vattenfall as the largest firm with 19 per cent). Thus, the larger electric power market improved the conditions for the market to function effectively without abuse of market power. However, the outcome of the markets functioning is closely related to the transmission network and congestion therein. This issue is discussed in the next section.

The Nordic electric power market is a combination of several markets. The first market is the non-mandatory Nordic power exchange, Nord Pool. In short, Nord Pool handles the day ahead spot market for physical contracts, Elspot. The second market is a market that handles bilateral contracts. In this market, electricity contracts are handled and settled between two parties, a buyer and a seller, without intermediaries. In addition to these markets there is a financial derivatives market, which handles futures, forwards and option contracts. The system spot price plays an important role in the Nordic power market, as it also function as a reference price for the bilateral and financial contracts. The spot market has increased its volume turnover, from handling 16 per cent of the electricity consumed in the area in 1996 to about 70 per cent in 2011.

As the Nord Pool spot market handles a large portion of the electricity consumed in the area, and functions as a reference price for bilateral and

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7 Swedenergy (2005).
8 To be precise it should be said that the market for physical deliveries actually consists of the day ahead market, Elspot and the intraday market, Elbas. Initially the intraday market only covered Sweden but it has expanded and now covering the Nordic region, Germany and Estonia.
9 As from 2010 Nasdaq OMX owns and operate the financial derivatives market.
10 Nordpools (2011).
financial contracts, Nord Pool has a vital function in the electric power market. In the Nordic electric power market, the electric power price is settled in the one day ahead spot market at Nord Pool. The pricing principle in the spot market is a single price, double auction model where the system price is set hour by hour by the intersection of demand and supply bids. In Figure 2 below, the relative marginal cost and supply are presented.

The supply bidders (electricity power generators) bid in how much they are willing to sell and at what price. If the market is working, the generators bid should be based on their marginal cost of production.\(^\text{11}\) The merit order in Figure 2 is also based on the marginal costs for different production technologies and shows when different production sources are used for production. Demand on the other hand, is a function of how much electricity is needed at the moment. Household demand is determined by, among other things, outside temperature (electricity for heating purposes) and how dark it is outside (electricity for lighting). For the industrial sector, electricity demand is generally determined by the economic situation, with lower energy demand in recessions.

**Figure 2: Merit order and marginal cost in the Nordic electric power market**

Source: The Energy Markets Inspectorate

\(^{11}\) The relevant marginal cost is the short run marginal cost of electric power production, including relevant cost of production (different for different power plants) e.g. fuel costs and EU-ETS allowances costs. For hydro power production the relevant cost is not the marginal cost (which is nearly zero). Instead the production decision is based on the calculated “water value”. The water value is a complex calculation based on parameters such as future inflow and expected prices.
The market clearing price in the day ahead market will be where demand and supply intersect. The price will be set at the marginal cost of the marginal bid, i.e. the bid that clears the market. The pricing principle also means that all suppliers that get their bids accepted (bids lower than the marginal bid, i.e. in Figure 2 to the left of the intersection) get paid the market clearing price. Also, the consumers have to pay the market clearing price. Given that no one can exercise market power, the pricing principle used is efficient, even though it allows firms with low marginal cost of production to earn extra profits.

In the case shown in Figure 2 suppliers with sources such as wind or hydro production have a lower marginal cost than the market clearing price. For these firms the difference between their marginal cost and the market clearing price will contribute to cover their fixed cost and to their short run profit. A normal misconception is that this profit is due to abuse of market power, however, it is not. These profits are due to the usage of production sources with lower marginal cost than the production source setting the price.\textsuperscript{12} In this sense the electricity market is supposed to work like any other competitive market. The issue of market power is an issue of whether a single producer (or a group of producers) can act strategically in the sense that they can affect the market price through their supply bids. There are thus two different questions where the market power issue is discussed in paper I.

\textbf{Transmission capacity and bottlenecks}

In the previous chapter it was mentioned that the transmission network could affect the market outcome due to congestion. A fundamental feature of electricity is that it is produced in power plants and then transported to the customers through a transmission network. To handle the fact that transmission lines have limitations in their transport capacity and from time to time will be congested, the Elspot market is divided into several bidding areas. As of 1 November 2011 Sweden consists of four bidding areas and the Nord Pool area in total of 13 bidding areas. The Nord Pool system is built such that if there is no congestion between the bidding areas, the whole Nord Pool area will have the same price. However, if the available transmission capacity is not sufficient, the flow of power between the bidding areas will be congested and different area prices will be established. So, even if supply and demand are the key factors determining the hourly market prices, available transmission capacity will also play a role. That is, to relieve the congestion different area prices are introduced and the price is raised to reduce demand in the areas affected.

\begin{footnotesize}
\begin{itemize}
\item[\textsuperscript{12}] For further discussion regarding marginal cost pricing and other potential pricing schemes for electric power exchanges see e.g. Gómez and Rothwell (2003) or Stoft (2002).
\end{itemize}
\end{footnotesize}
One effect of congestion on transmission lines is, as described above, that different bidding areas get different prices. In addition, congestion also implies that the relevant market area will be limited to the bidding areas that have no congestion between them. This will have implications for competition in the Nord Pool area in that the electric power generators in the smaller areas will get larger market share in those areas during the hours the transmission lines are congested.\textsuperscript{13}

In the process towards an internal European electricity market linking different regions together is crucial. For this purpose market coupling of different regions is undertaken. This involves making all cross-border transmission capacities available to all market participants, and that energy transactions between the participating power exchanges can be done by connecting their price calculations.\textsuperscript{14} To support market coupling and ensure that the different areas will receive equal prices, transmission capacity has to expand and the bottlenecks have to be removed. The building of new transmission capacities in Europe is in progress, although the process takes time. One problem is if transmission capacity is not sufficient, since this, as discussed above, will reduce the relevant market. This would be in conflict with the intentions of a single internal market for electricity in the sense that markets effectively become smaller instead of bigger.

**The Swedish electric power production structure**

Since the introduction of nuclear power plants in the 1970s and 1980s, electric power generation in Sweden has consisted primarily of hydro- and nuclear power, which cover approximately 90 per cent of Swedish power generation on a yearly basis.

The electric power generation mixture in Sweden did not change much between the years 1995-2006 (Table 1). However, integration with other countries has resulted in an increased flow of electric power across borders. As such, the production mixture of neighbouring countries is also to some extent imported. Moreover, the production mixture varies from year to year, mostly due to how precipitation influences hydro power production. For example, year 2000 was a year with high precipitation, resulting in hydro power production above average in Sweden. On the other hand, 2003 was instead a year with low precipitation and all time low levels in the reservoirs. In recent years it can also be seen that more wind power is coming in to the system, probably due to the introduction of the green certificate system.

\textsuperscript{13} See e.g. Steen et al (2003) or Energy Markets Inspectorate (2012) for an elaborate discussion on bottlenecks, relevant market size and market power.

\textsuperscript{14} See e.g. nordpoolspot.com for an elaborate discussion.
Table 1: Electricity production in Sweden 1995-2011, percentage

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<th>Year</th>
<th>Hydro</th>
<th>Nuclear</th>
<th>Wind</th>
<th>Other*</th>
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*Includes i.e. CHP, industrial back-pressure and Gas-turbines **Negative sign equals net export

Source: Statistics Sweden (SCB)

2 Summary of the papers


In the first paper of this thesis we examine how the reform of the Nordic electricity markets has worked in terms of competition in the electric power supply market. Our question is whether the deregulation has been successful: has the common power market been competitive or have electricity suppliers had market power? Moreover, since there was a stepwise evolution from national markets to a multi-national and largely deregulated power market, we also ask how the degree of market power has evolved during this integration process.

A straightforward measure of market competitiveness is the price-marginal cost markup; since it is zero in a perfectly competitive market, meaning that the electricity price should equal the production cost of the marginal unit of production. However, even though market prices are easily accessible in the Nordic power market, this is not the case with marginal
costs and therefore some other method must be used to measure the degree of market power.

In the study, a conjectural variation method named the Bresnahan (1982) and Lau (1982) method is used. This model does not need knowledge of marginal cost to calculate market power. The Bresnahan – Lau model instead allows for identification of market power using aggregated industry data. The model implies that conjectural variation elasticities are estimated and used to identify the level of market power. The conjectural variation elasticity at the industry level is the average of the individual firms’ conjectural variation elasticities, which measure the firms’ output response to the single firms’ output change as conjectured by this firm. Thus, if there is perfect competition, there is no output response since a single firm cannot affect output at the industry level, whereas the response is one-to-one if there is no competition since the industry behaves as a single firm. The conjectural variation elasticity is estimated from a two-equation system, where the first equation is electricity demand as a function of electricity price and at least one exogenous variable. The second equation is electricity supply, derived from profit maximization, which is the electricity price as a function of industry output, the same exogenous variables as for electricity demand and other exogenous variables. The data set used consists of weekly data from all Nord Pool participants, covering the period from week 1 in 1996 to week 16 in 2004. The price variable is the Nord Pool spot price at the system level.

The results show that electric power generators have had a small, but statistically significant, degree of market power during the whole period. However, the results from analysing the integration effect, i.e. how the market power has been affected by additional countries joining Nord Pool, show that the degree of market power has been reduced as the market has expanded and more countries joined the collaboration. In the last subperiod (2002-2004), when both Finland and Denmark had entered Nord Pool together with Sweden and Norway, the results show that there was no statistically significant market power present in the Nordic electric power market. In economic terms, the implied Lerner index gives a markup of less than one per cent in the different subperiods and an even smaller markup for the whole period. This means that compared to the case of perfect competition the price at Nord Pool is one per cent higher. One interpretation of the calculated markup is that the impact of market power on the electricity price has not been that severe and that the Nord Pool market has worked rather well.

Our results are in line with previous studies (e.g Hjalmarsson, 2000 and Vassilopoulos, 2003) in that all found little or no evidence of market power. Fridolfsson and Tangerås (2009) conducted a survey over research regarding market power in electric power markets that also concluded that there is no
Evidence from the literature of any systematic abuse of market power in the Nordic electric power market. Brännlund et al (2012) performed an econometric study of the Nordic electric power market concluding that the market seems to function as an effective market is supposed to.

**Paper [II] Consumer Welfare in the Deregulated Swedish Electricity Market**

From the first paper in this thesis, we know that the spot market at Nord Pool has been characterised by a low degree of market power. However, ten years after the reform high electricity prices in Sweden have sparked a debate that portrays the electricity market deregulation as the cause of high consumer prices and large producer profits. How are high prices consistent with the results that the Nord Pool power exchange shows no evidence of market power abuse?

The second paper in this thesis analyses how the deregulation of the Swedish electricity market has affected the price of electric power and how the electric power price, in turn, has affected consumers’ welfare. The study uses an equivalent variation approach and the analysis is performed using monthly data, covering the period from January 1996 to January 2007. The equivalent variation approach, which is a exact welfare measure, allow us to answer the question of how deregulation has affected consumers’ welfare through shifts in the electric power price, where the actual price after the deregulation is compared to a hypothetical price path in absence of the deregulation. This alternative and hypothetical price path is based on the regulation guiding the Swedish power prices before 1996. The difference between the alternative price and the prevailing Swedish area price is then used to calculate the effects on consumer welfare, making it possible to quantify the effects on consumer welfare from changes in the electric power price, while excluding the impact of tax increases and other governmental interventions such as the effects of introducing green certificates (in 2003) and the EU Emissions Trading System (in 2005).

To construct the alternative price path it is important to understand how the pre-deregulated price was determined, since that should be the base for the alternative price. The pricing principle was described in the introduction, and could be approximated by average cost pricing. In this paper, average cost of electric power production is measured by the producer price index (PPI) for electricity production, and since the pricing principle in the regulated market can be approximated as average cost pricing (e.g. Damsgaard and Green (2005)), the PPI for electricity production will be used to derive the alternative price path if the market had not been deregulated. To convert the PPI from index form to a price path, the January 1996 power price is used as the base. That is, the January 1996 electric power
price is multiplied with the PPI for each month to get a price path that shows what the price would have been without the deregulation. The two alternative price paths are presented in Figure 3 below.

**Figure 3: Price comparison, 1996-2007**

![Price comparison chart](chart)

Source: Nord Pool and own calculation

To measure the effects on consumer welfare, the prevailing Swedish area price is compared to the alternative price path. The calculated EV-measure reveals that consumer welfare has increased by 4 billion SEK in 1996 prices over the period studied. Calculation shows the consumer welfare gains are less than 100 SEK per consumer per year, indicating a welfare gain just below three per cent for the average customer. Sensitivity analysis using alternative scenarios also support the conclusion that for the period studied the deregulation has increased, not decreased, welfare for the Swedish electricity consumers.

The finding of positive welfare effects is in line with previous literature (e.g. Bowitz et al, 2000 and Damsgaard and Green, 2005). The result is also consistent with Brännlund et al (2012), who, using a econometric approach, also find that higher consumer prices that have been observed since deregulation in large can be explained by increases in input prices and increasing tax levels, and not by the deregulation.
**Paper [III] Multinational Electricity Market Integration and Electricity Price Dynamics**

In the first paper of this thesis it has been shown that the Nord Pool power exchange has not been characterized by market power. It was shown that initially there were some minor problems with market power, but that expansion into a larger market seems to have reduced the problems. In the second paper it was shown that consumer welfare on average has not been affected to any large extent by the deregulation and the introduction of the new pricing scheme. However, as compared to a regulated market with prices reflecting average rather than marginal costs, it could be expected that the deregulated market has a higher volatility in prices. Higher volatility creates uncertainty for both consumers as well as producers, uncertainty that could affect both negatively.

Paper III empirically studies whether and to what extent the Nordic multinational electricity market integration has affected the electricity price dynamics on the Nordic power exchange. In particular, the focus is on determining what effect the multinational market integration, during the years 1996-2006 has had on the conditional mean electricity price, upon the conditional variance, upon the mean jump-intensity (expected frequency of larger price movements) and on the mean jump size. The question of how the multinational market integration has affected electricity price dynamics is of particular importance in light of the commitment within Europe towards further integration of other European electricity markets. An understanding of the effects of electricity market integration on electricity price dynamics will help participants, as well as decision makers, to build better expectations about the effects of future integration on electricity price dynamics.

Previous studies concerning electricity price dynamics, e.g. Byström (2005) and Guthrie and Videback (2007), have established a number of salient features concerning electricity price dynamics: (i) Mean reversion to the long-run equilibrium price level (reflecting the marginal cost of producing electricity) exists; (ii) Large daily volatilities (compared to financial price/return series) and volatility clustering is present; (iii) Jumps (large price changes) are frequently encountered; (iv) Price series show strong seasonal patterns mainly due to the strong dependence of electricity demand on weather conditions. In order to capture these features of electricity price dynamics a mixed EGARCH-jump model is utilized in the empirical study. The conditional mean specification (excluding contributions from jumps) of the electricity price includes autoregressive components reflecting mean reversion, as well as weather variables capturing seasonal effects. The time varying conditional variance component (EGARCH)
captures the smooth changes in volatility and allows for volatility clustering. The jump component explains the more infrequent larger price movements. The model allows for both positive as well as negative jumps, i.e. a mean jump size permitted to be either positive or negative is estimated, which is important for electricity price modeling since large jumps are often followed by a reverse price jump.

Empirically the study reveals that the conditional mean electricity price increased when Finland entered, and remained at this higher level when Denmark also joined. Turning to the price volatility, this increased with Finland's entrance, but decreased when Denmark joined. However, the price jump-intensity decreased both when Finland and Denmark entered the market. In short, this means that a larger electricity market seems to reduce the probability of sudden price jumps, but also that the effect on volatility seem to depend on the characteristics, i.e. production structure, of the integrated markets.


In the third paper in the thesis, we found that the multinational electricity market integration seems to have created a market that handles external shocks to supply and demand more efficient than the separate national markets previously did. However, one question that was left unanswered in paper III was the cause of electricity price jumps. As such, the purpose of paper IV is to empirically explore the possible causes behind electricity price jumps in the Nordic electricity market. The question is analysed empirically using essentially the same data set as in paper III, covering 1996-2006.

For people working with risk management, portfolio management and electricity derivative pricing an understanding of electricity price dynamics is crucial when doing business. Since electricity is not a storable good the conventional derivatives pricing models based on Black-Scholes model are not appropriate. Instead valuation of electricity derivatives is dependent on models that properly describe the dynamics of the underlying electricity spot price (e.g. Huisman and Mahieu, 2003). As a consequence a literature (e.g Pilipovic, 1998; Lucia and Swartz, 2002; Huisman and Mahieu, 2003; Byström, 2005; Guthrie and Videback, 2007) has emerged focusing on characterizing electricity price dynamics.

One of the well documented features of electricity prices in the literature concerns the frequent occurrence of large price changes or jumps. The occurrence of electricity price jumps is often loosely motivated by shocks to the electricity demand or to an inelastic electricity supply, but these possible causes for price jumps have, to the author’s knowledge, not previously been formally studied. In paper IV, a two-stage study is conducted to investigate
the extent to which shocks in the demand and supply for electricity translate into electricity price jumps, and the extent to which this process is affected by the prevailing market structure.

A mixed GARCH-EARIJ jump model is utilized in the first stage to identify electricity price jumps by properly separating “normal” variation from that caused by price jumps. In the second stage ordered probit models with the identified price jumps as the dependent variable are utilized to empirically study the question at issue. The used proxies for exogenous demand and supply shocks are day to day changes in temperature and in nuclear power production, respectively.

The main findings from the study is that whether demand and supply shocks translate into electricity price jumps largely depends on the prevailing market structure, i.e. on how far the market works from capacity constraints. This result is loosely consistent with the perspective considered in Paper III in that the price volatility and jump probabilities will be determined by how close to the capacity constraints the market is working. Through a simple supply and demand analysis at an aggregate level it can be seen in Figure 4 that, after Finland entered the Nord Pool collaboration (Period 2), the intersection of demand and supply was relatively closer to the capacity constraint, in which price jumps, in particular positive jumps, are more likely to occur.

**Figure 4: Electricity supply and demand in the Nord Pool area**

![Electricity supply and demand graph]

Source: Nordel and own calculation

However, after Denmark entered Nord Pool (Period 3), the intersection was shifted somewhat further away from the capacity constraint. Such a
movement would mitigate the impact from temporary positive demand shocks, which in turn decreases the probability of positive price jumps. A notable feature of the empirical analysis is also that the marginal effects from positive demand and negative supply shocks on the jump probabilities are mostly insignificant and of small magnitude.

### 3 General findings and policy implications

Paper I analysed the presence of market power at Nord Pool. The main conclusion is that pricing in the Nord Pool works relatively well and that market power has been reduced as the market has grown larger. The policy conclusion here is that larger electric power markets work better to prevent the exercise of market power. The conclusion should remain even today since it is based on basic economic principles that more companies in a market create better conditions for competition.

However, it should be noted that the results in paper I are based on aggregated prices at the system price level with no transmission constraints. Thus, the results does not say anything about how the competition work in shorter time spans and how competition is affected if transmission is congested resulting in several price areas. Since the analysis is based on a weekly average data, use of market power in shorter terms than that are not analysed. However, systematic use of market power in shorter time periods should be, if it is extensive, visible even in an aggregate analysis. Thus, the fact that the analysis at the aggregated level only show a small impact of use of market power indicate that any abuse also should have a small impact for shorter time frames.

The transmission constraint issue is that congested transmission lines create separate price areas and thus several smaller markets. This could have impact on the competitive behavior in the market. One example is the introduction of four bidding areas in Sweden in 2011, dividing Sweden into smaller price areas when transmission capacity within Sweden is not sufficient. Previous research (Steen, 2003, Damsgaard et al, 2007) has shown that congestion on transmission lines can affect how firms act and market outcomes. However, upcoming market development, with increased transmission capacity and possibly more active customers, can further reduce potential market abuse. One conclusion that can be drawn from paper I regarding this discussion is that given that there is sufficient transmission capacity, competition will take place in a larger market, and accordingly work better. On the other hand one can also say that a deregulation which opens up competition probably is not sufficient for achieving an efficient competitive market as long as there exists severe limitations in transmission capacity. Finally, development after 2007 also implicates more intermittent power in the system. How this development
affects the prices and the market’s ability to withstand market power is out of the scope of the thesis since the data used does not cover this time span. However, it does not seem very bold to say that short run price volatility will increase in the future. This matter is discussed in e.g. Mauritzen (2010) and Twomey and Neuhoff (2010).

Paper II in this thesis analysed how the deregulation of the Swedish electricity market has affected the price of electric power and how the shift in the pricing scheme, in turn, has affected consumers’ welfare. The conclusion of the analysis is that the deregulation has affected the well-being positively. This is also in line with previous literature, e.g. Bowitz et al (2000), Damsgaard and Green (2005). Brännlund et al (2012) uses an econometric approach also finding that the deregulation did not affect consumers’ welfare negatively.

One reason for the result is that while the price path under deregulation has been volatile with both dips and peaks, the alternative price has been more stable but at a higher price level. The less volatile alternative price path is due to differences in the pricing methods. The deregulated price is more volatile because the price is determined by supply and demand in a competitive environment, and set equal to the cost of the marginal unit of energy production necessary to meet demand, while the pre-deregulated price resembled average cost pricing. The average cost based price does not fluctuate as much as the marginal unit based price because a sudden demand increase (decrease) – and the subsequent price jump (dip) – is averaged out by the other facilities. In the deregulated case, a sudden demand increase will instead allow those generation facilities with a marginal cost lower than the marginal facility, to increase their profits.

The main policy conclusions of paper II is that the change in pricing mechanism has been to the benefit of the customers. An assumption of the analysis was that the production structure in Sweden did not change dramatically after the deregulation, which also is shown in Table 1. If the production structure had changed it would be more difficult to draw conclusions regarding the price changes. In the light of climate change and how it has affected policies regarding electric power generation, leading to more renewable energy sources, the electricity power mixture has started to change after 2007. This could be a reason to re-evaluate the impact of the pricing scheme change after the deregulation. However, in terms of welfare changes, the new policy regarding renewables has nothing to do with the change of pricing principle following the deregulation as such and should therefore not be incorporated in the welfare analyses of the impact of the deregulation.

In paper III, we empirically studied whether and to what extent the Nordic multinational electricity market integration has affected electricity price dynamics in Nord Pool. The results indicated that a larger electricity market
seems to lower the probability of sudden price jumps, but that the effect on volatility depends on the production structure of the integrated markets. This implies that multinational electricity market integration seems to have created a market that handles external shocks to supply and demand more efficiently than the separate national markets previously did.

However, the conclusion that a larger electric power market will lower the probability of price jumps and handle external shocks more efficiently, rests on an implicit assumption that the interconnection between areas are strong enough to keep the different areas together as one. With the focus on an internal European market for electricity new interconnectors are built and the transmission capacity strengthened. As such the policy implication of paper III still holds and is of even more relevance today and in the future than during the studied period.

The conclusions in paper III that the price volatility will be determined by how close to the capacity constraint the market is working and that the size of the price jumps also depend on the capacity constraint in the market are still valid today. The result is driven by different costs of operating the different power plants. Baseload electric power is relatively cheap but when the market is moving towards the capacity limit more expensive electric power is needed for supply and demand to add up. As long as the market concept we have today is intact, there will be different production technologies in the market, with different marginal costs, resulting in a merit order curve suggesting increased probability of large price jumps when the market is working near its capacity limit, the same argument holds for price volatility.

The results in paper III can also provide some intuition about further European electricity market integration, in that the change toward more thermal power in the Nord Pool area is similar to what is expected from further European market integration. Further European integration would result in a production structure with relatively more thermal power, compared to the current Swedish structure, which could increase Swedish electric power prices. This can be verified by comparing the production mixture in Sweden for the period studied (1996-2007) to the overall European production mixture. In Sweden approximately five per cent of the electric power is produced using thermal power plants. In 2009 more than 40 per cent of the electric power production in EU-27 came from coal fired plants (www.IEA.com). As such, further market integration with Europe will cause the Swedish mixture to be of relatively more thermal power. Thermal power is relatively more expensive to produce than electric power from hydro and nuclear power plants, and this can, combined with more interconnectors in the future, imply that the marginal unit more often will be the more expensive thermal power, also in Sweden. However, it should also be mentioned that including more intermittent power sources could affect
the outcome. Research results indicate that more wind power in the system can cause average price to decline but volatility to increase (e.g. Elforsk, 2009, Green and Vasilakos, 2012 and Mauritzen, 2013).

Paper IV investigates to what extent shocks in demand and supply for electricity translate into electricity price jumps, and how this process is affected by the prevailing market structure. The main findings from the study are that the prevailing market structure, i.e. on how far the market works from capacity constraints will determine how the demand and supply shocks translate into electricity price jumps. A notable finding of the empirical analysis is that the marginal effects from positive demand and negative supply shocks on the jump probabilities are mostly insignificant and of small magnitude. One interpretation of this is that the market is working relatively efficiently in handling these types of shocks. It is also concluded that from a Nordic perspective, market integration seems to have worked well in terms of creating a market more capable of handling external shocks, especially in periods when the market has not been working close to capacity constraints.

To make an overall conclusions from the four papers in this thesis there are two things that should be highlighted. First, the pricing of electric power, i.e. marginal cost pricing, seems to have created an electric power market that is competitive and also is beneficial for consumer welfare. Secondly, enlarging electric power markets seems to have several good implications. Larger markets works to; i) prevent market power abuse, ii) reduce the probability for sudden price jumps, iii) create better conditions for markets to handle external shocks to supply and demand. However, to some extent all this is conditional on interconnections between different areas.

All in all, from the general findings in this thesis there are some overall policy conclusions to be made.

- First, the pricing of electric power at Nord Pool seems to be close to marginal cost pricing. As such, pricing at Nord Pool seems to be close to that in a competitive market, and there is no need to intervene in the market for this reason. Nevertheless, policy makers should be careful in monitoring future developments in the electric power market. One reason for this is that introduction of more intermittent renewable energy such as wind- and solar power will have an impact on the electric power market.
- Second, the change of pricing method following with the deregulation has been beneficial for consumer welfare. As such, there is no need for policy makers to intervene in the electric power market’s pricing principle to protect customers against high prices. If policy makers are to lower the customers electricity price they
should concentrate on other factors contributing to the price the customer faces, i.e. taxes and environmental fees, or work towards making customers more price sensitive and more active in their decisions when to consume the electricity.

- Third, enlarging electric power markets has reduced the probability of sudden price jumps. Price jumps are in most circumstances not beneficial for customers as they are often risk averse and prefer their price to be stable.

- Fourth, enlarging electric power markets seems to have created better conditions for the market to handle external shocks to supply and demand than separate national markets previously did. As this is beneficial for risk averse market participants, it is another reason for policy makers to continue the work towards an internal European market for electricity.

- Fifth. The knowledge that how close to the capacity constraint the market is working will affect the volatility and also how large price spikes can be has to be communicated to policy makers. It is then up to them to decide how to handle the matter. If policy makers are to lower the price spikes one solution is to build more capacity, another is to get the demand side more active and lower their consumption when price spikes occur.

- Last, but not least. In order for electricity market reforms and market integration to achieve their goals, the policy makers need to address that electricity market reforms has to be supplemented with enough transmission capacity. With sufficient transmission capacities between areas the relevant market area expands and the reforms have a better chance to succeed.

4 Future research

The rapid progress of the electricity market, both in Sweden and in Europe, implies that new research questions emerge, but also that previously interesting questions suddenly become obsolete. This demands that the research keep up with the changes. Old research results are not necessarily true when market conditions change and the decision makers need all the help they can get to get it right.

The research presented in this thesis give answers to some questions, but also raises new questions. In the light of the scope of this thesis it is in three particular areas that I would like to highlight regarding future research. First, regarding analyses of market power abuse the progress towards more intermittent electric power production sources need to be addressed even more. This is done by e.g. Mauritzen (2010) and Twomney and Neuhoff (2010). However, more research is needed in the light of intermittent electric
power growing fast. More research in the subject is also needed in the setting of the Nordic area where the intermittent production is incorporated in a hydro dominated power system.

Secondly, the effect of a more elastic demand side is another interesting subject for future research. Sweden could be an interesting case as the households from 1 October, 2012 can get hourly reading of their electricity consumption. This may have several interesting implications worth studying. For example how the price elasticity is affected and if the Nord Pool prices are affected by that. And if the price elasticity increases, what are the effects for the market functioning? Does it affect utilization of market power in electric power markets as theory foresees it should?

Thirdly, regarding the electric power price dynamics an elaboration on how different variables contribute to price spikes and volatility should be interesting, and also a natural continuation on paper IV. Also, using more high frequent data as well as accounting for possible congestion in the transmission system should be interesting to incorporate in the analysis.

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Elforsk 09:102: “Effects of Large Scale Wind Capacities in Sweden”.


We examine if the Nordic power market, Nord Pool, has been competitive or if electricity suppliers have had market power. Specifically, since the evolution from national markets to a multi-national and largely deregulated power market has taken place stepwise, we also examine how the degree of market power has evolved during this integration process. The Bresnahan–Lau method together with weekly data during 1996–2004 are used in the analysis, which shows that electricity suppliers have had small, but statistically significant, market power, but that the market power has been reduced as the Nord Pool area has expanded.

I. Introduction

Denmark, Finland, Norway and Sweden have cooperated during several years to provide their citizens with an efficient and reliable electricity source. In fact, all of them have reformed their electricity sectors and have today access to a common power market consisting of two parts: (i) bilateral trade of contracts between operators and (ii) the nonmandatory power exchange, Nord Pool.

Because of these reforms, it is natural to ask whether they have been successful: has the common power market been competitive or have electricity suppliers had market power? Moreover, since there was a stepwise evolution from national markets to a multi-national and largely deregulated power market, we also ask how the degree of market power has evolved during this integration process?

A straightforward measure of a market’s competitiveness is the price-marginal cost markup since it is zero at a perfectly competitive market, meaning that the electricity price should equal the production cost of the marginal unit of electricity. However, even though market prices are easily accessible in the Nordic power market, this is not the case with marginal costs and some other method must be used to measure the degree of market power. One such method is a conjectural variation method named as the Bresnahan–Lau method (Bresnahan, 1982; Lau, 1982).

The conjectural variation elasticity at the industry level is the average of the individual firms’ conjectural variation elasticities, which measure the firms’ output response to the single firm’s output change as conjectured by this firm. Thus, if there is perfect competition, there is no output response since a single
firm cannot affect output at the industry level, whereas the response is one-to-one if there is no competition since the industry behaves as a single firm.

The conjectural variation elasticity is estimated from a two-equation system, where the first equation is electricity demand as a function of electricity price and at least one exogenous variable, whereas the second equation is electricity supply, derived from profit maximization, which is electricity price as a function of industry output, the same exogenous variables as in electricity demand and maybe some other exogenous variables.

The exogenous variables are introduced to solve an identification problem. Bresnahan (1982) solved this problem by using a rotation variable in the demand equation, whereas Lau (1982) showed that the identification of market power is possible as long as demand is nonseparable in at least one exogenous variable. Thus, if at least one exogenous variable is part of an interaction term in the demand equation, the identification problem is solved since the interaction term acts as a rotation variable and it is also nonseparable in the exogenous variable.  

Hjalmarssson (2000) and Vassilopoulos (2003) are the only studies that we are aware of which measures the degree of market power in the Nord Pool area, and they find that the power market has been competitive. However, none of them studies the effect of market expansion on the degree of market power, meaning that the present article fills a gap in the literature.

The rest of this article is outlined as follows: The Bresnahan–Lau method or model is presented in Section II, Section III contains the empirical analysis and Section IV concludes this article with a discussion.

II. The Bresnahan–Lau Model

The static model

The Bresnahan–Lau model is a static model since there are no lagged or lead values of the variables included. Specifically, the electricity demand function is

\[ Q = D(P, Z; \alpha) + \varepsilon \]  

where \( Q \) is quantity demanded, \( P \) is price of power, \( Z \) is a vector of exogenous variables, \( \alpha \) is a vector of parameters to be estimated and \( \varepsilon \) is a random term. Moreover, the electricity supply relation is

\[ P = c(Q, W; \beta) - \lambda h(Q, Z; a) + \eta \]  

where \( W \) is a vector of exogenous variables, \( \beta \) is a vector of parameters to be estimated, \( \lambda \) is the degree of market power and \( \eta \) is a random term.

\( c(\cdot) \) in Equation 2 is the marginal cost of producing electricity, meaning that when \( \lambda = 0 \), the price of power is equal to the marginal cost and we have a perfectly competitive power market since all suppliers of electricity are price-takers. However, when suppliers are price-setters, the marginal revenue as perceived by the single supplier is equal to the marginal cost, and this is because \( P + h(\cdot) \) is the marginal revenue at the industry level and \( \lambda \) is the perceived percentage of this revenue. Thus, when \( \lambda = 1 \), we have a perfect cartel in the power market.

Then, by assuming a linear demand function for electricity,

\[ Q = \alpha_0 + \alpha_P P + \alpha_Z Z + \alpha_{PZ} PZ + \varepsilon \]  

including an interaction term between \( P \) and \( Z \) that acts as a rotation variable, and a linear marginal cost function,

\[ c(\cdot) = \beta_0 + \beta_Q Q + \beta_W W \]  

the electricity supply relation is

\[ P = \beta_0 + \beta_Q Q + \beta_W W - \lambda \cdot \left( \frac{Q}{\alpha_P + \alpha_{PZ} Z} \right) + \eta \]  

Thus, if we first estimate Equation 3, meaning that we can calculate \( Q^* \), we can identify the degree of market power, \( \lambda \), after having estimated Equation 5.

The dynamic model

Steen and Salvanes (1999) argue that a dynamic reformulation of the Bresnahan–Lau model into an error-correcting framework is necessary for two reasons. The first reason is that this framework allows for short-run deviations from long-run equilibrium in data, and the second reason is that this framework solves the inference problem when using non-stationary data.

\[ \text{II. The Bresnahan–Lau Model} \]

\[ \text{The static model} \]

\[ \text{The dynamic model} \]

\[ \text{The conjectural variation elasticity is estimated from a two-equation system, where the first equation is electricity demand as a function of electricity price and at least one exogenous variable, whereas the second equation is electricity supply, derived from profit maximization, which is electricity price as a function of industry output, the same exogenous variables as in electricity demand and maybe some other exogenous variables.} \]

\[ \text{The exogenous variables are introduced to solve an identification problem. Bresnahan (1982) solved this problem by using a rotation variable in the demand equation, whereas Lau (1982) showed that the identification of market power is possible as long as demand is nonseparable in at least one exogenous variable. Thus, if at least one exogenous variable is part of an interaction term in the demand equation, the identification problem is solved since the interaction term acts as a rotation variable and it is also non-separable in the exogenous variable.} \]

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where \( W \) is a vector of exogenous variables, \( \beta \) is a vector of parameters to be estimated, \( \lambda \) is the degree of market power and \( \eta \) is a random term.

\( c(\cdot) \) in Equation 2 is the marginal cost of producing electricity, meaning that when \( \lambda = 0 \), the price of power is equal to the marginal cost and we have a perfectly competitive power market since all suppliers of electricity are price-takers. However, when suppliers are price-setters, the marginal revenue as perceived by the single supplier is equal to the marginal cost, and this is because \( P + h(\cdot) \) is the marginal revenue at the industry level and \( \lambda \) is the perceived percentage of this revenue. Thus, when \( \lambda = 1 \), we have a perfect cartel in the power market.

Then, by assuming a linear demand function for electricity,

\[ Q = \alpha_0 + \alpha_P P + \alpha_Z Z + \alpha_{PZ} PZ + \varepsilon \]  

including an interaction term between \( P \) and \( Z \) that acts as a rotation variable, and a linear marginal cost function,

\[ c(\cdot) = \beta_0 + \beta_Q Q + \beta_W W \]  

the electricity supply relation is

\[ P = \beta_0 + \beta_Q Q + \beta_W W - \lambda \cdot \left( \frac{Q}{\alpha_P + \alpha_{PZ} Z} \right) + \eta \]  

Thus, if we first estimate Equation 3, meaning that we can calculate \( Q^* \), we can identify the degree of market power, \( \lambda \), after having estimated Equation 5.

\[ \text{The dynamic model} \]

Steen and Salvanes (1999) argue that a dynamic reformulation of the Bresnahan–Lau model into an error-correcting framework is necessary for two reasons. The first reason is that this framework allows for short-run deviations from long-run equilibrium in data, and the second reason is that this framework solves the inference problem when using non-stationary data.
Market power in the expanding Nordic power market

Start by writing the electricity demand function as an autoregressive distributed lag model:

\[ Q_t = \alpha_0 P_t + \alpha_{1} P_{t-1} + \alpha_{Z,0} Z_t + \alpha_{Z,1} Z_{t-1} + \alpha_{X,0} X_t + \alpha_{X,1} X_{t-1} + \epsilon_t \]  

(6)

and continue by writing the electricity supply relation as an autoregressive distributed lag model:

\[ P_t = \beta_{0} Q_t + \beta_{1} Q_{t-1} + \beta_{W,0} W_t + \beta_{W,1} W_{t-1} + \lambda_0 Q_t^* + \lambda_1 Q_{t-1}^* + \beta_{P,1} P_{t-1} + \eta_t \]  

(7)

where the long-run stationary equilibrium is found by setting \( Q_t = Q_{t-1}, P_t = P_{t-1}, Z_t = Z_{t-1}, PZ_t = PZ_{t-1}, W_t = W_{t-1} \) and \( Q_t^* = Q_{t-1}^* \). Thereafter, if we relax the restriction of one lag and include an intercept term, Equations 6 and 7 can be written in error-correcting forms as follows:

\[ \Delta Q_t = a_0 + \sum_{k=1}^{\infty} \alpha_{Q,k} \Delta Q_{t-k} + \sum_{i=0}^{\infty} \alpha_{P,i} \Delta P_{t-i} + \epsilon_t \]  

(8a)

\[ \Delta P_t = \beta_0 + \sum_{k=1}^{\infty} \beta_{Q,k} \Delta Q_{t-k} + \sum_{i=0}^{\infty} \beta_{P,i} \Delta P_{t-i} + \psi_{P,Q} \Delta Q_{t-k} + \epsilon_t \]  

(8b)


III. Empirical Analysis

Data set

The data set consists of weekly data from all Nord Pool participants, covering the period from week 1 in 1996 to week 16 in 2004. See Table 1 for the dates in the integration process, and Table 2 for the variables used, their definitions and data sources.

<table>
<thead>
<tr>
<th>Country</th>
<th>Date for affiliation</th>
<th>Date for complete integration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norway</td>
<td>1 January 1993</td>
<td>1 January 1993</td>
</tr>
<tr>
<td>Sweden</td>
<td>1 January 1996</td>
<td>1 January 1996</td>
</tr>
<tr>
<td>Finland</td>
<td>29 December 1997</td>
<td>1 March 2002</td>
</tr>
<tr>
<td>Western Denmark</td>
<td>1 July 1999</td>
<td>1 March 2002</td>
</tr>
<tr>
<td>Eastern Denmark</td>
<td>1 October 2000</td>
<td>1 March 2002</td>
</tr>
</tbody>
</table>

The price variable is Nord Pool’s spot price at the system level (\( P \)). Further, since the industry sector is the largest consumer of electricity, we include industrial production (\( Prod \)) when studying electricity demand. A problem, however, is that data are available only on a monthly basis, whereas all other variables are available on a weekly basis. There are two options at hand: (i) to exclude this variable (Vassilopoulos, 2003) or (ii) to interpolate data into weekly estimates (Hjalmarsson, 2000). We choose to interpolate since the variation of this important variable within each month is expected to be small.

Two other variables affecting electricity demand are the temperature (\( Temp \)), which is a proxy for the amount of electricity needed for heating, and the length of a day (\( Daylength \)), which is a proxy for the amount of electricity needed for lighting. We also need at least one interaction variable to be able to identify the degree of market power. For this reason, we let the spot price at the system level to interact with the temperature as well as the length of a day in the Nord Pool area (\( P*Temp \) and \( P*Daylength \)).

To determine electricity supply, we need to approximate the marginal cost function and also find variables that shift this function. For this reason, we look at the opportunity cost of hydro generation, and two factors that affect this cost are inflow of water to reservoirs (\( Inflow \)) and how full they already are. We choose the inflow variable as a shift variable.

The Nordic power market consists of a relatively large amount of hydro generation, which is a cheap electricity source and has almost no variable costs (Andersson and Bergman, 1995), meaning that hydro power is a base load electricity. When more energy is needed, more expensive sources such as thermal power are used, and this residual electricity is produced with a number of inputs such as bio fuel, coal, gas and oil.

Contrary to hydro power, the technology of residual electricity has higher and more variable costs (Green and Newbery, 1992). Therefore, we incorporate the coal price (\( Coal \)) and the Brent crude
oil price (Oil) into electricity supply to account for the thermal part of electricity generation. Moreover, to account for the residual electricity trend, we include residual electricity in relation to total electricity production (Reset) as a variable in the analysis.

Finally, the increase in electricity traded at Nord Pool's spot market is an exogenous trend that need to be taken into consideration when building the empirical model. Following Hjalmarsson (2000), this is accomplished by regressing the system turnover (Turnover) on the market share (Market share) and, thereafter, use the residual as a detrended quantity variable (Q).

See Table 3 for descriptive statistics of the variables used in the empirical analysis in the different subperiods in the integration process.

Statistical tests

Before specifying the two-equation regression model, we need to test if the variables are stationary. If this is not the case, we also need to test for cointegration to ensure the existence of a long-run equilibrium in data.

Finally, a separability test is preformed on the interaction variables to make sure that the degree of market power is identifiable (Lau, 1982).

Dickey–Fuller’s augmented unit root test is used in companion with the Akaike Information Criterion (AIC) to test if the variables are stationary. However, a potential problem is that the variables are highly seasonal, meaning that we have to deseasonalize data before using the test. This is accomplished by introducing weekly dummy variables and estimate the following equation:

$$y_t = \alpha_0 + \sum_{i=2}^{5} \alpha_i Week_i + \hat{\gamma}_t$$  \hspace{1cm} (10)

where \(\hat{\gamma}_t\) is the regression residual, which is the deseasonalized value of \(y_t\). See Table A1 in the Appendix for results.

Thereafter, we use the Johansen (1988) approach to search for cointegrated relations between the variables. Specifically, we use the Johansen and Juselius (1990) multivariate cointegration test, which is a maximum likelihood test on the results from a
vector autoregression. As above, a potential problem is that the variables are highly seasonal, meaning that deseasonalized data are used in the tests. See Tables A2 and A3 in the Appendix for results, which show that we have cointegrated relationships among the integrated variables, both at the demand and supply sides of the power market.

Finally, electricity demand must be nonseparable in at least one of the interaction variables, and the appropriate test is an extension of the cointegration test by introducing restrictions that the interaction variables are zero. The restricted model is, thereafter, compared to the unrestricted model using a likelihood ratio test. See Table A2 in the Appendix for results, which show that the interaction variables should be included in the regression model.

### Estimation results

The demand function and the supply relation for electricity are

\[
Q_{ij} = a_0 + \sum_{i=1}^k a_{Qj, t-i} Q_{t-i} + \sum_{i=1}^k a_{Prod, t} Prod_{t-i} + \sum_{i=0}^k a_{Temp, t} Temp_{t-i} + \sum_{i=0}^k a_{Daylength, t} Daylength_{t-i} + \sum_{j=1}^l \sum_{i=0}^k a_{CV_j, t} CV_{j, t-i} + \varepsilon_t \tag{11}
\]

and

\[
\Delta P_{mji} = \beta_0 + \sum_{m=1}^M \sum_{i=1}^k \beta_{Pm, t-i} \Delta P_{m, t-i} + \sum_{j=0}^J \beta_{Qj, t-i} Q_{t-i} + \sum_{j=0}^J \sum_{i=0}^k \lambda_j Q_{t-i} + \sum_{j=0}^J \sum_{i=0}^k \beta_{Inflow, t-i} Inflow_{t-i} + \sum_{j=0}^J \sum_{i=0}^k \beta_{Coal, t-i} Coal_{t-i} + \sum_{j=0}^J \sum_{i=0}^k \beta_{Oil, t-i} Oil_{t-i} + \sum_{j=0}^J \sum_{i=0}^k \beta_{Resel, t-i} Resel_{t-i} + \sum_{j=0}^J \sum_{i=0}^k \gamma_C V_{j, t-i} + \eta_t \tag{12}
\]

where \(\{CV\}_{j=1}^l\) are cointegrated vectors. Because of a simultaneity problem that arises in demand and supply models, two-stage least squares is used in the analysis. In Equation 11, the first lag of the system price, the temperature, and the inflow of water to reservoirs are used as instruments, and in Equation 12, the temperature and the length of a day are used as instruments. Both equations are estimated using autocorrelation and heteroscedasticity consistent SEs.

First, Equation 11 is estimated for the whole period using five lags. Insignificant variables are, thereafter, removed from the regression equation and a parsimonious model is derived. See Table A4 in the Appendix.
Appendix for results for the whole period and for each subperiod in the integration process, which show that lagged quantities have a positive impact on electricity demand. The estimates for the cointegrating vectors show that the current price has a negative impact on electricity demand. Moreover, increased temperature and longer days cause electricity demand to fall.

Second, Equation 12 is estimated including $Q/C_3^{[-1]} = Q/C_1 + \ldots + P$, in the regression equation. Since the price variables are nonstationary, an error-correction model is used to estimate electricity supply, and as the error-correction term, we use the first lag of the cointegrating vector. Electricity supply is estimated for the whole period, and a parsimonious model is derived as above, which is estimated for each subperiod in the integration process. See Table A5 in the Appendix for results, which show that the inflow of water to reservoirs has a negative impact on electricity price, while the use of residual electricity has a positive impact on this price. The error-correction term indicates a slow error-correction in line with previous literature (Hjalmarsson, 2000; Vassilopoulos, 2003).

Finally, estimates of the degree of market power, $\lambda$, are found in Table 4. The results show that electricity suppliers have had a small, but statistically significant, degree of market power during the whole period, even though it has been reduced as the market has expanded. In the last subperiod, there was no market power in the Nordic power market. In economic terms, the estimated market powers indicate small markups over marginal costs. In fact, the implied Lerner index gives a markup of less than 1% in the different subperiods and an even smaller markup for the whole period.

### IV. Discussion

The aim of this article has been to examine how the degree of market power has changed as the Nordic power market has evolved from national markets to a multi-national market. While previous studies have not found any evidence of market power in the Nord Pool area (Hjalmarsson, 2000; Vassilopoulos, 2003), our study, which uses a more comprehensive data set, indicates that there has been a small, but statistically significant, degree of market power during almost the whole period. More importantly, our results show that the degree of market power has been reduced as the market has expanded.

However, the implied Lerner index gives a markup of less than 1% over marginal cost, meaning that the impact of market power on the electricity price has not been that severe. Steen (2003) examined the Norwegian market with results similar to ours and concluded that ‘the results are probably more a word of warning that we should be careful to allow more concentration in this market’. Most likely, there are several reasons why the markup has been low, one of them being the threat of entry.

Wolfram (1999) argues that there are two reasons why firms in the UK have not utilized all potential market power: (i) the threat of market interventions from the authorities and (ii) the threat of entry into the market. Although her results may not be directly transferable to the Nordic power market, Edin (2006) argues that it is possible that the threat of entry has kept the price close to marginal cost also in the Nordic market.

Moreover, Amundsen and Bergman (2002) analyse the effect of cross-ownerships in the electricity market and how mergers will affect this market. They conclude that mergers and cross-ownerships may re-establish at least part of the market power that the deregulation has removed.

Finally, Amundsen and Bergman (2006) compare the Nordic power market to the Californian power market and find that the Nordic market has worked well. This is because the Nordic market is characterized by a simple but sound market design, successful dilution of market power, strong political support for a market-based electricity system, and voluntary

### Table 4. Degree of market power

<table>
<thead>
<tr>
<th>Variable</th>
<th>9601–0416</th>
<th>9601–9908</th>
<th>9909–0209</th>
<th>0210–0416</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q^*$</td>
<td>6.97E–05*</td>
<td>5.56E–04**</td>
<td>2.02E–04*</td>
<td>-7.58E–04</td>
</tr>
<tr>
<td></td>
<td>(1.47E–05)</td>
<td>(2.38E–04)</td>
<td>(5.26E–05)</td>
<td>(2.06E–03)</td>
</tr>
</tbody>
</table>

Notes: 9601–0416 refers to the period week 1 of 1996 to week 16 of 2004, etc. * and ** significant at the 1 and 5% levels, respectively.

3 $\lambda \in [0, 1]$ in Table 4. However, since no minus sign is included in the regression equation, $\lambda$ changes sign. Therefore, in Table A5 in the Appendix, $\lambda \in [-1, 0]$.

4 The implied Lerner index is defined as $(P - MC)/P = -\lambda/\varepsilon$, where $\varepsilon$ is the demand elasticity (Steen, 2003).
informal commitment to public service by the power industry.

**Acknowledgements**

The authors are grateful to an anonymous referee, Jörgen Hellström, Mark Taylor and seminar participants at Umeå University for helpful comments and suggestions as well as for financial support from the JC Kempe Memorial Foundation and Sparbankernas Forskningsstiftelser. The usual disclaimer applies.

**References**


Appendix

Table A1. Augmented Dickey–Fuller (ADF) unit root tests

<table>
<thead>
<tr>
<th>Variable</th>
<th>I(0) Lags</th>
<th>I(1) Lags</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P$</td>
<td>−2.73 7</td>
<td>−9.10* 6</td>
</tr>
<tr>
<td>Prod</td>
<td>−2.94 9</td>
<td>−11.82* 8</td>
</tr>
<tr>
<td>Temp</td>
<td>−6.05* 7</td>
<td>−</td>
</tr>
<tr>
<td>Inflow</td>
<td>−7.50* 2</td>
<td>−</td>
</tr>
<tr>
<td>Coal</td>
<td>−1.85 14</td>
<td>−3.49* 13</td>
</tr>
<tr>
<td>Oil</td>
<td>0.24 6</td>
<td>−10.57* 5</td>
</tr>
<tr>
<td>Resel</td>
<td>−3.20 5</td>
<td>−9.13* 4</td>
</tr>
<tr>
<td>$P*Temp$</td>
<td>−3.21* 8</td>
<td>−</td>
</tr>
<tr>
<td>$P*Daylength$</td>
<td>−4.18 9</td>
<td>−</td>
</tr>
</tbody>
</table>

Notes: The critical values are from Fuller (1976).
* significant at the 1% level.

Table A2. Multivariate cointegration test of the demand function

<table>
<thead>
<tr>
<th>Demand function</th>
<th>95% critical value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 cointegration vector $r = 0$</td>
<td>71.69* 29.70</td>
</tr>
<tr>
<td>1 cointegration vector $r \leq 1$</td>
<td>30.04* 15.40</td>
</tr>
<tr>
<td>2 cointegration vectors $r \leq 2$</td>
<td>5.93** 3.76</td>
</tr>
</tbody>
</table>

Standardized eigenvectors

<table>
<thead>
<tr>
<th>Variable</th>
<th>$P$</th>
<th>Prod</th>
<th>$P*Daylength$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$CV1$</td>
<td>1.00</td>
<td>0</td>
<td>−0.01</td>
</tr>
<tr>
<td>$CV2$</td>
<td>1.00</td>
<td>853.46</td>
<td>0</td>
</tr>
</tbody>
</table>

Separability tests

$H_0$: $\beta_{1,P} = \beta_{2,P} = 0$

$H_0$: $\beta_{2,Prod} = 0$

$H_0$: $\beta_{1,P*Daylength} = 0$

Notes: The critical values are from Osterwald-Lenum (1992).
* and ** significant at the 1 and 5% levels, respectively.

Table A3. Multivariate cointegration test of the supply relation

| Supply relation
| 95% critical value |
|---------------------|--------------------|
| 0 cointegration vector $r = 0$ | 31.30** 29.70 |
| 1 cointegration vector $r \leq 1$ | 16.23** 15.40 |
| 2 cointegration vectors $r \leq 2$ | 6.21** 3.76 |

Standardized eigenvectors

<table>
<thead>
<tr>
<th>Variable</th>
<th>$P$</th>
<th>Oil</th>
<th>Resel</th>
</tr>
</thead>
<tbody>
<tr>
<td>$CV1$</td>
<td>1.00</td>
<td>−1.69</td>
<td>−110.93</td>
</tr>
<tr>
<td>$CV2$</td>
<td>1.00</td>
<td>−51.07</td>
<td>−2.36E+05</td>
</tr>
</tbody>
</table>

Notes: The critical values are from Osterwald-Lenum, (1992).
*$k = 2$ number of lags, $n = 430$ number of observations.
** significant at the 5% level.
Table A4. Estimation results of the demand function

<table>
<thead>
<tr>
<th>Variable</th>
<th>9601–0416</th>
<th>9601–9908</th>
<th>9909–0209</th>
<th>0210–0416</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>4.60E+05* (9.41E+05)</td>
<td>3.43E+05* (1.28E+05)</td>
<td>7.25E+05* (1.53E+05)</td>
<td>4.95E+05** (2.36E+05)</td>
</tr>
<tr>
<td>Q(−1)</td>
<td>0.78* (0.04)</td>
<td>0.90* (0.03)</td>
<td>0.52* (0.05)</td>
<td>0.67* (0.11)</td>
</tr>
<tr>
<td>Temp</td>
<td>−4.65E+04*** (1.85E+04)</td>
<td>−962.25 (1.41E+04)</td>
<td>1.17E+05* (2.51E+04)</td>
<td>5.29E+04 (4.09E+04)</td>
</tr>
<tr>
<td>Daylength</td>
<td>−3.21E+04* (495.68)</td>
<td>−1.58E+04* (443.86)</td>
<td>−4.97E+04* (788.63)</td>
<td>−4.76E+04* (1.21E+04)</td>
</tr>
<tr>
<td>CV1</td>
<td>−712.57* (189.48)</td>
<td>−291.97*** (174.23)</td>
<td>−1.01E+04** (417.72)</td>
<td>−889.17* (188.69)</td>
</tr>
<tr>
<td>CV2</td>
<td>−151.34** (73.48)</td>
<td>−208.56** (100.24)</td>
<td>−211.05** (103.96)</td>
<td>−46.80 (183.89)</td>
</tr>
<tr>
<td>R²</td>
<td>0.91</td>
<td>0.96</td>
<td>0.95</td>
<td>0.81</td>
</tr>
</tbody>
</table>

Notes: * and ** significant at the 1, 5 and 10% levels, respectively.

Long-run parameters:
- **Constant**: 2.10E+06* (5.24E+05) | 4.89*** (2.56) | 1.08 (2.13) | 5.01 (3.99) |
- **Temp**: −2.12E+05* (6.53E+04) | −2.93E−05 | −5.66E−04** | −2.02E−04* |
- **Daylength**: −1.46E+05* (3.40E+04) | −2.38E−04 | −5.26E−05 | −8.99E−07** |
- **CV1**: −3.25E+04* (1.20E+04) | −4.97E+04* (788.63) | −2.51E+04 | −5.29E+04 (4.09E+04) |
- **CV2**: −689.73** (352.57) | −889.17* (188.69) | −46.80 (183.89) | −889.17* (188.69) |

Estimates of the individual components in CV1 and CV2:
- **P1**: −3.25E+04 | −211.05** (103.96) |
- **P2**: −689.73 | −46.80 (183.89) |
- **Prod**: 325.00 | 4.95E+05** (2.36E+05) |

Table A5. Estimation results of the supply relation

<table>
<thead>
<tr>
<th>Variable</th>
<th>9601–0416</th>
<th>9601–9908</th>
<th>9909–0209</th>
<th>0210–0416</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>4.12* (1.48)</td>
<td>4.89*** (2.56)</td>
<td>1.08 (2.13)</td>
<td>5.01 (3.99)</td>
</tr>
<tr>
<td>ΔQ</td>
<td>4.75E−05*** (2.49E−05)</td>
<td>1.99E−05 (2.93E−05)</td>
<td>3.02E−05 (2.57E−05)</td>
<td>1.96E−04** (1.01E−04)</td>
</tr>
<tr>
<td>Q*</td>
<td>−6.97E−05* (1.47E−05)</td>
<td>−5.56E−04** (2.38E−04)</td>
<td>−2.02E−04* (5.26E−05)</td>
<td>7.58E−04 (0.00)</td>
</tr>
<tr>
<td>Inflow</td>
<td>−9.28E−07* (3.11E−07)</td>
<td>−1.04E−06** (4.53E−07)</td>
<td>−8.99E−07** (4.44E−07)</td>
<td>−2.08E−07 (7.40E−07)</td>
</tr>
<tr>
<td>ΔResel</td>
<td>763.98* (288.12)</td>
<td>441.57 (278.24)</td>
<td>639.07* (173.88)</td>
<td>1.57E+04** (686.12)</td>
</tr>
<tr>
<td>CV1(−1)</td>
<td>−0.06*** (0.04)</td>
<td>−0.04*** (0.02)</td>
<td>−0.07* (0.03)</td>
<td>−0.10 (0.08)</td>
</tr>
<tr>
<td>R²</td>
<td>0.16</td>
<td>0.15</td>
<td>0.18</td>
<td>0.28</td>
</tr>
</tbody>
</table>

Notes: * and ** significant at the 1, 5 and 10% levels, respectively.

Estimates of the individual components in CV1(−1):
- **P(−1)**: −0.06 |
- **Oil(−1)**: 0.10 |
- **Resel(−1)**: 6.66 |
Abstract

The deregulation of the Swedish electricity market in 1996 affected both the market design and the pricing of electricity. Since 1996, the electricity price faced by consumers has increased dramatically. Due to the high electricity price and large company profits, a debate about the success of the deregulation has emerged. As such, the aim of this paper is to investigate whether or not the deregulation of the Swedish electricity market has improved consumers’ welfare. The theoretical framework is an equivalent variation method and the analysis is performed using monthly data for the period January 1996 to January 2007. The results indicate that deregulation has kept the power price (excluding taxes) down and increased consumer welfare in Sweden.

Keywords: Equivalent variation, Consumer welfare, Power market.
JEL classification: D60, L13, L43.
1 – Introduction

High electricity prices in Sweden have sparked a debate among policy-makers and politicians. Consumers have seen their electricity bills increase while power generators have earned significantly higher profits. The public debate is often steered by the media, which portrays the electricity market deregulation as the cause of high consumer prices and large producer profits. The media often emphasizes that deregulation has lowered consumers’ well-being, despite the fact that the objective was the opposite. The purpose of this paper is to analyze the effects on consumer welfare caused by the deregulation of the Swedish electricity market.

Sweden deregulated its electricity market in 1996. Power production and retailing were opened up to competition, while transmission remained regulated. The rationale for deregulation is to develop a more competitive market which should lead to a more efficient use of resources. Efficiency gains should imply a lower electricity price (Bergman et al., 1994). The fact that the opposite appears to have happened does not necessarily imply that deregulation has failed; instead, the increase in consumer prices may be misleading. The price of power together with transmission costs and taxes are the components that sum to the electricity price consumers face. A review of the price development shows that taxes have gone up by more than 200 percent since 1996 while transmission costs have remained almost constant in real terms. Furthermore, environmental fees have been introduced during this period. In summary, factors other than the deregulation of the market may have caused the electricity price increases for consumers.

In this paper, I analyze how the deregulation of the Swedish electricity market has affected the power price and how this, in turn, has affected consumers’ welfare. The approach adopted in previous studies has been to look at the consumer welfare in terms of consumer prices (e.g. Damsgaard and Green, 2005). This study uses the Swedish area price at the Nord Pool spot market in order to isolate the effect of the deregulation on

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1 The transmission cost is the aggregated costs of transmission and distribution.
2 The electricity taxes discussed are taxes on households and the commercial sector. The electricity taxes on industry have had a less rapid growth. Since 1 May 2003 a system of green certificates is in operation in Sweden to encourage investment in environmentally friendly power production. The CO2 allowance market introduced in 2005 was a European Union initiative and therefore the potential impact on electricity prices is not a result of Swedish deregulation.
electricity prices per se, apart from exogenous increases in taxes or the introduction of green certificates.\(^3\)

To answer the question of how deregulation has affected consumers’ welfare through shifts in the power price, the actual price after the deregulation is compared to a hypothetical price path in absence of the deregulation. This alternative and hypothetical price path is based on the regulation guiding the Swedish power prices before 1996. The difference between the alternative price and the prevailing Swedish price is then used to calculate the effects on consumer welfare, making it possible to quantify the effects on consumer welfare from changes in the power price while excluding the impact of tax increases and other governmental interventions such as the effects of introducing green certificates.

Worldwide deregulation in the electricity sectors began in the late seventies. In 1978, Chile started to liberalize its electricity market introducing a wholesale market pool in which generators would sell their power to retailers. In 1982, the liberalization was expanded when large end-users were allowed to choose their retailer and negotiate prices. Deregulation of European electricity markets started in England and Wales (E&W) in 1990, when the industry was privatized, and competition between generators was introduced. The E&W deregulation was followed by the deregulation of the Norwegian market in 1991. Throughout the 1990’s deregulation continued and today most of the OECD-countries have to some extent liberalized their electricity markets (Al-Sunaidy and Green, 2006). Sweden deregulated its electricity market in 1996 and joined Norway in the first international electricity market, Nord Pool, the same year. In recent years Nord Pool has expanded to also include Finland (1998) and Denmark (2000).\(^4\)

Newbery and Pollitt (1997), Green and McDaniel (1998) and Domah and Pollitt (2001) discuss the welfare effects of the E&W deregulation. Newbery and Pollitt (1997) analyze the privatization of the Central Electricity Generation Board (CEGB), the owner of the generation facilities and the high-voltage net, and conclude that the welfare effects of the privatization will depend on the corporation tax level and the time span until prices have reverted to the pre-deregulated level. Domah and Pollitt (2001) analyze the

---

\(^3\) It may be that deregulation has generated some spill over effects to the regulated parts of the market. Damsgaard and Green (2005) assumed that transmission costs fell one percent per year after 1996 due to the deregulation. According to Damsgaard and Green, low profits in generation in the late 1990s forced the vertically integrated companies to cut costs in distribution. Excluding these potential spill over effects will, if they exist, result in an underestimation of potential consumer welfare gains.

\(^4\) In 2005 part of Germany was included to Nord Pool when the KONTEK bidding area opened.
effects of the privatization of twelve regional electricity companies and find that the privatization yielded significant net social benefits. However, they conclude that the benefits of the privatization were unevenly distributed, both across time and between groups in society. The deregulation in 1990 did not allow all electricity consumers to choose their electricity supplier, so it was not until 1998 that the E&W market was opened up to full competition. Green and McDaniel (1998) use Cost-Benefit analysis (CBA) to analyze the social welfare effects of the 1998 E&W restructuring. Green and McDaniel (1998) argue that consumer prices will fall, and that electricity suppliers will face high additional transactions costs in the first five years after the restructuring. Based on lower prices and additional transactions costs their main scenario shows that consumers will gain while producers will lose. Producers will lose more than consumers gain so their results indicate a social welfare loss due to the restructuring. However, the welfare loss could be converted into a surplus if competition forces the companies to make further cost savings which would be larger than the transactions costs involved.

Bowitz et al (2000) and Damsgaard and Green (2005) discuss the welfare effects of the Swedish deregulation. Damsgaard and Green (2005) study the effect of the Swedish deregulation using CBA. They build counterfactual scenarios based on how they believe the electricity price and international trade with electricity would have evolved without deregulation. They then compare the counterfactual scenarios to the actual result. Their analysis focuses on the electricity price end customers face by splitting customers into three categories: households, commercial and industry. The result in their main scenario shows that Sweden has benefitted from deregulation by a total of 10.9 billion SEK\textsuperscript{5} up to 2004. Finally, Bowitz et al (2000) analyze the combined effect of the deregulations in Norway, Sweden and Finland. Bowitz et al (2000) conclude that until 1999 deregulation had a negative welfare effect. They found that lower average prices in the prevailing situation led to a positive consumer surplus but a negative producer surplus, which resulted in an annual net surplus of 1.5 billion NOK\textsuperscript{6}. However, the reason for the negative overall welfare effect was an environmental dimension that assumed that the pollution costs were higher than the positive net value of consumer and producer surplus.

The rest of this paper is organized as follows. Section 2 discusses the theoretical method, section 3 describes the data and discusses the empirical

\textsuperscript{5} 1 SEK equals approximately 0.125 USD.  
\textsuperscript{6} 1 NOK equals approximately 0.15 USD.
model. Section 4 contains results and section 5 includes discussion and conclusions.

**2 – Method**

This paper studies the change in consumer welfare due to the deregulation of the Swedish electricity market using an equivalent variation (EV) approach. The difficulty with the EV approach is to find the direct or indirect utility function in order to calculate the EV. Two alternative solutions to this problem have been used in the literature. The first approach starts with specifying the direct or the indirect utility function and then derives the observable demand functions by maximizing the direct utility function subject to a budget constraint or by integrating the indirect utility function using Roy’s identity. The second approach uses the observable Marshallian demand to specify the required demand systems. The second approach is econometrically preferable, as it will generate demand functions that fit the data well (Hausman, 1981). In this paper, the latter approach is used. We specify a linear Marshallian demand function for electricity based on model fit and earlier literature (e.g. Johnsen (1998), Hjalmarsson (2000) and Steen (2003)). The demand function is represented by

\[ x = \beta p + \gamma y + \delta_i k, \quad i = 1, \ldots, N, \]

where \( p \) is the power price, \( y \) income and \( k \) a vector containing variables that affect electricity demand. Since the interest is on the demand for electricity, an incomplete demand model for electricity is specified. A composite good is specified using the consumer price index (CPI). The power price and income are deflated using the CPI, meaning that the composite good disappears from the equation. This procedure results in a demand function that is zero degree homogeneous in price and income, and the corresponding quasi-indirect utility function and quasi-expenditure function will be exact welfare measures if they fulfill the integrability conditions (Hausman, 1981). Using expenditure functions it is possible to specify the EV measure and, if we consider a price change from \( p^0 \) to \( p^1 \), the EV measure can be written

\[ EV = e(p^0, u^1) - e(p^1, u^1), \]
which can be used to quantify the effects on consumer welfare. Hausman (1981) showed that under these conditions all that is needed to establish the exact measure of welfare changes is knowledge of the Marshallian demand function. Following Hausman (1981) starting with equation (1) and using Roy’s identity gives

\[ x = \beta p + \gamma y + \delta k = -\frac{\partial v(p, y)}{\partial p} / \frac{\partial v(p, y)}{\partial y}, \]  

(3)

which is a linear partial differential equation. In order to make welfare comparisons we need to stay on a given indifference curve, independent of the price level. This is secured by using the equation

\[ u(t) = u^1 \]

where \( u^1 \) is the utility level in the equivalent variation case. Differentiating \( v(p(t), y(t)) \) and setting it equal to zero will assure that we stay on the same indifference curve when the price changes, that is

\[ \frac{\partial v(p(t), y(t))}{\partial p} \frac{dp(t)}{dt} + \frac{\partial v(p(t), y(t))}{\partial y} \frac{dy(t)}{dt} = 0. \]  

(4)

Rearranging equation (4), substituting into equation (3), and using the implicit function theorem gives an expression which expresses \( y \) as a function of \( p \) in an ordinary differential equation

\[ \frac{dy(p)}{dp} = \beta p + \gamma y + \delta k. \]  

(5)

Solving equation (5) gives the solution

\[ y(p) = A e^{\frac{\beta}{\gamma} p} + \frac{1}{\gamma} \left( \beta p + \frac{\beta}{\gamma} + \delta k \right), \]  

(6)

where \( A \) is the constant of the integration that depends on the initial level of utility. If we choose \( A = u^1 \) as the cardinal utility index we can solve equation (6) for the quasi-indirect utility function associated with the incomplete demand system.
Inverting equation (7) gives the quasi-expenditure function

\[ e(p^1, u^1) = e^{yp^1} u^1 - \frac{1}{\gamma} \left( \beta p^1 + \frac{\beta}{\gamma} + \delta k \right) \]  

(8)

Before measuring the equivalent variation the integrability conditions should be checked to verify that the derived Marshallian demand function has its origin in a utility function. LaFrance and Hanemann (1989) derived the necessary restrictions to obtain exact welfare measures from an incomplete demand model. They showed that by augmenting the incomplete demand system with a composite commodity representing total expenditure on all other goods, it is possible to proceed as if the augmented system was complete. That is, for the demand function in equation (1) to be weakly integrable, equation (7) has to be continuous and homogeneous of degree zero in prices and income. Equation (7) also has to be decreasing in price and increasing in income, \( \beta \leq 0 \) and \( \gamma \geq 0 \). Finally, for equation (1) to be weakly integrable, the Slutsky substitution terms \( s_{ij} = \delta x_i / \partial p_j + (\delta x_i / \partial y)^* x_j \) have to be symmetric and negative semidefinite (LaFrance and Hanemann, 1989).

When the integrability conditions are fulfilled it is straightforward to calculate the equivalent variation. Using equation (2) and (8) we find that in the case of a price change from \( p^0 \) to \( p^1 \), the EV-measure can be written

\[ EV = e^{y(p^0 - p^1)} \left[ y^0 + \frac{1}{\gamma} \left( \beta p^1 + \frac{\beta}{\gamma} + \delta k \right) - \frac{1}{\gamma} \left( \beta p^0 + \frac{\beta}{\gamma} + \delta k \right) \right] - y^0 \]  

(9)

where \( \gamma > 0 \) indicates a positive income effect.
3 - Data and empirical model

3.1 Data

The data used in this paper covers the period January 1996 to January 2007. The variable description and descriptive statistics are displayed in Table 1.

Table 1  Variables, descriptive statistics, definition and data sources.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean*</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>221.73 (106.91)</td>
<td>Swedish area price. SEK/MWh</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Source: Nord Pool ASA</td>
</tr>
<tr>
<td>Consumption</td>
<td>1.34E+ 07 (2.01E+06)</td>
<td>Electricity consumption in Sweden in MWh (including export and import).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Source: Swedish Energy Agency</td>
</tr>
<tr>
<td>Industrial production</td>
<td>0.99 (0.13)</td>
<td>Swedish industrial production index, SNI C-E.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Source: Statistics Sweden</td>
</tr>
<tr>
<td>Temperature</td>
<td>7.04 (7.32)</td>
<td>Average temperature in Sweden. Weighted average using average temperature</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(in °C) from Malmö, Stockholm, Östersund, Umeå and Luleå. Source: SMHI</td>
</tr>
<tr>
<td>Length of day</td>
<td>12.34 (3.85)</td>
<td>Number of hours the sun is above the horizon in Gothenburg, Sweden.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Source: <a href="http://www.stjarnhimlen.se">www.stjarnhimlen.se</a></td>
</tr>
<tr>
<td>Inflow</td>
<td>5747718 (4399223)</td>
<td>Inflow to the water reservoirs, recalculated into MWh. Source: Nord Pool ASA.</td>
</tr>
<tr>
<td>Consumer Price Index</td>
<td>1.02 (0.003)</td>
<td>Index of the consumer prices in Sweden. Source: Statistics Sweden.</td>
</tr>
<tr>
<td>Income</td>
<td>1.9E+ 11 (1.78E+ 10)</td>
<td>Gross Domestic Product in SEK. Source: Statistics Sweden.</td>
</tr>
</tbody>
</table>

*Standard error in parenthesis

All variables except income are monthly observations and in real terms. Income is measured with real GDP which is not available on a monthly basis. To get monthly observations on income, GDP is interpolated from yearly observations.
3.2 The demand model

The variables in the demand model are the power price, income, temperature, length of day, and industrial production. The price that is used is the Swedish area price at the Nord Pool spot market, which is the price that the Swedish retailers face when buying power at Nord Pool.\(^7\) The Nord Pool spot price is the foundation for the prices the Swedish consumers face.\(^8\) Due to mark ups, green certificates and taxes, the correlation between the spot price and the retail prices is not perfect. However, calculating the correlation between the spot price and contract types for small and medium large consumers shows that the correlation between the spot price and the retail prices is high. For the flexible price contracts that retailers offer to costumers, a type of contract that has become increasingly more common each year, the correlation is as high as 99 percent. The average correlation between the spot price and the observable types of contracts is 0.68.\(^9\) Correlation for large consumers (large industries) are not publically available but are generally believed to be at least as high.\(^10\)

In order to deal with the apparent endogenity problem when estimating a demand model including both prices and quantities, we rely on an instrumental variable approach. In this study, the power price is instrumented using inflow to the water reservoirs, temperature and the lagged power price as instruments. We estimate the demand model with OLS, using standard errors corrected for autocorrelation and heteroscedasticity. Income measures the purchasing power of the consumers and higher income is expected to increase the demand for electricity. Temperature is measured in degrees

\(^7\) The spot price is important not just as the price at Nord Pool but also as a reference price for bilateral and financial contracts.

\(^8\) Comparing the retail market in Sweden to the power market, the Nord Pool market, these markets are quite similar in terms of market structure, with the four largest firms covering over 50 percent of the market and over 100 other, small firms active in the market.

\(^9\) The observable types of contracts are one, two, and three year contracts, flexible price contracts and standard price contracts. The correlation between Nord Pool spot price and the observable contracts are: one year 0.75, two year 0.69, three year 0.65, flexible price 0.99 and standard price contract 0.62.

\(^10\) Large consumers often negotiate their contracts bilaterally and therefore prices are not public. Large customers often have contracts with variable prices, but the contracts are secured by hedging. An alternative is fixed price contracts with an option to re-sell electricity if the electricity is not consumed. Both of these contract types imply that the Nord Pool spot price is the relevant reference price and that the correlation between the large customer contracts and the Nord Pool spot price should be at least as high as the correlation for the small and medium large customers contracts.
Celsius and is used as a proxy for electricity demand for heating purposes. The climate in Sweden leads to a reverse electricity demand which, peaks in the winter (for heating use) rather than in the summer (for air conditioning use). Length of day is a proxy used to measure the demand for electricity for lighting. The winter days are shorter resulting in higher demand for electricity for lighting than in summer. The industrial production variable is used to measure the industry demand for electricity; a positive correlation between industry production and the demand for electricity is expected. Finally, monthly dummy variables are incorporated to account for any additional seasonality in electricity demand.

3.3 Alternative price

To construct the alternative price path it is important to understand how the pre-deregulated price was determined. Before deregulation, the electricity market was divided in two parts based on customer characteristics: a high and low voltage market. The high voltage market was a market for generators, large industries and retail distributors, while the low voltage market was a market for retail distributors and their consumers (Bergman et al, 1994). In addition to these markets there was a market for temporary energy exchange for generators. This market worked like an "electric power pool" and was characterized by extensive cooperation and information exchange between the participants. Generators with a shortage (surplus) of power could buy (sell) power from the "power pool". The exchange price was based on the so called split-savings principle, a method where the price was determined by the average of the buying firms’ marginal cost and the selling firms’ marginal cost (Hjalmarsson, 1993).

Before deregulation, the electricity market was characterized by local and regional monopolies in both generation and distribution. There was no competition between generators or between distributors (SPK 1989:8). The high voltage market, where the state owned company Vattenfall was the dominating actor with 50 percent of the generation capacity, was not directly regulated. Pricing was, however, indirectly regulated through state-ownership of Vattenfall and the formal objective of Vattenfall to break even subject to a required return.\textsuperscript{11} This established Vattenfall as the price leader and also worked to set a price ceiling. The generators’ collaboration in the "power pool" resulted in a price floor which also prevented further entry to the market.

\textsuperscript{11} The required return was equal to the depreciation on replacement values and a rate of interest on loans from the government at the bond rate level.
(Bergman et al, 1994). The pricing in the high voltage market was conducted through high voltage tariffs consisting of four elements: a fixed fee, a contractual demand charge, a peak load charge and an energy charge (SPK, 1989:8). The energy and the peak load charge were priced by marginal cost while the contractual charge and the fixed charge were determined by the rate of return constraint. The four elements of the high voltage tariff can be aggregated into three variables: transmission, energy and a fixed fee. In turn, the fixed fee and transmission are variables describing the network costs. In reality, network costs have been constant in real terms (see Figure 1). This leaves the energy part of the market as the remaining variable to explain changes in prices in the high voltage market.

**Figure 1  Price decomposition, 1970-2006.**

The split-saving principle used in the “power pool” before deregulation imply that the price on power could be described as an average cost of production. Damsgaard and Green (2005) also argue that the required rate of return restriction on state- and municipality-owned generators makes average cost pricing a reasonable approximation of the pricing principle on the high voltage market before deregulation. In this paper, average cost of electricity production is measured by the producer price index (PPI) for electricity production, and since the pricing principle in the regulated market was approximately equal to average cost pricing, the PPI for electricity production will be used to derive the alternative price path if the market had not been deregulated. To convert the PPI from index form to a price path, the
January 1996 power price will be used as the base. That is, the January 1996 power price is multiplied with the PPI for each month to get a price path that shows what the power price would have been without the deregulation. However, a requirement for the prevailing PPI to work as an alternative price path is that the production structure has not changed significantly during the years under study. Table 2 shows the production structure before and after the deregulation, and it shows that the production structure has remained relatively constant during these years.

**Table 2  Electricity production in Sweden 1990-2006, proportions.**

<table>
<thead>
<tr>
<th>Year</th>
<th>Hydro</th>
<th>Nuclear</th>
<th>Wind</th>
<th>Other*</th>
<th>Net import**</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>0.51</td>
<td>0.465</td>
<td>0</td>
<td>0.036</td>
<td>-0.011</td>
</tr>
<tr>
<td>1991</td>
<td>0.439</td>
<td>0.518</td>
<td>0</td>
<td>0.047</td>
<td>-0.004</td>
</tr>
<tr>
<td>1992</td>
<td>0.522</td>
<td>0.436</td>
<td>0</td>
<td>0.053</td>
<td>-0.011</td>
</tr>
<tr>
<td>1993</td>
<td>0.522</td>
<td>0.421</td>
<td>0</td>
<td>0.062</td>
<td>-0.006</td>
</tr>
<tr>
<td>1994</td>
<td>0.417</td>
<td>0.506</td>
<td>0</td>
<td>0.070</td>
<td>0.007</td>
</tr>
<tr>
<td>1995</td>
<td>0.474</td>
<td>0.472</td>
<td>0</td>
<td>0.063</td>
<td>-0.009</td>
</tr>
<tr>
<td>1996</td>
<td>0.358</td>
<td>0.502</td>
<td>0.001</td>
<td>0.095</td>
<td>0.044</td>
</tr>
<tr>
<td>1997</td>
<td>0.480</td>
<td>0.470</td>
<td>0.001</td>
<td>0.067</td>
<td>-0.018</td>
</tr>
<tr>
<td>1998</td>
<td>0.511</td>
<td>0.492</td>
<td>0.002</td>
<td>0.069</td>
<td>-0.074</td>
</tr>
<tr>
<td>1999</td>
<td>0.492</td>
<td>0.491</td>
<td>0.003</td>
<td>0.067</td>
<td>-0.051</td>
</tr>
<tr>
<td>2000</td>
<td>0.532</td>
<td>0.373</td>
<td>0.003</td>
<td>0.059</td>
<td>0.033</td>
</tr>
<tr>
<td>2001</td>
<td>0.521</td>
<td>0.460</td>
<td>0.003</td>
<td>0.064</td>
<td>-0.048</td>
</tr>
<tr>
<td>2002</td>
<td>0.446</td>
<td>0.441</td>
<td>0.004</td>
<td>0.075</td>
<td>0.034</td>
</tr>
<tr>
<td>2003</td>
<td>0.364</td>
<td>0.450</td>
<td>0.004</td>
<td>0.093</td>
<td>0.089</td>
</tr>
<tr>
<td>2004</td>
<td>0.406</td>
<td>0.512</td>
<td>0.006</td>
<td>0.090</td>
<td>-0.014</td>
</tr>
<tr>
<td>2005</td>
<td>0.489</td>
<td>0.472</td>
<td>0.006</td>
<td>0.083</td>
<td>-0.050</td>
</tr>
<tr>
<td>2006</td>
<td>0.419</td>
<td>0.445</td>
<td>0.007</td>
<td>0.089</td>
<td>0.041</td>
</tr>
</tbody>
</table>

Source: Swedish Energy Agency.
*Include Industrial back-pressure power, Combined heat and power, Cold condensing power and Gas turbines.
**Positive sign equals net import, negative sign net export.

Before 1996, hydro and nuclear power represented on average 90-95 percent of the generation. This has not changed after the deregulation. Note, however, that the year 1996 was a dry year with relatively little precipitation resulting in limited hydro power production, while the year 2000 was a wet
year with relatively high precipitation and hydro power production. In addition, the year 2003 was a very dry year with all time low levels in the water reservoirs. As such, hydro power production has varied depending on the precipitation, but this does not imply a change in the production structure. In other words, reduced precipitation leads to increased nuclear power production both before and after deregulation.

3.4 Empirical EV-measure

To compute the effects of the deregulation on consumer welfare, the alternative price is set against the prevailing Swedish area price from the deregulated period. The estimated parameters from the demand function are used together with the alternative price in equation (10) to calculate the effects on consumer welfare.

$$ EV = e^{\gamma (p^0 - p^{alt})} \left[ y^0 + \frac{1}{\gamma} \left( \beta p^{alt} + \frac{\beta}{\gamma} + \delta_1 \text{temp} + \sum_{j=2}^{12} \delta_j \text{dummy} \right) \right] - \frac{1}{\gamma} \left( \beta p^0 + \frac{\beta}{\gamma} + \delta_1 \text{temp} + \sum_{j=2}^{12} \delta_j \text{dummy} \right) - y^0. $$

The EV measure is calculated for each month in the sample and then aggregated over the whole period.

4 – Results

4.1 The demand model

The estimation is performed using a general to specific model approach, where variables whose parameters are not statistically significant

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12 The precipitation pattern is reflected in the power price. Low reservoir levels in 1996 and 2003, resulted in higher power prices since more expensive production sources were used to meet demand. The higher prices in 2003 compared to 1996 may have been a result of the more expensive energy sources in Denmark. The even higher prices during 2005 and 2006 may have been caused by the introduction of the European market for CO\textsubscript{2} allowances.

13 Net import of electricity (see Table 2) has also increased since deregulation. In this study the net import of electricity, which is four percent of market supply on average, will not be taken into account.
are removed from the model. The estimation result for the demand model is presented in Table 3.

**Table 3  Estimation results of the demand function.**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Coefficient</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>11137500*</td>
<td>1.72E+ 06</td>
</tr>
<tr>
<td>Price</td>
<td>-2819.31*</td>
<td>830.94</td>
</tr>
<tr>
<td>Temperature</td>
<td>-167487*</td>
<td>21172.2</td>
</tr>
<tr>
<td>Income</td>
<td>2.97E- 05*</td>
<td>9.40E- 06</td>
</tr>
<tr>
<td>dFebruary</td>
<td>-1450700*</td>
<td>127758</td>
</tr>
<tr>
<td>dMarch</td>
<td>-525577*</td>
<td>173577</td>
</tr>
<tr>
<td>dApril</td>
<td>-1798210*</td>
<td>242534</td>
</tr>
<tr>
<td>dMay</td>
<td>-1939190*</td>
<td>329989</td>
</tr>
<tr>
<td>dJune</td>
<td>-2752610*</td>
<td>414270</td>
</tr>
<tr>
<td>dJuly</td>
<td>-2286160*</td>
<td>464204</td>
</tr>
<tr>
<td>dAugust</td>
<td>-1983420*</td>
<td>454200</td>
</tr>
<tr>
<td>dSeptember</td>
<td>-2190730*</td>
<td>363932</td>
</tr>
<tr>
<td>dOctober</td>
<td>-1186670*</td>
<td>262745</td>
</tr>
<tr>
<td>dNovember</td>
<td>-1073020*</td>
<td>184964</td>
</tr>
<tr>
<td>dDecember</td>
<td>-388686*</td>
<td>124894</td>
</tr>
</tbody>
</table>

R² = 0.97  
Adjusted R² = 0.96  
N = 132  
SBIC= 1920.77  
Log-Likelihood= -1881.71

<table>
<thead>
<tr>
<th>Ljung-Box Q-statistics</th>
<th>Statistic</th>
<th>Critical value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q(1)</td>
<td>1.00</td>
<td>3.84</td>
</tr>
<tr>
<td>Q(2)</td>
<td>2.03</td>
<td>5.99</td>
</tr>
<tr>
<td>Q(4)</td>
<td>2.12</td>
<td>9.49</td>
</tr>
<tr>
<td>Q(8)</td>
<td>10.00</td>
<td>15.51</td>
</tr>
<tr>
<td>Q(12)</td>
<td>12.50</td>
<td>21.03</td>
</tr>
</tbody>
</table>

* Significant at the 1 % level
All coefficients have the expected signs. The price has a negative sign meaning that a higher price reduces electricity demand. Increased income increases the demand for electricity. Warmer temperatures lead to reduced demand for electricity for heating. Length of day should intuitively have the same sign as temperature: the longer the day the less electricity required for lightning. However, we remove this variable from the demand model due to a high correlation with temperature (83 percent), causing multicollinearity problems. In addition, industrial production is not significant and is therefore excluded from the final demand model. To account for seasonal effects, monthly dummy variables for all months except January are used. The resulting negative signs tell us that the electricity demand is highest in January and lowest in the summer. The long run elasticity of demand for power is calculated and equals -0.047, which is in line with previous studies. Finally, the results from the estimation of the demand model show that all integrability conditions are fulfilled. The Slutsky substitution terms are negative definite, the income parameter is positive and the price parameter is negative.

4.2 Welfare effects

To measure the effects on consumer welfare, the prevailing Swedish area price is compared to the alternative price path described in section 3.3. The resulting monthly EV-measures are discounted back to 1996 using a discount rate of 5 percent and then added together. The aggregated EV measure tells us that the deregulation has been advantageous for electricity consumers in Sweden. In total, consumer welfare has increased by 4 billion SEK in 1996 prices over the period studied. The reason for this result is that while the price path under deregulation has been volatile with both dips and peaks, the alternative price has been more stable but at a higher price level (see Figure 2).

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14 For an extensive discussion about the elasticity of demand for electricity, see Nilsson and Pettersson, (2008).
15 Discounting the EV-measure to 2007 does not qualitatively alter the results. The results drop from 4 billion SEK to 3.8 billion SEK.
16 The underlying data used in the calculations are available from the author on request.
Figure 2  Price comparison, 1996-2007.

The less volatile alternative price path is due to differences in the pricing methods. The deregulated price is more volatile because the price is determined by supply and demand in a competitive environment, and set equal to the cost of the marginal unit of energy necessary to meet demand, while the pre-deregulated price was based on the average cost of production in the different generation facilities. The average cost based price does not fluctuate as much as the marginal unit based price because a sudden demand increase (decrease) – and the subsequent price jump (dip) – is averaged out by the other facilities. In the deregulated case, a sudden demand increase will allow those generation facilities with a marginal cost lower than the marginal facility, to increase their profits. To consider the possibility that the alternative price path calculated using the PPI starts from an incorrect level, for example due to 1996 being a dry year, a sensitivity analysis is performed. The PPI is reconstructed to start both from a price level 5 percent below and 5 percent above the base scenario. The sensitivity analysis shows that a 5 percent lower initial price will lower the increase in consumer welfare from 4 billion SEK to

17 The competitiveness of the Nord Pool market has been studied by Hjalmarsson (2000) and Bask et al. (2009). Both studies show that the Nord Pool spot price has been very close to the marginal cost of production after the deregulation.
653 million SEK, and that a 5 percent increase in the start level will improve the welfare effect to 7.3 billion SEK. However, note that the welfare effects are positive in the sensitivity analysis as well, indicating that the positive welfare effect calculated in the base scenario is quite robust to changes in the initial price level.

Comparing the results from this study to earlier studies of the deregulation of the Swedish electricity market (e.g. Damsgaard and Green, 2005 and Bowitz et al., 2000) reveals that these studies also found that the deregulation increased consumer welfare. The studies are made using different approaches and different datasets, although the results are qualitatively the same. This gives further support to the results presented in this paper.

It might be interesting to set the increase in consumer welfare in perspective. An increase in consumer welfare of 4 billion SEK is a lot of money, but spread over the 11 years of deregulation covered in this paper, and the approximately 9 million consumers (households, commercials and industry), the consumer welfare gains equal less then 100 SEK per consumer per year. The average electricity use per capita in Sweden in 2003 was approximately 16,000 kWh (Statistics Sweden). Given an average Swedish power price of 0.22 SEK/kWh, the cost for power per capita would be approximately 3,500 SEK per year, indicating a welfare gain just below three percent. In this context the magnitude of consumer welfare gain from deregulation may appear small, but the results are consistent with previous studies: deregulation has benefitted the typical Swedish electricity consumer.

5 - Conclusion

The purpose of this paper is to calculate the effects on consumer welfare due to the deregulation of the Swedish electricity market in 1996. The analysis is performed using an equivalent variation method and an alternative price path based on how the power price was set before the deregulation. When this alternative price path is compared to the prevailing Swedish area price it is clear that the deregulated price – a price based on marginal cost pricing – has been lower, on average, during the studied period, leading to an increase in consumer welfare. The results from the base scenario in this paper show that the deregulation has increased consumer welfare by 4 billion SEK. Sensitivity analysis using alternative scenarios reinforces the conclusion that the deregulation has increased consumer welfare. Set into perspective, the welfare gains from deregulation is not that impressive, less than 100 SEK per
consumer per year. However the deregulation effects are positive and the consumer welfare has improved.

The results from this study can be compared to previous studies of the welfare effects of the deregulation of the Swedish electricity market. Bowitz et al (2000) found that the Nordic deregulation had increased consumer welfare by 5.6 billion NOK\textsuperscript{18} per year between the period 1996 to 1999. Disaggregation indicates that the Swedish consumers gained 1.3 billion NOK per year after the deregulation. If this trend is extrapolated until 2006, this equals a welfare gain for consumers of 14.3 billion NOK. It should, however, be noted that extrapolating probably overestimates the welfare effects. This is because the Nord Pool price has been very high during 2003 and 2006, and high prices will decrease the welfare gain from the deregulation. Damsgaard and Green (2005) calculate several different scenarios, all showing positive effects of the deregulation. Their main scenario estimates welfare gains for all electricity consumers to be 4.2 billion SEK in total for the period 1996 to 2004. It should be noted that Damsgaard and Green (2005) use the electricity price faced by consumers, including taxes and environmental fees, while this paper uses the Swedish power price on Nord Pool. In this paper, the market effects of the deregulation have thus been separated from the political decisions that affect the price of electricity. Using this approach, it is clear that the increased price of electricity for consumers after 1996 is not due to the deregulation as such, but rather due to political decisions to increase energy taxes and to introduce green certificates.

References


\textsuperscript{18} 1 NOK equals approximately 1.2 SEK


Multinational Electricity Market Integration and Electricity Price Dynamics

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Electricity price, market integration, jump risk, EGARCH

The paper empirically explores the electricity price dynamics in the Nordic power market, Nord Pool, during the years 1996-2006. Empirically the study reveals that the conditional mean electricity price increased when Finland joined, and remained at the higher level when Denmark also joined. Turning to the price volatility, this increased when Finland joined, but decreased when Denmark also joined. However, the price jump-intensity decreased both when Finland and Denmark joined the market. This means that a larger electricity market seems to reduce the probability of sudden price jumps. That is, the multinational electricity market integration seems to have created a market that handles external shocks to supply and demand more efficient than the separate national electricity markets previously did.

I. INTRODUCTION

Over the last 20 years electricity markets around the world have experienced rapid restructuring. Two noticeable trends are the liberalization of electricity markets and the establishment of power exchange markets. Another trend is the integration of different geographical electricity markets. Apart from in Europe restructuring processes are ongoing in a number of places around the world, e.g. in the United States, Australia and New Zealand. In the European Union, as stated in the EU Electricity Market Directives (2003/54/EG), there is a clear intention to create a single European market for electricity.

In the Nordic countries, the process of electricity market integration has led to the establishment of the only multinational exchange, the Nordic power exchange, Nord Pool. The power exchange started in 1993 in Norway and has since then developed. In 1996, Sweden was integrated into the Nordic power exchange. Over the years the Nordic power exchange has grown both in terms of participants as well as concerning the amount of total trade in electricity going through the power exchange. In March 1999 Finland was fully integrated, later, in March 2002 Denmark was also fully integrated with the Nordic power exchange. Apart from participants from the Nordic countries traders from a large number of countries (e.g. Germany, the Netherlands, England and the United States) are actively trading at the Nord Pool today.

In this paper, we empirically study whether (and to what extent) the Nordic multinational electricity market integration has affected the electricity price dynamics at the Nordic power exchange. In particular, the focus is upon the effect on the conditional mean electricity price, upon the conditional variance, upon the mean jump-intensity (expected frequency of larger price movements) and on the mean jump size. The question is of particular importance in light of the commitment within Europe towards further integration of other European electricity markets. An understanding of the effects of international electricity market integration on electricity price dynamics will help both participants as well as decision makers to build better expectations about future electricity price dynamics. To the authors knowledge this is the first empirical study of how electricity price dynamics has been affected by multinational market integration.¹ The study is related in spirit to the financial literature concerning asset price dynamics and market liquidity (e.g. [10]). In comparison to the financial literature, where direct relationships between e.g. volume and expected returns are studied, this study is measuring increasing volumes and so on, indirectly by use of dummy variables comparing periods of different market sizes, i.e. not direct in terms of higher volumes, number of trades etc. However, since electricity is not a storable good comparisons of results should be done with caution.

Previous studies concerning electricity price dynamics (e.g. [3], [5], [7], [12], [13], [15], [19]) have established a number of salient features concerning electricity price dynamics: (i) Mean reversion to the long-run equilibrium price level (reflecting the marginal cost of producing electricity) exist; (ii) Large daily volatilities (compared to financial price/return series) and volatility clustering is present; (iii) Jumps (large price changes) are frequently encountered; (iv) Price series show strong seasonal patterns mainly due to the strong dependence of electricity demand on weather conditions. In

¹ However, [1] perform a simulation study predicting the effects on prices of an integration of the Swedish, Norwegian and Finnish electricity markets.
order to capture these features of electricity price dynamics a mixed EGARCH-jump model is utilized in the empirical study. The conditional mean specification (excluding contributions from jumps) of the electricity price includes autoregressive components reflecting mean reversion as well as weather variables capturing seasonal effects. The time varying conditional variance component (EGARCH) captures the smooth changes in volatility and allows for volatility clustering. The jump component explains the more infrequent larger price movements. The model allows for both positive as well as negative jumps, i.e. a mean jump size (allowed to be either positive or negative) is estimated, which is important concerning electricity price modeling since large jumps are often followed by a reverse price jump (see for example [13]). The GARCH-jump mixture has previously been used in mainly financial applications, e.g. [14], [20] and [18] and an extension of the model to include a conditional autoregressive jump intensity parameter is considered by [6].

In summary, the results from this study show that the conditional mean electricity price increased when Finland joined the Nord Pool exchange, and the price remained at the higher level when Denmark also joined. This can be explained by the change in the production structure toward more expensive thermal power when these countries joined Nord Pool. Turning to the price volatility, this increased when Finland joined and decreased when Denmark also joined Nord Pool. When Finland joined Nord Pool, descriptive statistics show that the market was operating quite close to full capacity. As such, our interpretation of the result is that shocks in the market during this period more often moved the intersection between supply and demand into the steep section of the supply curve causing large price jumps.

The paper is organized as follows. Section 2 describes the relevant features of the Nordic power exchange and describes the process of multinational electricity market integration. Section 3 presents a descriptive analysis of the data used. Section 4 outlines the econometric model. Section 5 contains the empirical results while the final section discusses the empirical results.

II. Market Integration in the Nordic Power Exchange

Since the beginning of the 1990ties, the Nordic power markets have evolved from separate national power markets to a multi-national power market. The restructuring process is due to a combination of national initiatives and initiatives from the European Union. The first step towards a deregulated electricity market was taken by Norway, and in 1993 a Norwegian market for power exchange opened. In Sweden, it was not until 1996 that legislation for competition in electricity became effective. Sweden joined the Norwegian power market the same year, in what became the first international power exchange, Nord Pool. Finland joined the Nord Pool in 1998 but was not fully integrated until March 1999 when the border tariffs were removed. In 1999, the western part of Denmark joined Denmark joined the Nord Pool while the eastern part of Denmark joined in 2000. In practice, the Danish market was not fully integrated until 2002, when the border tariffs were removed.

The Nordic power market consists of two markets. The first market handles bilateral contracts. The second market place is the Nordic power exchange, Nord Pool. In short, Nord Pool consist of one spot market for physical contracts, Elspot, and one financial derivatives market, Eltermin, which handles futures, forwards and option contracts.

The pricing principle in Elspot is a single price, double auction model where the system price is set by the intersection of demand and supply bids. The Elspot price plays an important role in the Nordic power market as it function as a reference price for bilateral and financial contracts.

The market integration in the Nord Pool area has lead to a consolidation of different generation structures. The generation structure differs largely between the participating countries, pushing the generation mixture in the Nord Pool exchange towards relatively more expensive thermal power as Finland and Denmark joined. The integration of new members has also increased the amount of electricity consumers in the area, and thus the electricity consumption.

A schematic picture of the supply and demand shifts are shown in Figure 1. As can be seen in Figure 1, the intersection of supply and demand is at its lowest in the first period when only Norway and Sweden are active in the market, while the market operates quite far from it's capacity constraint. When Finland joined the market, the intersection of supply and demand is at a somewhat higher price level and also closer to the capacity constraint. This means that positive demand shocks or negative supply shocks could have a large impact on the price during this period. Finally, when Denmark joined the Nord Pool the intersection of supply and demand are at approximately the same price level as in the period before, but further away from the capacity constraint.

Reference [8] shows that after the deregulation and until the year 2000, the capacity marginal declined in the Nordic system meaning that the...
In light of the previous literature (e.g. [3], [5], [7], [12], [13], [15], [19]) prices and price volatility is assumed to be determined as follows. First, the long-run equilibrium price level of electricity reflects the marginal cost of producing that electricity. Second, the daily volatilities and the jumps that are determined by different types of exogenous changes in supply and demand. Changes causing normal volatility, can, for example be normal, but unexpected, changes in temperature as compared to forecasts by the weather services. The large jumps (large price changes) are, in contrast, encountered when there are large exogenous shocks to supply or demand of electricity (e.g. large unpredicted temperature shocks, storms, production or transformation breakdowns etc).

In the empirical part of the paper, we would therefore expect that market integration has the following effects on the price, volatility and jumps. First, market integration on the Nord Pool exchange has changed the supply structure toward more expensive electricity production sources. The restructuring of the market thus implies that there is an increased probability of the relatively more expensive coal fired power plants being the marginal source of electricity, which would lead to higher prices as the market has become more integrated. Second, as the market becomes more integrated and increases in size both types of external shocks, affecting volatility and the jump frequency, will be less likely to have an impact on the market as a whole. As such, it is expected that the variance and jump-intensity should also decrease as the market has become more integrated.

III. DATA AND DESCRIPTIVES

The data used in the empirical study have been provided by Nord Pool and SMHI. The data cover the time period January 1, 1996 to February 12, 2006, in total 3696 daily observations. In Figure 2 the first differences of the average daily electricity prices, \( p_t = \log(P_t) \), as stated at the Nordic power exchange are displayed.

![Figure 2: First Differences of \( \log(p_t) \)](image)

From the figure it is evident that the price series contain a number of sharp price changes, i.e. peaks or jumps, as well as display patterns of volatility clustering. Also, positive (negative) jumps seem to be immediately followed by a reverse negative (positive) jump indicating jump reversals.\(^5\)

Electricity prices contain seasonal patterns both in the short run (weekly patterns) and in the long run (intra yearly patterns). In order to capture short run seasonality "day of the week" dummies are used. Seasonality within the years is captured by including temperature and inflow to the reservoirs as variables in the regression models.\(^6\) Both temperature and inflow to the reservoirs show strong seasonal patterns. Hence, these variables should be useful in order to capture seasonality in the electricity price.\(^7\)

In Table 1 the unconditional means and standard deviations (in parenthesis) for the logarithmic electricity price as well as for the other variables for the whole period and for three sub periods are reported.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Period 1</th>
<th>Period 2</th>
<th>Period 3</th>
<th>Whole period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (C)</td>
<td>6.124</td>
<td>7.360</td>
<td>7.536</td>
<td>7.015</td>
</tr>
<tr>
<td>Inflow (MWh)</td>
<td>478514</td>
<td>606411</td>
<td>534034</td>
<td>537330</td>
</tr>
<tr>
<td>Variance (Inflow)*</td>
<td>0.266</td>
<td>0.375</td>
<td>0.314</td>
<td>0.317</td>
</tr>
<tr>
<td>Variance (Temp)*</td>
<td>7.338</td>
<td>7.161</td>
<td>7.519</td>
<td>7.406</td>
</tr>
</tbody>
</table>

\(^{1}\)Time varying conditional variance estimated with GARCH (1,1)

The first sub period correspond to the period 1996-01-01 to 1999-02-28 when the Nordic power exchange consisted of Norway and Sweden, the second to the period 1999-03-01 to 2002-02-28 when Finland was included, while the last sub period corresponds to the period 2002-03-01 to 2006-02-12 when Denmark had been fully integrated.\(^8\)

IV. ECONOMETRIC MODEL

To accommodate the salient features of electricity price dynamics a discrete time model including time-varying conditional variance and a jump component is utilized. The natural logarithm of the electricity price \( p_t = \log(P_t) \), is modeled conditional on the information set, \( \phi_{t-1} = \{P_{t-1}, \ldots, p_{t-1}, x_{t-1}, \ldots, x_{t-1}\} \), where \( x_{t-1} \) constitute covariates. The model is specified as

\[
p_t = \mu_t + \varepsilon_t + J_t, \tag{1}
\]

where \( \mu_t \) is the time-varying mean of the electricity price process excluding the contribution from the jump component (see (6)), \( \varepsilon_t \) is a random disturbance term and \( J_t \) is a jump

---

\(^5\) The Dickey-Fuller (DF) test of stationarity (random walk with drift; \( \Delta p_t = c + \gamma p_{t-1} + \varepsilon_t \) gives a value of -6.33 while the augmented DF test (random walk with drift; \( \Delta p_t = c + \gamma p_{t-1} + \sum_{j=1}^{\infty} \phi_t p_{t-j} + \varepsilon_t \) gives a value of -3.93 which are both smaller than the critical value of -3.42. Thus, the logarithmic electricity price is regarded as stationary.

\(^6\) Since the variables "inflow to reservoirs" and "temperature" are highly correlated only the former is used to capture seasonality. The time varying variance, estimated with GARCH(1,1) models, of both variables are used as explanatory variables in the regressions.

\(^7\) Dummies indicating the summer holiday (July) and the introduction of the system with tradable emission rights (2005-01-01) were also included in the regression analysis but did not contribute in any significant way and were therefore excluded in the empirical study.

\(^8\) To capture the effect of market integration the relevant date to consider is when the border tariffs were removed and the markets were fully integrated. Measuring the effect of market integration (through dummies) with official dates (before markets were fully integrated) gave qualitatively similar results.

component. The stochastic innovations $\varepsilon_t$ and $J_t$ are assumed independent. The $\mu_t$ part is parameterized as,

$$
\mu_t = \alpha_0 + \alpha_1 p_{t-1} + \alpha_2 p_{t-7} + \sum_{k=1}^{K} \beta_k x_{tk} \; ,
$$

where the lagged electricity price variables captures the characteristic mean-reversion of the electricity price process (e.g. [7], [15] and [19]) as well as the daily seasonal pattern. The vector of covariates $x_t$ contains variables accounting for seasonality (discussed in the data section) as well as dummy variables to capture possible effects from multinational market integration in the conditional mean electricity price.

A. The Jump Component

The jump component in (1) is specified as $J_t = \sum_{k=1}^{K} Y_{t,k}$, where $Y_{t,k} \sim \text{NID}(\theta, \sigma^2)$, is the size of the k:th jump during the interval (t-1,t). The jump size variable is governed by a normal distribution with mean jump size $\theta$ and variance $\sigma^2$. The possible effect of market integration on the mean jump size is studied by letting the jump size be time varying $\theta = \theta(x_t)$, where $x_t$ includes dummies indicating multinational integration.

A Poisson distribution conditional on the information set $\phi_{t-1}$ is assumed to describes the arrival of the integer valued number of jumps, $n_t \in \{0,1,2,...\}$, over the interval (t-1,t). The conditional density of $n_t$ is given by

$$
Pr(n_t = j | \phi_{t-1}) = \frac{\exp(-\lambda_t) \lambda_t^j}{j!} \; , \; j = 0,1,2,... \; (2)
$$

The expected number of jumps are given by $E[n_t | \phi_{t-1}] = \lambda_t$. In order to study the effect of market integration on the expected number of jumps we follow [2], [9], [11] and [16] and consider a time-varying jump intensity specification by conditioning on explanatory variables. In the current case this implies specifying $\lambda_t = \exp(\beta_k x_{tk})$, where dummies for market integration are included in $x_t$.\(^{10}\)

B. Conditional Variance

The random disturbance $\varepsilon_t$ in (1) is assumed to be a normal i.i.d. mean-zero innovation defined as $\varepsilon_t = \sigma_t z_t$, where $z_t \sim \text{N}(0,1)$ and $\sigma_t$ is assumed to follow an EGARCH(1,1) ([17]) process.\(^{11}\) In order to capture the possible effects of multinational market integration (through dummy variables) on the conditional variance the specification is enhanced with the explanatory variables $\sum_{k=1}^{K} \delta_k x_{tk}$. The process given by

\[
\begin{align*}
\ln(\sigma_t^2) &= \omega_0 + \omega_1 \xi_{t-1} + \omega_2 \ln(\sigma_{t-1}^2) + \\
\delta_0 \xi_{t-1} - \sqrt{2/\pi} + \sum_{k=1}^{K} \delta_k x_{tk}
\end{align*}
\]  

(3)

where the normalized residual is given by $\xi_t = \frac{\varepsilon_t}{\sqrt{\sigma_t^2}}$. The residual, $\varepsilon_t$, is specified as $\varepsilon_t = p_t - \mu_t - \theta_j \lambda_t$, where $E(p_t) = \theta_j \lambda_t$.

C. Estimation

The conditional density of the electricity price process is a discrete mixture of distributions given by

$$
Pr(p_t | \phi_{t-1}) = \sum_{j=0}^{\infty} f(p_t | n_t = j, \phi_{t-1}) Pr(n_t = j | \phi_{t-1}) \; (4)
$$

where

$$
\begin{align*}
f(p_t | n_t = j, \phi_{t-1}) &= \\
&= \frac{1}{\sqrt{2\pi \sigma_t^2 + j\delta_t^2}} \exp \left( -\frac{(p_t - \mu_t - \theta_j)^2}{2(\sigma_t^2 + j\delta_t^2)} \right) \; (5)
\end{align*}
$$

and $Pr(n_t = j | \phi_{t-1})$ is given by (2). Construction of the likelihood function may be based on the conditional density given in (4) noting that it involves an infinite sum over the possible number of jumps $n_t$. In practice the maximum number of jumps may be truncated to a large value $\tau$, so that the probability of $\tau$ or more jumps is zero. In the empirical estimation $\hat{\tau} > \tau$ is investigated to ensure that the likelihood and parameter estimates do not change. Maximum likelihood estimation of the models is based on (4).

V. EMPIRICAL STUDY

In order to empirically study the effect of multinational market integration on electricity price dynamics a number of model specifications were tested.\(^{12}\) Initially model structures with parsimonious parameterization were estimated and then successively more elaborate specifications were considered.\(^{13}\) It should be emphasized that the conditional mean and conditional variance of the electricity price in the above models are given by (e.g. [6])

$$
E(p_t | \phi_{t-1}) = \mu_t + \theta_j \lambda_t \; (6)
$$

and

$$
\text{Var}(p_t | \phi_{t-1}) = \sigma_t^2 + (\sigma_t^2 + \theta_j^2) \lambda_t \; (7)
$$

Thus, the effect of market integration upon the conditional electricity price can either be through $\mu_t$ and/or trough $\theta_j$ and $\lambda_t$. The effect on the conditional variance similarly can be effected through $\sigma_t^2$ and/or through $\theta_j$ and $\lambda_t$. Hence, the

\(^{9}\) Other lag structures for $\mu_t$ were also considered. The current specification was however favored in terms of having residuals with the lowest autocorrelation.

\(^{10}\) A specification with an autoregressive conditional jump intensity (see [6]) was also considered in the empirical analysis. Since the extension did not contribute further it is not reported in the paper.

\(^{11}\) Initially a GARCH process was utilized in line with [6]. However, due to numerical identification problems caused by the parameter restrictions imposed in the GARCH model an EGARCH model was instead chosen.

\(^{12}\) Throughout the different models the mean specification are the same. The specification was favored in terms of log-likelihood and in terms of being free of autocorrelation.

\(^{13}\) Estimation results for the different specifications are available from the authors upon request.
jump component affects both the conditional mean and the conditional variance of the electricity price.

In Table 2 the estimation results for the model specification favored by the Akaike information criteria is reported.

### Table 2: Estimation Results

<table>
<thead>
<tr>
<th>Jump components:</th>
<th>Variable</th>
<th>Estimate</th>
<th>s.d</th>
<th>Variable</th>
<th>Estimate</th>
<th>s.d</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln((A_t)) = (\gamma_0 + \gamma_1 \delta_{\text{Fin}} + \gamma_2 \delta_{\text{Den}} + \gamma_3 \sigma^2_{\text{Inflow}} + \gamma_4 \sigma^2_{\text{Temp}})</td>
<td>(\theta_0)</td>
<td>0.114* (0.018)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\theta_1) = (\theta_0 + \theta_1 \delta_{\text{Fin}} + \theta_2 \delta_{\text{Den}} + \theta_3 \sigma^2_{\text{Inflow}} + \theta_4 \sigma^2_{\text{Temp}})</td>
<td>(\theta_1)</td>
<td>-0.385* (0.075)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Conditional variance:

\[
\ln(\sigma^2_t) = \alpha_0 + \alpha_1 d_{\text{Fin}} + \alpha_2 d_{\text{Den}} + \alpha_3 (d_{\text{Fin}} - d_{\text{Den}})^2 + \alpha_4 d_{\text{Inflow}} + \alpha_5 d_{\text{Temp}}
\]

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate</th>
<th>s.d</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\alpha_0)</td>
<td>0.122* (0.017)</td>
<td></td>
</tr>
<tr>
<td>(\alpha_1)</td>
<td>-0.080* (0.017)</td>
<td></td>
</tr>
<tr>
<td>(\alpha_2)</td>
<td>0.071* (0.017)</td>
<td></td>
</tr>
<tr>
<td>(\alpha_3)</td>
<td>0.084* (0.016)</td>
<td></td>
</tr>
<tr>
<td>(\alpha_4)</td>
<td>0.038* (0.016)</td>
<td></td>
</tr>
<tr>
<td>(\alpha_5)</td>
<td>0.013 (0.016)</td>
<td></td>
</tr>
</tbody>
</table>

Log-likelihood: -26,782
AIC: 53,626

| \(\sigma^2\) | (0.008) |
| \(E(p_t | \phi_{t-1})\) | 5.188 |
| \(Var(p_t | \phi_{t-1})\) | 0.102 |

*Standard errors calculated with the delta method in parenthesis

The overall change in the conditional mean (through changes in \(\mu\), \(\theta\), and \(\lambda\) due to the inclusion of Finland was an increase in the conditional mean electricity price. This increase is driven by an (almost) unchanged probability of jumps and an increased mean jump size. Going from period 2 to period 3 there was a small increase in the conditional mean electricity price. The small change, which is not statistically significant, is a result of two opposite forces: an increase in \(\mu\) and a decreased contribution from jumps. Hence, during period 3 when Denmark was included, the lowered probability of jumps and the lower mean jump size held the conditional mean electricity price down. Noteworthy is that the contribution from the jumps to the conditional mean of the electricity price is close to zero in period 1 and 3, while there is a positive contribution in period 2. Referring back to Figure 2 this seems to, at least visually, correspond rather well since there is more and more pronounced jumps during period 2. The result concerning Denmark joining the Nord Pool power exchange is a slightly higher conditional mean electricity price. This was a result of a quite lowered jump intensity (\(\lambda\)) and a lowered mean jump size (\(\theta\)), despite the higher \(\mu\). The conditional mean electricity price, in comparison with period 1, increased statistically significantly both in period 2 and period 3.

The conditional variance of the electricity price increased in period 2 when Finland joined Nord Pool. The increase in conditional electricity price volatility is driven by an increased variance due to jumps. The increased probability of jumps and the increased mean jump size during the period contributed by raising the conditional variance of the electricity price while \(\sigma^2\) was almost unchanged. Going from period 2 to period 3 the conditional variance of the electricity price declined. This was an effect of a lowered \(\lambda\) and a lowering of the variance contribution from jumps during this period.

VI. DISCUSSION AND CONCLUSION

In this paper, the effect of international market integration upon electricity price dynamics in the Nordic power exchange is empirically studied. The aggregated effects of market integration indicate that the conditional mean electricity price was increased significantly by the inclusion of Finland and Denmark to the Nord Pool exchange. The conditional variance of the electricity price increased (decreased) when Finland (Denmark) joined the Nord Pool exchange. In contrast, in the financial literature a positive relationship between volumes

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*Significant at the 5 percent level. dFin and Den are the dummies for market integration.

The parameter estimates concerning the \(\mu\), specification indicate that the \(\mu\) part of the conditional mean electricity price increased when Denmark joined the Nordic power exchange while there was no significant effect when Finland joined. The "day of the week" dummies are all positive (except for Saturday) in reference to Sunday. The variable inflow into water reservoirs shows that higher inflows lower the conditional mean electricity price.

14. In order to study the aggregated effect of market integration upon the conditional mean (6) and variance of the electricity price (7), these effects have been calculated and are reported in Table 3.

### Table 3: Parameter Estimates for Key Variables*

<table>
<thead>
<tr>
<th>Period</th>
<th>Period 2</th>
<th>Period 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\mu)</td>
<td>5.188</td>
<td>5.201</td>
</tr>
<tr>
<td>(\lambda)</td>
<td>0.110</td>
<td>0.096</td>
</tr>
</tbody>
</table>

14. Models including temperature instead of inflow into reservoirs gave similar results. In these specifications higher temperatures lowered the conditional mean electricity price.

15. Wald tests are used throughout the paper to test whether the conditional mean and variance of the electricity price changes over the different periods.
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VIII. BIOGRAPHIES

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Why do electricity prices jump? Empirical evidence from the Nordic electricity market

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1. Introduction

For electricity market participants, an understanding of electricity price dynamics is crucial for risk management, portfolio management and electricity derivative pricing. For example, since electricity is not a storable good the conventional derivative pricing models, e.g., based on the Black–Scholes model, are not appropriate. Instead, valuation of electricity derivatives is dependent on models that properly describe the dynamics of the underlying electricity spot price (e.g., Huisman and Mahieu, 2003). As a consequence a literature (e.g., Bourbonnais and Meritet, 2006; Byström, 2005; Clewlow and Strickland, 2000; Guthrie and Videbeck, 2007; Huisman and Mahieu, 2003; Lucia and Schwartz, 2002; Pilipovic, 1998) has emerged focusing on characterizing electricity price dynamics. One of the well documented features of electricity prices in this literature concerns the frequent (in comparison to financial and other natural resource price series) occurrence of large price changes or price jumps. Consequently, most statistical models portraying electricity prices nowadays include components separately accounting for price jumps or allowing for a different price jump regime (see e.g., Huisman and Mahieu, 2003).

The occurrence of electricity price jumps is often loosely motivated by shocks to the electricity demand (e.g., caused by sudden large changes in temperature) or by shocks to an inelastic electricity supply (e.g., caused by production or system breakdowns), but these possible causes for price jumps have not previously been formally studied. An understanding of the underlying causes for electricity price jumps will also improve the understanding of jump processes in general. Thus, the purpose of the current paper is to study the extent to which shocks in the demand and supply for electricity translate into electricity price jumps and the extent to which this process is affected by the prevailing market structure. The questions are analyzed empirically using a sample of electricity spot prices from the Nordic power exchange, Nord Pool, 1996–2006.

The methodological approach used in the paper is to identify jumps in the first stage, using a time series model and then conditional on the identified jumps to study the correlation between shocks in the demand and supply for electricity and electricity price jumps in the second stage. This approach has been used in the financial literature to study jump spillover by, e.g., Asgharian and Bengtsson (2009) and Hellström and Soultanaeva (2012). Since identification of jumps (or underlying jump intensity and mean jump size) is accomplished with reference to "normal" electricity price variation ("normal" price changes), it is important to utilize an appropriate model characterizing "normal" electricity price variation. To accomplish this a mixed GARCH–EARJI jump model (Hellström and Soultanaeva, 2012) is utilized in the empirical study to properly separate "normal" variation from that caused by price jumps.
Note here that a large price change in one period may be perceived as a normal price variation in more volatile periods and approaches defining jumps as simply price changes larger (in absolute value) than some threshold value (e.g., Bystrom, 2005) do not account properly for the time varying "normal" price volatility.

To capture the salient features of electricity price dynamics, i.e., mean reversion, large daily volatilities, volatility clustering and seasonal patterns, the conditional mean specification of the electricity price change in the current empirical study includes autoregressive components reflecting mean reversion as well as seasonal effects and the time varying conditional variance component (GARCH) capturing smooth changes in volatility and allowing for volatility clustering. The GARCH-jump mixture has previously been used in mainly financial applications, e.g., Jorion (1988), Vlaar and Palm (1993), Nieuwland et al. (1994), and Bakraer and Gray (1998) and an extension of the model to include a conditional autoregressive jump intensity parameter is considered by Chan and Mauheu (2002). In the current empirical study different specifications for the mean jump size, the conditional jump intensity and the conditional variance are considered during the jump identification stage. The estimated time varying jump probabilities at different times are, based on the observed direction of price changes, categorized into a categorical variable indicating no, positive and negative jumps.

In the second stage the identified jumps along with proxies for shocks in the demand and supply for electricity are used to analyze the process generating electricity price jumps. Taking the three-category jump series as an ordinal dependent variable an ordered profit model is utilized to determine the extent to which shocks in the demand and supply for electricity translate into price jumps, particularly positive jumps. In this study jumps in temperature and nuclear power production are used as proxies for demand and supply shocks, respectively. The estimation results suggest that whether demand and supply shocks translate into electricity price jumps to a large extent depends on the prevailing market structure. In particular, when the market structure is such that the market is working closer to capacity constraints then shocks tend on average to cause more electricity price jumps. We also find that the demand shocks and the supply shocks have different impacts on price jumps under different market structures.

The paper is organized as follows. Section 2 describes the relevant features of the Nordic power exchange and discusses the possible causes of electricity price jumps. Section 3 presents the empirical design and Section 4 contains the empirical results. The final section discusses the findings of the paper.

2. The Nordic power exchange and hypothesized causes for price jumps

Since the early 1990s, the Nordic power market has evolved from separate national power markets to a multi-national power market. The restructuring process is due to a combination of national initiatives and initiatives from the European Union, aiming at fully opened electricity markets. The first step towards deregulation was taken by Norway in 1991 when the Norwegian Energy Act introduced competition and separated transmission of electricity from production of electricity. In 1993 a Norwegian market for power exchange opened.

In Sweden, it was not until 1996 that legislation for competition in electricity became effective. Sweden joined the Nordic power market in the same year, in what became the first international power exchange, Nord Pool. Finland joined the Nord Pool in 1998 but was not fully integrated until March 1999 when the border tariffs were removed. In 1999, the western part of Denmark joined the Nord Pool while the eastern part of Denmark joined in 2000. In practice, the Danish market was not fully integrated until 2002 when the border tariffs were removed.

Somewhat simplified, the Nordic power exchange, Nord Pool, can be said to consist of one spot market for physical contracts, Elspot, and one financial derivative market, Eltermi, which handles futures, forwards and option contracts. The Elspot is a non-mandatory day ahead power exchange. The electricity not handled through Elspot is instead handled through bilateral contract. In 1996 the Elspot managed 16% of all electricity consumed in the Nord Pool area. Over the years Elspot’s market share has significantly increased and in 2006 over 60% of the total electricity consumption was settled in this market. As a reference price for bilateral and financial contracts Elspot’s price plays an important role in the Nordic power market.

The market integration in the Nord Pool area has lead to a consolidation of different generation structures. The structure differs largely among the participating countries. For example, in 2005 hydro accounted for 99% of the Norwegian power generation. In the same year hydro accounted for 46% of the Swedish power generation. The remaining part in Sweden was produced by nuclear power (45%) and other thermal power sources (8%). The generation from renewable energy sources in Sweden was less than 1% of the total generation in 2005. The Finnish generation mixture was similar to Sweden in that it is more diversified than the Norwegian. In 2005 the Finnish generation mixture consisted of 20% hydro power, 33% nuclear power, 47% other thermal power sources and 0.2% renewable energy. The Danish power generation mainly consists of thermal power but with a substantial part of renewable energy, primarily wind power. In 2005, 81% of the Danish energy was produced by thermal power and the remaining 19% by renewable energy sources. Given the different generation structures in the different countries the mixture in the Nord Pool area has thus been affected by the integration of new participants into the Nord Pool exchange. The integration of new members has also increased the number of consumers in the area, and thus the electricity consumption. All in all the changes in generation structure and in the demand from the enlarged market have had an impact on the balance between supply and demand for electricity in the area. A schematic picture of the supply and demand shifts is shown in Fig. 1.

As can be seen in Fig. 1, the intersection of supply and demand was at its lowest in the first period when only Norway and Sweden were active in the market, while the market operated quite far from its capacity constraint. When Finland joined the market, the intersection of supply and demand was at a somewhat higher price level and also closer to the capacity constraint. This means that positive demand shocks or negative
supply shocks could have a large impact on the price during this period. Finally, when Denmark joined Nord Pool the intersection of supply and demand was at approximately the same price level as in the period before, but further away from the capacity constraint.4 A notable feature during the studied period is that the relative share of hydro power in the total market has declined. The reason for this is that when Finland and Denmark were integrated they brought with them a different electricity production structure, using more thermal power.

The pricing principle in the Nord Pool spot market is a single price, double auction model where the system price is set by the intersection of demand and supply bids.5 In light of the four salient features of electricity price dynamics reported in previous literature (e.g., Bourbounais and Meritet, 2006; Byström, 2005; Clewlow and Strickland, 2000; Guthrie and Videbeck, 2007; Huisman and Mahieu, 2003; Lucia and Schwartz, 2002; Pilipovic, 1996), prices and price volatility are assumed to be determined as follows. First, the long-run equilibrium price level of electricity reflects the marginal cost of producing that electricity. Second, the daily volatilities and the jumps are determined by different types of exogenous changes in supply and demand. As for the changes associated with normal volatility in the electricity prices, these changes can, for example, be normal but unexpected changes in temperature as compared to forecasts by the weather services. In contrast, the jumps (larger price changes) are encountered when there are large exogenous shocks to supply or demand for electricity (e.g., large unpredicted temperature shocks, storms, production or transformation breakdowns etc.). In the empirical part of the paper, identified jumps in temperature and in nuclear power production (using the jump identification methods outlined in Section 3.1) are used as proxies for shocks in the demand and supply for electricity, respectively. We expect that large unpredicted drops in temperature and large unpredicted decreases in nuclear power production will relatively increase the demand and decrease the supply, which in turn increases the probability of positive price jumps. Large unpredicted increases in temperature and large unpredicted increases in nuclear power production will work in an opposite way. In general we expect that the closer the market works to capacity constraints in production the more likely it is that demand and supply shocks translate into electricity price jumps.

3. Data and empirical design

The data used in the empirical study were provided by Nord Pool and SMHI6 and cover the time period from January 1, 1996 to February 12, 2006. All in all the sample consists of 3696 daily observations. In Figs. 2 and 3 the average daily electricity prices, $p_t$, as stated at the Nordic power exchange, and the price changes in terms of logarithmic price changes $r_t = \ln(p_t/p_{t-1})$ are displayed.

From the figures it is evident that the price series contain a number of sharp price changes, i.e., spikes or jumps, as well as display patterns of volatility clustering. Also, positive (negative) jumps seem to be immediately followed by a reverse negative (positive) jump indicating jump reversals. Table 1 contains summary statistics for the electricity price change (logarithmic price changes), change in temperature and change in nuclear production.

The empirical price change distribution is positively skewed and fat tailed indicating a larger frequency of extreme values compared to a normal distribution. In general the extreme observations are of a larger absolute magnitude for positive extreme values than for a negative as indicated by the minimum/maximum value of price change. The Ljung–Box statistic for 7 and 14 lags of the price change series indicates a strong day-of-the-week effect whereas the Ljung–Box statistic (with the same lags) for the squared price changes provides support for volatility clustering and favors a time varying specification of the conditional variance (e.g., GARCH).

In Figs. 4 and 5 the change in the average daily temperature and the change in nuclear power production are displayed.

3.1. Identification of jumps

To accommodate the salient features of electricity price dynamics and to identify jumps a discrete time series model including time-varying conditional variance and a jump component is utilized. The logarithmic price change, $r_t = \ln(p_t/p_{t-1})$ is modeled to capture changes in the electricity price, $p_t$ conditional on the information set $\phi_{t-1} = \{r_{t-1}, \ldots, r_t\}$. The model is specified as

$$r_t = \mu_t + \epsilon_t + \epsilon_{t+1},$$

where $\mu_t$ is the time-varying conditional mean of the price change process, $\epsilon_t$ is a random disturbance term and $\epsilon_{t+1}$ is a jump innovation component. The $\mu_t$ parameter is modeled as

$$\mu_t = \alpha_0 + \sum_{s=1}^{S} \alpha_s r_{t-s},$$

where the lagged electricity price variables capture the characteristic mean-reversion of the electricity price process (e.g., Clewlow and Strickland, 2000; Lucia and Schwartz, 2002; Pilipovic, 1996) as well as the day-of-the-week seasonal pattern ({$r_{t-s}$}).5 The stochastic innovations $\epsilon_t$ and $\epsilon_{t+1}$ are assumed to be independent and to represent "normal" price variation, thought to capture normal day-to-day changes in supply and demand, and jump variation, thought to capture more rare unusual market events, respectively.

Intuitively, jumps are identified in relation to an assumed specified structure for the "normal" price variation, $\epsilon_t$. In the current paper the normal price variation is assumed to be normally distributed with a time varying conditional variance governed by a GARCH specification. Price changes, more extreme positive or negative, that do not fit this representation of the normal price variation are captured by $\epsilon_{t+1}$.

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4 In the empirical study the Akaike information criteria (AIC) was used to determine the lag structure of the conditional mean.

5 Several studies have studied market efficiency in the Nord Pool market. The majority of these studies have not found any proofs for price manipulation, i.e., Hjalmarsson (2000) and Amundsen and Bergman (2006). Overall, scientists seem to agree that the Nord Pool exchange has worked and works quite efficiently. However, there are some studies, i.e., Baik et al. (2011), Johnson et al. (1999) and Steen (2003), that found evidence of market inefficiency at the Nord Pool exchange. In the cases where market inefficiency could not be rejected, the calculated mark ups have been small indicating that the executed market power is marginal.

6 SMHI is the Swedish Methodological and Hydrological Institute.
are regarded as jumps. Note here that what is regarded as a “normal” price change, i.e., falling within what is regarded as “normal” price variation, changes over time through the time varying conditional variance. This means that a price change of a certain magnitude in periods with low “normal” variation may be regarded as a jump while a price change of equal magnitude may be regarded as normal price variation in more volatile periods. The details of the specifications for \( \epsilon_1 \) and \( \epsilon_2 \) are given in the following subsection.

3.1.1. The jump component and conditional variance

The jump innovation component in Eq. (1) is specified as
\[
\epsilon_t = \sum_{k=0}^{n_t-1} \epsilon_t \delta Y_{t-k} - \mathbb{E} \left( \sum_{k=0}^{n_t-1} \epsilon_t \delta Y_{t-k} \right),
\]
where \( Y_t \) is the size of the \( k \)-th jump during the interval \((t-1, t)\). The jump size variable is assumed to be governed by a normal distribution with mean jump size \( \eta \) and variance \( \sigma^2 \). The expected value of the jump innovations is by construction zero, i.e., \( \mathbb{E}(\epsilon_t) = 0 \). Compared to the specification used by, e.g., Huisman and Mahieu (2003), this specification of the jump component is not constrained to only consider positive jumps. A Poisson distribution conditional on the information set \( \delta \) is assumed to describe the arrival of the integer valued number of jumps, \( n_t \in \{0, 1, 2, \ldots \} \), over the interval \((t-1, t)\). The conditional density of \( n_t \) is given by
\[
P_r(n_t = j|\delta_{t-1}) = \frac{\exp(-n_t) n_t^j}{j!} \quad j = 0, 1, 2, \ldots
\]
(2)

The expected number of jumps are given by
\[
\mathbb{E}[n_t|\delta_{t-1}] = \lambda_t
\]
where \( \lambda_t \) is the jump intensity. Note here that the model allows for an expected number of jumps, \( \lambda_t \), during time \( t \), each of mean size \( \eta \). The aggregated jump size on a daily basis, i.e., the total net price change from \((t-1, t)\) due to jumps, is thus \( \lambda_t \eta \). Since this study is based on daily data the actual number of jumps during a day is not observable. However, by using the daily aggregated jump size, \( \lambda_t \eta \), the mean parameters \( \lambda_t \) and \( \eta \) may be identified fitting the model on daily data.

Since it is reasonable to assume that the jump intensity varies over time a time-varying specification is outlined. In the spirit of Chan and Maheu (2002) the time varying jump intensity is specified in an exponential autoregressive form (EARJ(1,1)) given by
\[
\ln(\lambda_t) = \gamma_0 + \gamma_1 \ln(\lambda_{t-1}) + \gamma_2 \xi_{t-1}.
\]
(3)

The jump intensity residual \( \xi_{t-1} \) represents the innovation to \( \lambda_{t-1} \) as measured ex post, i.e., evaluated at time \( t \). The jump intensity residual is calculated as
\[
\xi_{t-1} = \mathbb{E}[\delta_t|\delta_{t-1}] = \lambda_{t-1} - \mathbb{E}[\delta_t|\delta_{t-1}] = \sum_{j=0}^{\infty} P_r(n_t = j|\delta_{t-1}) \mathbb{E}[\delta_t|n_t = j|\delta_{t-1}] - \lambda_{t-1}.
\]
(4)

In principle, if we had access to the actual number of jumps at time \( t-1 \), the jump intensity residual would be the difference between the actual number of jumps and the conditional expected number of jumps at \( t-1 \), i.e., \( \xi_{t-1} = n_{t-1} - \lambda_{t-1} \). Since we do not observe the actual number of jumps at \( t-1 \), we instead utilize the expected number of jumps at \( t-1 \) evaluated at time \( t \), \( \mathbb{E}[n_t|\delta_{t-1}] \) using the information set at time \( t-1 \) (unknown at \( t-1 \) but known at \( t \)). The ex-post probability used in this calculation, calculated at time \( t \), that \( j \) jumps occurred, at time \( t-1 \), is given by
\[
P_r(n_{t-1} = j|\delta_{t-1}) = \int_{r_{t-1}}^{r_{t-1} - j} \mathbb{E}[n_t|\delta_{t-1}] \mathbb{E}[\delta_t|n_t = j|\delta_{t-1}] P_r(n_t = j|\delta_{t-1})
\]
(5)

where \( P_r(n_{t-1} = j|\delta_{t-1}) \) is given below in Eq. (7), \( \int_{r_{t-1}}^{r_{t-1} - j} \mathbb{E}[n_t|\delta_{t-1}] \) in Eq. (8) and \( P_r(n_{t-1} = j|\delta_{t-1}) \) in Eq. (2). Note here that \( P_r(n_{t-1} = j|\delta_{t-1}) \) is the ex-post (evaluated at \( t \)) inference on \( n_{t-1} \) given time \( t-1 \) information, i.e., \( \mathbb{E}[n_{t-1}|\delta_{t-1}] \) in Eq. (4) represents the ex-post (at time \( t \)) assessment of the expected number of jumps that occurred from \((t-2, t-1)\) given the information set \( \delta_{t-1} \), while \( \lambda_{t-1} \) in Eq. (4) is by definition the conditional expectation of \( n_{t-1} \) given the information set \( \delta_{t-1} \). Thus, the jump intensity residual \( \xi_{t-1} \) represents the change in the researcher’s conditional forecast of \( \lambda_{t-1} \) as the information set is updated, i.e., \( \xi_{t-1} = \mathbb{E}[n_{t-1}|\delta_{t-1}] - \mathbb{E}[n_{t-1}|\delta_{t-2}] \).

The exponential specification of the jump intensity \( \lambda_t \) allows \( \lambda_{t-1} \) to affect the current \( \lambda_t \) asymmetrically, i.e., a shock of equal magnitude, positive and negative, has a different impact depending on the sign of \( \gamma_2 \). For example, for a positive \( \gamma_2 \), positive shocks captured by \( \xi_{t-1} \) have a larger impact on the current \( \lambda_t \) than negative shocks of equal magnitude.

The random disturbance \( \epsilon_{t1} \) in Eq. (1) is assumed to be a normal i.i.d. mean-zero innovation defined as \( \epsilon_{t1} = \sigma_{t1} \), where \( \sigma_{t1} \sim N(0, 1) \) and \( \epsilon_{t1} \) is assumed to follow a GARCH(p,q) (Bollerslev, 1986) process. The process is given by
\[
\sigma_t^2 = \sigma_0 + \sum_{i=1}^{p} \alpha_i \sigma_{t-i}^2 + \sum_{i=1}^{q} \beta_i \epsilon_{t-i}^2
\]
(6)

where the residual, \( \epsilon_{t1} \), is defined as \( \epsilon_{t1} = \epsilon_{t} - \mu \).

3.1.2. Estimation

The conditional density of the electricity price process is a discrete mixture of distributions given by
\[
P_r(r_{t-1} = j|\delta_{t-1}) = \sum_{j=0}^{\infty} f(r_{t-1} = j|\delta_{t-1}, \lambda_{t-1}) P_r(n_t = j|\delta_{t-1})
\]
(7)
where

\[
f(r_n|j \phi_{-1}) = \frac{1}{\sqrt{2\pi(\sigma^2 + j^2)}} \exp \left( \frac{\{r_n - \mu_j - \phi_j + \delta \lambda \}^2}{2(\sigma^2 + j^2)} \right)
\]

(8)

and \(P(r_n = j \phi_{-1})\) is given by Eq. (2). Construction of the likelihood function may be based on the conditional density given in Eq. (7) noting that it involves an infinite sum over the possible number of jumps \(n\). In practice the maximum number of jumps may be truncated to a large value \(\tau\), so that the probability of \(\tau\) or more jumps is zero. In the empirical estimation \(\tau > \tau\) is investigated to ensure that the likelihood and parameter estimates do not change. Maximum likelihood estimation of the models is based on Eq. (7).

3.2. Explaining electricity price jumps

Many investors on the electricity market are mainly concerned with either the risk of negative or the risk of positive price jumps, i.e., buyers face the risk of positive, while sellers the risk of negative price jumps. A modeling strategy allowing for different probabilities and explanations for positive and negative jumps is therefore of interest. To accomplish this, a two-step approach is followed. In the first step, the above GARCH–EARJI model is used to identify electricity price jumps. These identified jumps, separated as positive or negative, are then, in a second step, related to proxies for shocks in the demand and supply for electricity. To identify jumps we follow Maheu and McCurdy (2004) and consider actual jumps to have occurred if the ex-post probabilities of at least one jump is larger than 0.5, i.e.,

\[
P(r_n = 1 \phi_{-1}) = 1 - P(r_n = 0 \phi_{-1}) > 0.5
\]

The ex-post probability of zero jumps is given by

\[
P(r_n = 0 \phi_{-1}) = \frac{f(r_n|0 \phi_{-1})}{f(r_n|j \phi_{-1})} \tag{9}
\]

The jump identification process results in a binary series indicating in time when jumps have occurred. These jumps are then further distinguished into positive and negative jumps based on the observed price changes generating a new series of jumps as a categorical variable. This new series is then used along with proxies for demand and supply shocks to study the correlation between these shocks and price jumps by use of an ordered probit model (see e.g., Green, 2003). The dependent variable in the ordered probit models is the identified actual price jumps defined as

- \(0\) pricechange at unidentified as negative jump
- \(1\) pricechange at unidentified as positive jump
- \(2\) pricechange at unidentified as positive jump

Since the dependent variable is based on a subjective decision rule ("the ex-post probabilities of at least one jump is larger than 0.5") and since it is an estimated dependent variable (possibly with errors) a sensitivity analysis for \(P(r_n = 1 \phi_{-1}) = 1 - P(r_n = 0 \phi_{-1}) > 0.4\) and

\[
P(r_n = 1 \phi_{-1}) = 1 - P(r_n = 0 \phi_{-1}) > 0.6 \quad \text{is also performed.} \]

In the former case more observations will be classified as jumps and in the latter fewer.

As for the explanatory variables it is noted that time dummies are collapsed and regrouped to capture the physical circumstances in the Nordic countries. The weekend grouping Saturday and Sunday is used to reflect the expected lower demand on the weekend compared to the working days. July in Sweden is usually taken as summer vacation in which a part of industries and institutions, e.g., schools, are closed. The variable of warm nights is constructed by grouping the months from May to October, in which a relatively low demand is expected due to the warmness and brightness, in particular in view of the household consumption of electricity. As proxies for demand and supply shocks, we use jumps in temperature (demand shocks) and jumps in nuclear power production (supply shocks), where these are identified in a similar way as the electricity price jumps (see Section 3.1). Data for temperature is measured as a weighted average of the participating countries’ average temperature, where the weights are the countries’ GDP shares. The participating countries’ average temperatures, in turn, are the weighted average of the average temperatures in selected cities, where the weights are the cities’ populations. The data for temperatures were obtained from Norges Lysverk. Data for nuclear power production correspond to the total daily production of nuclear power and has been provided by Svenska Kraftnät (Swedish national grid).

To study the possible different impacts of demand and supply shocks on electricity prices under different market structures, interaction terms between demand/supply shocks and different market regimes are utilized. The market structure dummies correspond to the period 1996-01-01 to 1999-02-28 when the Nordic power exchange consisted of Norway and Sweden, the period 1999-03-01 to 2002-02-28 when Finland was included along with Sweden and Norway and the period 2002-03-01 to 2006-02-12 when Sweden, Norway, Finland and Denmark had been fully integrated.

4. Empirical results

The estimation results for the GARCH(1,1)–EARJI(1,1) model used in the jump identification stage are reported in Table 2. The model was favored in terms of AIC and in terms of having the lowest autocorrelation for the total residuals and the squared total residuals. The results indicate that the average daily expected number of jumps, i.e., average \(E[N|\phi_{-1} = 1]\) \(\lambda\), over the full sample period is 0.06 and that the mean jump size is positive (\(\mu = 11.548\)) and statistically significant at the 5 percent level. The parameters in the time-varying jump intensity specification (\(\lambda\)) are all significant at the 5 percent level and indicate that the jump intensity is highly persistent over time, i.e., \(\gamma_1 = 0.974\). To test for the importance of including jumps in the electricity price process we follow Saphores et al. (2002), and perform a Monte-Carlo (MC) based test for the presence of jumps in the presence of GARCH effects. Based on 99 simulated samples, generated from the null DGP, the MC test p-value is

---

9 A direct approach to separately model positive and negative jumps would be to extend the current model to include separate jump intensities and jump size parameters for positive and negative jumps. This is, however, not a straightforward task and is therefore deferred to future research.

10 A more efficient way to relate the underlying proxies for shocks in demand and supply to electricity price jumps is to directly parameterize the jump intensity \(\lambda\). Estimation results following this approach in the current paper did, however, give insignificant results for all demand and supply shock proxies. Plausible explanations for these results are that (i) the considered basic model with the common jump intensity, \(\lambda\), for both positive and negative jumps is too restrictive and that possible opposite effects from explanatory variables upon the probability of negative and positive jumps cancel out when modeling with a common jump probability (through \(\lambda\)); (ii) our proxies for demand and supply shocks are not good enough to capture the possible underlying relationships when modeling with a common \(\lambda\).

11 To account for the possible effects related to the tech bubble and the turbulence in the US markets around 2001, a dummy with the value of one for the period, March 10, 2000, until October 2002, zero otherwise, was also included. The variable was, however, insignificant in all considered specifications and therefore dropped from the model.

12 Details about the calculations, e.g. about what cities that are used may be obtained upon request.
0.02. This confirms the inclusion of jumps as an integral part of the electricity price dynamics. Concerning the GARCH(1,1) specification, in the GARCH(1,1)–EGBJR(1,1) model the estimation results imply a modest persistence ($\omega_0 = 0.742$) of the time varying variance at least in comparison with general financial return series. The Ljung–Box statistics ($Q$) for the total residuals and squared total residuals, at 7 and 14 lags, indicate that some autocorrelation is still present in the residual series.

The estimated jump probabilities, calculated according to Eq. (9), for the year 2001 are displayed in Fig. 6.

Conditional on $P(E_g\geq 1|\theta_{01}) = 1 - P(E_g = 0|\theta_{01}) > 0.5$ the estimated model identifies 23 jumps during 2001. Of these jumps 20 are positive and 3 are negative based on the observed price change. For the full sample the corresponding figures are 132 jumps in total, 113 positive and 19 negative. The mean jump size for the jumps (based on the price changes on the identified jump days) is $-23,006$ (s.d. 9,431) and 34,456 (s.d. 32,269) for days identified with positive jumps. Overall the identified jumps correspond rather well to the largest price changes in the sample. Out of the identified jumps, 94% correspond either to the 10% largest positive or the 10% most negative price changes. The correspondence is, in particular, higher for positive price changes. In Table 3 the distribution of jumps over years, months, and weekdays is displayed.

The number of jumps distributed over the months indicates that the highest number of total jumps (20) occurred in July, August; Autumn: September, October, November.

Table 2

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate</th>
<th>S.d.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conditional mean: $\mu_t = \alpha_0 + \alpha_1 r_{t-1} + \alpha_2 r_{t-2} + \alpha_3 r_{t-3}$</td>
<td>$0.464^{*}$</td>
<td>(0.099)</td>
</tr>
<tr>
<td>$\alpha_0$</td>
<td>$-0.006$</td>
<td>(0.014)</td>
</tr>
<tr>
<td>$\alpha_1$</td>
<td>$0.327^{*}$</td>
<td>(0.015)</td>
</tr>
<tr>
<td>$\alpha_2$</td>
<td>$0.212^{*}$</td>
<td>(0.013)</td>
</tr>
</tbody>
</table>

Conditional variance: $\sigma^2_t = \omega_0 + \omega_1 \varepsilon^2_{t-1} + \omega_2 \varepsilon^2_{t-2}$

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate</th>
<th>S.d.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\omega_0$</td>
<td>$1.47^{*}$</td>
<td>(0.531)</td>
</tr>
<tr>
<td>$\omega_1$</td>
<td>$0.142^{*}$</td>
<td>(0.009)</td>
</tr>
<tr>
<td>$\omega_2$</td>
<td>$0.742^{*}$</td>
<td>0.056</td>
</tr>
</tbody>
</table>

Jump components: $\ln(\lambda_t) = \gamma_0 + \gamma_1 \ln(\lambda_{t-1}) + \gamma_2 \varepsilon_{t-1}$

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate</th>
<th>S.d.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma_0$</td>
<td>$-0.064$</td>
<td>(0.029)</td>
</tr>
<tr>
<td>$\gamma_1$</td>
<td>$0.974^{*}$</td>
<td>(0.012)</td>
</tr>
<tr>
<td>$\gamma_2$</td>
<td>$0.509^{*}$</td>
<td>(0.159)</td>
</tr>
<tr>
<td>$\theta$</td>
<td>$11.548^{*}$</td>
<td>(2.149)</td>
</tr>
<tr>
<td>$\phi$</td>
<td>$13.802^{*}$</td>
<td>(0.713)</td>
</tr>
</tbody>
</table>

Log-likelihood $= -11,835$

AIC | 12,601

$Q(x/c)$ | 28,024

$Q(x/c^2)$ | 68,104

$Q(x/c^3)$ | 67,509

$Q(x/c^4)$ | 129,713

* Significant at the 5 percent level.

Fig. 6. Estimated jump probabilities, 2001.

The number of jumps distributed over the weekdays indicates a strong pattern. About 86% of the jumps occurred during Monday (76), Tuesday (20) and Wednesday (11) where Monday alone account for about 58% of the total number of jumps. The lowest number of total jumps (3) and positive jumps (1) occurred during Sundays.

The estimation results for the ordered probit models are presented in Tables 4a and 4b. Apart from the estimated coefficients we also present marginal effects upon the probabilities of positive ($P(E_g(y = 2))$ and negative ($P(E_g(y = 0))$ electricity price jumps. From the model without interaction variables (Table 4a) it is indicated that the market structure prevailing after 2002 (including the Swedish, Norwegian, Finnish and Danish markets) was associated with a lower (higher) risk for positive (negative) jumps compared to previous periods.

One possible interpretation of this would be that the market structure (intersection between demand and supply) during this period on average was further away from capacity constraints. Negative demand shocks, i.e., proxied by positive temperature shocks, significantly at the 1 percent level, lower the probability for positive electricity price jumps while there was no significant effect from positive demand shocks. Positive supply shocks, proxied by positive jumps in nuclear power production, significantly at the 1 percent level, increase (decrease) the probability for positive (negative) electricity price jumps while negative supply shocks did not significantly affect the probabilities for electricity price jumps. The dummy indicating weekends, significant at the 1 percent level, implies that positive (negative) electricity price jumps are less (more) likely to occur on the weekend. This latter result seems intuitive since the demand for electricity is expected to be lower on the weekend due to less industrial activity. In this case, the market on the weekend may work somewhat further away from capacity constraints compared to during the working days.

Table 4b reports estimation results for the model allowing for different impacts of demand and supply shocks (through interaction variables) during the three different market regimes. A noticeable feature of the results is that the estimates for the interaction terms have different signs and significance during the different market structures, i.e., the effect of demand and supply shocks differ between the different market structures. During the first period (containing Sweden and Norway) neither positive nor negative demand or supply shocks significantly affected the probability for electricity price jumps. In contrast, in the second period (containing Sweden, Norway and Finland) negative demand shocks (positive jumps in temperature), significant at the 1 percent level, lowered the probability for positive electricity price jumps while positive demand shocks (negative jumps in temperature), significant at the 5 percent level, decreased the probability for negative electricity price jumps. Further, positive supply shocks, significant at the 5 percent level, decreased the probability for negative electricity price jumps while there was no significant effect from negative supply shocks. During the third period (containing Sweden, 14 The results from the sensitivity analysis, i.e., from changing the decision rule about when actual jumps have occurred, indicate that the results presented in the paper are robust in terms of signs, significant variables and marginal effects. These results may be obtained from the authors upon request.
Norway, Finland and Denmark) negative demand shocks (positive jumps in temperature), significant at the 1 percent level, decreased the probability for negative electricity price jumps while there was no significant effect from positive demand shocks (negative jumps in temperature). Positive supply shocks during the third period, significant at the 1 percent level, lowered the probability for positive electricity price jumps while there was no significant effect from negative supply shocks. As in the first model (Table 4a) the weekend dummy indicates a significant, at the 5 percent level, lowered (increased) probability of positive (negative) electricity price jumps during the weekend.

In short, since the proxies for demand and supply shocks, i.e., jumps in temperature and in nuclear production, have frequencies fairly evenly distributed over the three market structures the results indicate that the structure of the market, i.e., the average intersection of demand and supply relative to capacity constraints, plays an important role in whether demand and supply shocks translate into jumps in the electricity prices. Overall we do not receive any statistically significant marginal effects on positive electricity price jumps from demand and supply shocks. This might be taken as a sign that the Nordic electricity market is working rather well in handling, in particular, positive demand shocks and negative supply shocks. With respect to the economic significance of those statistically significant marginal effects, we see that demand shocks tend to have a stronger impact than supply shocks in the sample.

Table 3
Structure of the number of identified jumps.

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Positive</th>
<th>Negative</th>
<th>Total</th>
<th>Positive</th>
<th>Negative</th>
<th>Total</th>
<th>Positive</th>
<th>Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan.</td>
<td>15</td>
<td>15</td>
<td>0</td>
<td>1996</td>
<td>8</td>
<td>7</td>
<td>1</td>
<td>Monday</td>
<td>76</td>
</tr>
<tr>
<td>Feb.</td>
<td>11</td>
<td>9</td>
<td>2</td>
<td>1997</td>
<td>10</td>
<td>8</td>
<td>2</td>
<td>Tuesday</td>
<td>20</td>
</tr>
<tr>
<td>Mar.</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>1998</td>
<td>14</td>
<td>14</td>
<td>0</td>
<td>Wednesday</td>
<td>11</td>
</tr>
<tr>
<td>Apr.</td>
<td>9</td>
<td>8</td>
<td>1</td>
<td>1999</td>
<td>11</td>
<td>11</td>
<td>0</td>
<td>Thursday</td>
<td>9</td>
</tr>
<tr>
<td>May</td>
<td>20</td>
<td>16</td>
<td>4</td>
<td>2000</td>
<td>21</td>
<td>17</td>
<td>4</td>
<td>Friday</td>
<td>5</td>
</tr>
<tr>
<td>Jun.</td>
<td>15</td>
<td>13</td>
<td>2</td>
<td>2001</td>
<td>23</td>
<td>20</td>
<td>3</td>
<td>Saturday</td>
<td>8</td>
</tr>
<tr>
<td>Jul.</td>
<td>17</td>
<td>14</td>
<td>3</td>
<td>2002</td>
<td>15</td>
<td>14</td>
<td>1</td>
<td>Sunday</td>
<td>3</td>
</tr>
<tr>
<td>Aug.</td>
<td>11</td>
<td>11</td>
<td>0</td>
<td>2003</td>
<td>9</td>
<td>7</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sept.</td>
<td>7</td>
<td>4</td>
<td>3</td>
<td>2004</td>
<td>7</td>
<td>3</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oct.</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>2005</td>
<td>10</td>
<td>8</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nov.</td>
<td>10</td>
<td>8</td>
<td>2</td>
<td>2006</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dec.</td>
<td>10</td>
<td>9</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

59 For example, there were 119, 119 and 120 jumps in temperature during each period, respectively.

5. Discussion

In this paper, a two-stage study is conducted to investigate the extent to which shocks in the demand and supply for electricity translate into electricity price jumps and the extent to which this process is affected by the prevailing market structure. The questions are analyzed empirically using a sample of electricity spot prices from the Nordic power exchange, Nord Pool, 1996–2006. A mixed GARCH–EARI jump model is utilized in the first stage to identify electricity price jumps by properly separating “normal” variation from that caused by price jumps. In the second stage ordered probit models with the identified price jumps as a dependent variable are utilized to empirically study the questions at issue. The used proxies for demand and supply shocks are jumps in temperature and in nuclear power production (identified in the same manner as electricity price jumps), respectively.

The main finding from the study is that whether demand and supply shocks translate into electricity price jumps largely depends on the prevailing market structure, i.e., on how far the market works from capacity constraints. This is loosely consistent with the perspectives considered in Lundgren et al. (2008) in that the price volatility and jump probabilities will be determined by how close to the capacity constraints the market is working. By a simple supply and demand analysis at an aggregate level, we see that, after Finland joined the Nord Pool, the intersection of demand and supply was relatively closer to the capacity constraint in the market, in which price jumps, in particular positive jumps, are more likely to occur. However, after Denmark joined the Nord Pool, the intersection was shifted somewhat further away from...
the capacity constraint. Such a movement would mitigate the impact from temporary positive demand shocks, which in turn decreases the probability of positive price jumps. A notable feature of the empirical analysis is that the marginal effects from positive demand (negative temperature shocks) and negative supply shocks on the jump probabilities are mostly insignificant and of small magnitude. One interpretation of this is that the market is working relatively efficiently in handling these types of shocks. It may, however, also be an indication that our proxies for the demand and supply shocks are not good enough measures to capture underlying demand and supply shocks. In future studies it may be fruitful to examine other types of proxies for demand and supply shocks, e.g., better measures of economic activity, more detailed temperature data, data on production losses and so forth.

The results in this paper contribute to an improved understanding of electricity price dynamics and to the underlying causes for price jumps, which are important for electricity risk management, portfolio management and electricity derivative pricing. From a Nordic perspective, market integration seems to have worked well in terms of creating a market more capable of handling external shocks, especially in periods when the market has not been working close to the capacity constraints.

Acknowledgment

The authors thank the editor and an anonymous referee for their constructive comments that have significantly improved the content of the paper. Financial support from Vattenfall, the Wallander Foundation and Sparbankernas Forskningsstiftelse is gratefully acknowledged.

References


Table 4b

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Changes in predicted probability Pr(y = 2)</th>
<th>Changes in predicted probability Pr(y = 0)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>95% CI</td>
<td>95% CI</td>
</tr>
<tr>
<td>Finland</td>
<td>0.010</td>
<td>0.139</td>
<td>0.016</td>
</tr>
<tr>
<td>Denmark</td>
<td>-0.164</td>
<td>0.122</td>
<td>-0.0086</td>
</tr>
<tr>
<td>Positive Tm. jump</td>
<td>0.138</td>
<td>0.406</td>
<td>0.0036</td>
</tr>
<tr>
<td>Positive NP. jump</td>
<td>0.714</td>
<td>0.547</td>
<td>-0.0243</td>
</tr>
<tr>
<td>Negative Tm. jump</td>
<td>-0.214</td>
<td>0.278</td>
<td>-0.0105</td>
</tr>
<tr>
<td>Negative NP. jump</td>
<td>0.523</td>
<td>0.353</td>
<td>0.0456</td>
</tr>
<tr>
<td>Positive Tm. jump</td>
<td>-0.005</td>
<td>0.333</td>
<td>-0.0002</td>
</tr>
<tr>
<td>Positive NP. jump</td>
<td>0.215</td>
<td>0.371</td>
<td>0.0135</td>
</tr>
<tr>
<td>Negative Tm. jump</td>
<td>4.045*</td>
<td>0.225</td>
<td>0.0301</td>
</tr>
<tr>
<td>Negative NP. jump</td>
<td>-0.463*</td>
<td>0.234</td>
<td>-0.0111**</td>
</tr>
<tr>
<td>Positive Tm. jump</td>
<td>0.044</td>
<td>0.183</td>
<td>0.0025</td>
</tr>
<tr>
<td>Negative NP. jump</td>
<td>-0.056</td>
<td>0.258</td>
<td>-0.0029</td>
</tr>
<tr>
<td>Positive Tm. jump</td>
<td>0.101</td>
<td>0.264</td>
<td>0.0060</td>
</tr>
<tr>
<td>Negative NP. jump</td>
<td>0.052**</td>
<td>0.112</td>
<td>0.0024**</td>
</tr>
<tr>
<td>July</td>
<td>0.118</td>
<td>0.138</td>
<td>0.0076</td>
</tr>
<tr>
<td>Warmbright</td>
<td>-0.015</td>
<td>0.084</td>
<td>-0.0008</td>
</tr>
<tr>
<td>α1</td>
<td>-2.889</td>
<td>0.149</td>
<td></td>
</tr>
<tr>
<td>α2</td>
<td>1.847</td>
<td>0.108</td>
<td></td>
</tr>
<tr>
<td>Obs</td>
<td>3511</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Log likelihood</td>
<td>-551.82</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Log likelihood intercept only</td>
<td>-594.64</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Positive Tm. jump-dFin* represents the interaction term between the positive temperature jumps and the market structure after Finland joined; *Positive NP. jump-dFin* represents the interaction term between the positive temperature jumps and the market structure after Denmark joined. The other interaction terms are defined in the same manner.


List of dissertations at the Department of Economics, Umeå University

Holmström, Leif (1972) Teorin för företagens lokaliseringsval. UES 1. PhLic thesis


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