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Market Performance in the Nordic Electricity Market

An Analysis of Market Power during Energy Market Turbulence

by

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This paper analyzes the existence of market power on the Nordic electricity market between 2018-2022, and if the energy market turbulence caused by covid-19, and later deepened following the war in Ukraine, affected producers' bidding behavior. Market power was tested using Cournot assumptions, to see if producers withheld output strategically when demand was more inelastic. Auction data on system price and sell and buy bids from Nord Pool day-ahead market were used in the analysis. Producers' bidding strategy was then tested using a two-stage least squares regression model. The findings suggest that hydroelectric power producers systematically withhold production as demand becomes more inelastic. Implied price-cost markups associated with strategic withholding increased after 2020, suggesting that electricity producers exercised more market power when the electricity market after 2020. Nonetheless, the overall price effect of strategic withholding is small, measured as 0.2% of total system price in the period before 2020, and 1.6% after 2020.

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1. Introduction

Recent turbulence on the European energy market due to covid-19 and the Russian oil and natural gas embargo has had substantial effects on electricity markets, especially in Europe (Bento et al., 2021; Halbrügge et al. 2021; Ruan et al. 2021; Ari et al., 2022). A well-functioning electricity market is central to the operations in the broader economy, and the recent price spikes and heightened price volatility has had significant effects on both inflation, manufacturing, and consumer welfare in economies all over Europe (Ari et al., 2022). The rise in electricity prices has raised concerns of lawmakers and regulators on how to improve market performance and lower the costs to consumers caused by rising prices. Well-informed policy decisions require knowledge on what factors cause these sub-optimal market outcomes. This paper will focus on market power from power suppliers, as it is one of the more endogenous channels of price increases, compared to the price-effect from oil and natural gas prices, which are set on the global market. The results from the analysis may therefore indicate measures national lawmakers and regulators can take to improve market performance control. More specifically, the paper will examine if strategic output decisions from suppliers influences price formation, and whether the turbulence on the energy markets has affected how producers set their output.

This thesis will study the Nordic electricity market, for two reasons. Firstly, there is useful data on buy and sell bids for electricity available on the Nord Pool day-ahead market, which can be used to analyze how electricity producers bid their output. Secondly, the Nordic electricity market is dominated by fossil-free electricity production (Sandgren and Nilsson, 2021), meaning that turbulence in the global oil and natural gas market will not directly affect Nordic electricity prices by raising the cost of inputs. Turbulence in the global oil and natural gas market should, at least not directly, distort the behavior of Nordic electricity producers. Put together, the Nordic electricity market enables an analysis of how market participants are affected by an exogenous shock in energy markets, and how it is translated into strategic decisions on output from electricity producers.

Existing literature on the Nordic electricity market suggests that there is some level of market power exercised via strategic withholding of output when demand is particularly inelastic

(Fogelberg and Lazarczyk, 2019; Lundin and Tangerås, 2020). Research on other electricity markets comes to similar conclusions (Wolak, 2003; McRae and Wolak 2014; Kwoka and Sabodash, 2011). Market power is in the case of strategic withholding expressed by reducing output from low marginal cost sources, forcing them to be substituted by more costly alternatives; spot prices are then set by the most expensive source (Lundin and Tangerås, 2020). None of the mentioned papers look at market power in the context of recent developments in renewable market penetration and increasing price differences due to constraints in the transmission system. This paper will therefore contribute to the existing literature by providing an updated assessment of market power in the Nordic electricity market under transmission constraints and high renewable penetration, while providing insights on how market participants behave under turbulence in the global energy market.

This thesis applies the model developed by Lundin and Tangerås (2020), to analyze market performance on the Nord Pool day-ahead market with data on the system price and the related sell and buy bids. The model uses a two-stage least squares regression model to test Cournot assumptions - that firms strategically set output to influence prices. Cournot players, or the firms that strategically bid output, are wholly represented by hydroelectric power producers in the analysis. The null hypothesis is thus that Cournot players do not bid output strategically and that pricing in the market reflects perfect competition. As the null hypothesis could be rejected in all tests, the extent of the price-effects from market power was calculated using a Lerner index.

1.1 Aim and scope

This thesis will examine if electricity producers strategically set output to influence prices in the Nordic electricity market, and to what extent prices are manipulated if they do. The Nordic region is especially interesting due to its negligible use of oil, natural gas, for electricity generation (Sandgren and Nilsson, 2021). Price increases on the Nordic electricity market are therefore not directly related to increases in the price of these inputs. The analysis period is 2018-2022, where 2020 is a natural cut-off point to analyze the effects of market turbulence, as it represents the beginning of the covid-19 pandemic, which was followed by the Russian oil and natural gas embargo. The years before the covid-19 pandemic's arrival to Europe, 2018-2019, will provide a baseline with which the later period, 2020-2022, is tested against to see if market behavior changed following the market turbulence.

1.2 Outline

The thesis is divided into seven chapters. The second chapter discusses the theoretical approach and related literature. The third chapter examines the data used in the analysis. Methodology and the empirical analysis are found in the fourth and fifth chapter respectively. Findings from the empirical analysis and future research are then considered in chapter six, which is the discussion section. The main findings and conclusions are presented in the final chapter.

2. Theory

This section will first present the Nordic day-ahead market, Nord Pool, to provide context of the workings of the electricity market. The following section discusses the application of theoretical frameworks on oligopolistic competition in electricity markets. Related literature will then be discussed to provide insights from previous research while also highlighting potential gaps.

2.1 Institutional background

A brief overview of the Nord Pool day-ahead market, where approximately 80% of total electricity production in the Nordics is traded (Lundin and Tangerås, 2020), is useful to set the institutional framework for the analysis. Nord Pool was established in 1996 as a join-operation between the Norweigan and the Swedish transmission system operators to establish a common marketplace for electricity (Kristiansen, 2014). The establishment of Nord Pool was part of the deregulation of the Nordic electricity market, and both Denmark and Finland had joined the marketplace by 2000 (Kristiansen, 2014). The Nordic electricity market is as of recently fully integrated with the broader, European electricity market enabling greater trade with the continent (Lundin and Tangerås, 2020).

Electricity cannot be stored at any greater capacity so all electricity production must be consumed immediately to ensure a stable frequency in the grid system (Swedish National Grid System, 2021). Electric equipment and devices that use electricity will become damaged if the grid system deviates from its standard 50Hz (Swedish National Grid System, 2021). Transmission system operators are tasked to stabilize the frequency in the grid system and to ensure that the electricity can flow to where it is needed. Swedish, Danish, and Norwegian transmission system operators have split their countries into several, smaller *bidding zones,* to ensure that spot prices reflect local market conditions (Nord Pool, 2020b). Figure A1 in the appendix shows a map of the Nordic electricity market and its bidding zones. Prices between bidding zones will diverge when the transmission system is at full capacity, and higher marginal cost generators are switched on to meet local demand (Nord Pool, 2020b).

A key feature of the Nordic electricity market is its reliance on hydroelectric power and low use of fossil fuels and inputs in electricity production, see Table 2.1. This feature has important implications on pricing on the Nord Pool day-ahead market, where prices are set based on the marginal cost of the most expensive source needed to meet demand at any given hour (The Swedish Energy Markets Inspectorate, 2021). Hydroelectric power, renewables and to a lesser extent nuclear power has low marginal cost but if demand cannot be met by production from these sources, higher marginal cost sources are switched on until total output meets demand (Jablónska et al., 2012). The high marginal cost sources typically consist of fossil fuels, and their marginal cost is set by the spot prices on global energy markets (Jablónska et al., 2012). An example of a supply curve generated by marginal cost pricing is given in Figure 2.1, where the supply curves become almost vertical as the most expensive production sources are switched on.

Table 2.1

Share of total production per source in the Nordics, 2020.

Oil, natural gas, and coal	2.8%
Hydroelectric power	58.7%
Renewables	15.8%
Nuclear	18.0%
Other	4.7%

Note: Other consists of production from geothermal energy and biomass. Data is from Entso-e.

Electricity on the day-ahead market is traded via hourly auctions where buyers and sellers submit bid pairs on how much electricity they wish to buy or sell for every hour the following day (Nord Pool, 2020a). All bid pairs are inputted into the Euphemia optimization algorithm which calculates how the electricity will flow the following day to ensure the lowest prices, based on available transmission capacity in the grid system (NEMO Committee, 2020). Euphemia will then calculate the prices in all bidding zones as well as the Nordic system price, where the price is decided by the marginal cost of the most expensive production source used to meet demand (NEMO Committee, 2020).

2.2 Oligopolistic competition and the Cournot model

Oligopolistic competition refers to a market structure somewhere between the two extreme cases of perfect competition and monopolies. In the former, no market participant has market power and cannot influence the price of a good. A monopolist, in contrast, can set prices at its own volition since no competition exists to undercut their pricing. Oligopolistic competition is a combination of both, where a number of market participants compete for market share and have some degree of market power. Rudkevich, Duckworth and Rosen (1998) refer to market power as the ability of sellers to influence prices over a sustained period for their own profit, which is the definition that will be used in this paper as well. The model applied in this paper to test the existence of market power uses assumptions from oligopolistic competition to test whether prices are competitively set. In other words, the null hypothesis is that the prices are set competitively, and that there is no influence from market power in price formation. A rejection of the null would therefore imply that prices are affected by market power.

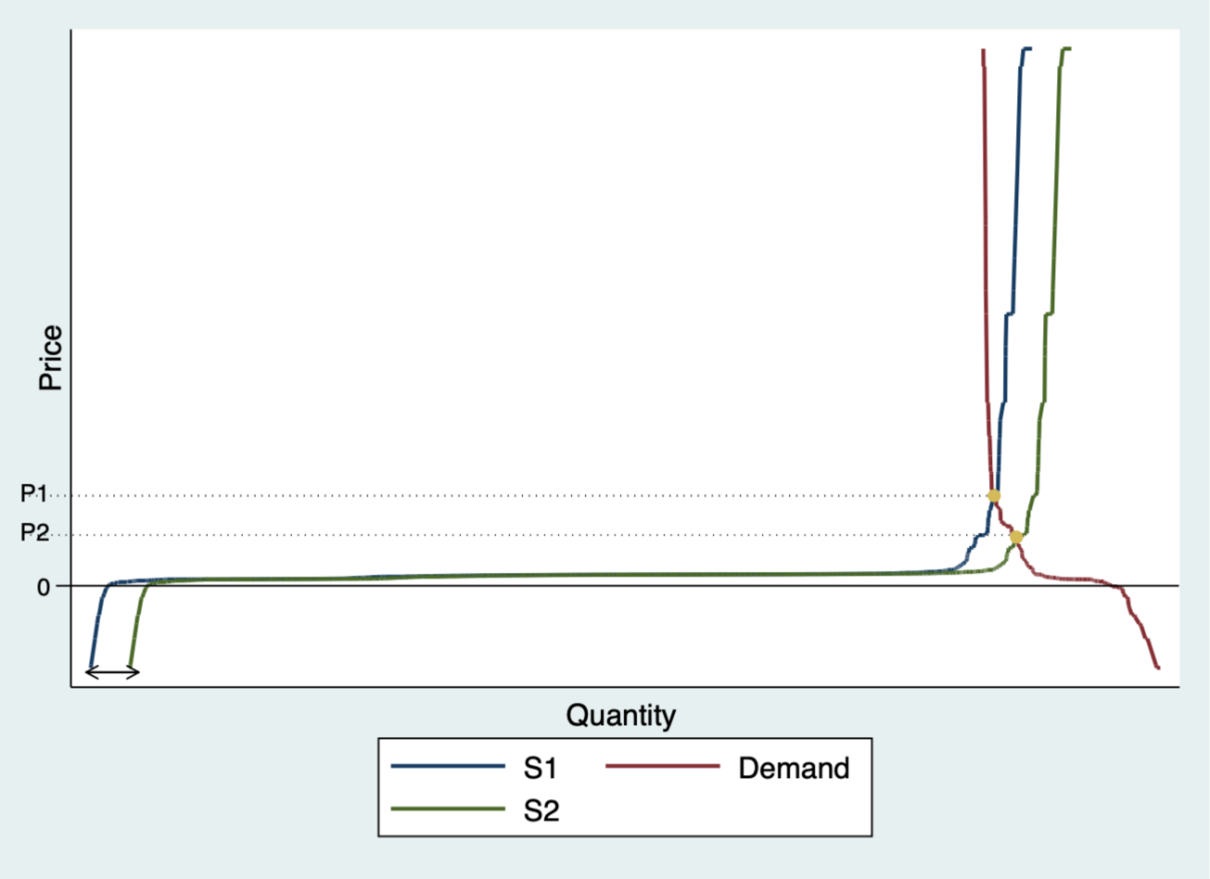
Klemperer and Meyer's (1989) seminal paper on oligopolistic competition analyzes how firms decide their supply function depending on the characteristics of their market. They find that any supply function in oligopolistic competition will fall between Cournot competition, which is when oligopolists form their supply function based on what quantity to produce, and Bertrand competition, which is when oligopolists form their supply function based on price. Further, they point out that a supply function under Cournot competition will tend towards being vertical, while a supply function under Bertrand competition will tend toward being horizontal. A market characteristic that incentivizes Cournot behavior, which therefore refers to strategies of exercising market power by setting quantities rather than prices, is inelastic demand curves (Klemperer and Meyer, 1989). Inelastic demand curves imply that consumers are insensitive to price and that a small shift in output has a large impact on prices. It is therefore not a profit maximizing strategy for firms within a Cournot market to compete in prices, since consumers are insensitive to them. Oligopolists within a Cournot market, also known as Cournot players, will instead base their profit maximizing strategies on output.

For electricity markets, demand elasticity tends to be highly inelastic in the short-term, and only slightly less so in the longer term (Csereklyei, 2020; Burke and Abayasekara, 2018). Miller and Alberini (2016) analyzed US electricity demand data and found that elasticities have remained consistent over time with no systemic changes occurring, even if there is a variance stemming from the time of day and season of the year. The inelasticity of demand for electricity has made Cournot models a commonly applied analytical framework for electricity markets.

An important characteristic of Cournot markets is that price is a function of demand. Consumers are price-takers and market players set their output at quantities they believe will maximize profits. Figure 2.1 illustrates how a reduction in output affects causes prices to increase, given that demand is inelastic. A shift in the demand curve from S2 to S1 causes prices to increase from P2 to P1. Such horizontal shifts of the supply curve have been found in several electricity markets (Wolak, 2003; McRae and Wolak 2014; Lundin and Tangerås, 2020). Lundin and Tangerås (2020) analyzed the Nordic electricity market in 2011-2013 and found evidence of leftward (S2 to S1) horizontal supply shifts when demand was more inelastic. The source of the horizontal supply shifts, they found, was inelastic 'Cournot bids' from electricity producers with low marginal costs. Cournot bids consist entirely of production from low marginal cost resources such as hydroelectric power and renewables. The authors netted out renewable production due to its intermittency, meaning that such bids were unlikely to be strategic, and found evidence of Cournot behavior; production was withheld from the market when demand was particularly inelastic, thereby causing prices to increase.

Figure 2.1

Illustration of horizontal shifts caused by deviations in Cournot output.



Note: Both supply curves and the demand curve are actual bid curves generated using bid data from January 1st, 2018, from Nord Pool, representing the bids for the 18:00-auction. The S1-curve is generated by subtracting 1.5GWh of output from the S2-curve, which is the actual supply curve of the *mentioned auction. The steepness of the demand curve will determine how much prices are affected by strategic Cournot bids.*

This thesis will use a slightly modified version of Lundin and Tangerås' (2020) model to analyze Cournot behavior in the Nordic electricity market between 2018-2022, where Cournot bids instead wholly refer to hydroelectric power production. Hydroelectric power production has essentially zero marginal costs, and power plant producers decide how much water to run through the turbines at any hour, making them the central Cournot bidders in the Nordic electricity market (Lundin and Tangerås, 2020). Furthermore, Cournot bids netted for renewable production approximates the total production from hydroelectric power production, with a correlation of 0.91 in 2018. Both factors make it possible to analyze Cournot behavior on the Nordic electricity market using hydroelectric power production. Hydroelectric power producers will therefore be referred to as Cournot players, and the electricity they produce as Cournot output.

The purpose of the Cournot model in this paper is to test whether there is oligopolistic competition and if it is translated into higher prices due to market power, or if prices are set competitively like in the Bertrand model or perfect competition. A regressions model, which will be discussed at greater depth in the methodology section, will be formulated using the Cournot assumptions of Lundin and Tangerås (2020). If the regression results are insignificantly different from zero, the null hypothesis cannot be rejected. Failure to reject the null hypothesis implies that price formation on the Nordic electricity market is free from the influence of market power via strategic output bids.

2.2 Related literature

The literature on the performance of electricity markets is extensive, and methods and insight from previous research will help to guide our analysis. This subsection will therefore explore previous findings from related literature for important considerations, trends, and gaps in the literature.

Previous analysis on market power in electricity markets indicate the existence of strategic output bids. The research most similar to this paper, Lundin and Tangerås (2020), analyzed the Nordic electricity market between 2011 and 2013, where they found price-cost markups of 4% caused by strategic withholding of output when demand was particularly inelastic. A related paper by Tangerås and Mauritzen (2018) analyzed Swedish hydroelectric power producers' behavior across markets over the same period and found evidence to suggest that they indeed exercised local market power, although only in select bidding zones. A paper by Fogelberg and Lazarczyk (2019) found evidence of electricity producers using production failures to disguise strategic withholding of supply. Such behavior was found more prevalent when electricity prices were high compared to during periods with low prices, suggesting that producers wish to influence prices by withholding supply. However, they found no evidence that the behavior is systematic. A similar analysis by Kwoka and Sabodash (2011) on the New York electricity market shows that electricity producers in the region supplied electricity differently when price spikes due to excess demand were likely. These results suggest that producers strategically withheld output to influence prices. Previous research has evidently found evidence of producers exercising market power by withholding outputs, causing prices to increase in periods of highly inelastic demand.

Although this thesis will look to apply a slightly modified version of the Lundin and Tangerås (2020) method, there are several factors that may have caused changes to how oligopolistic competition functions in the Nordic region after 2011-2013 (the period their paper analyzed). Yan and Folly (2014) find that demand elasticity may have a significant influence on market outcomes, as it affects Cournot players' ability to set prices. For example, higher demand elasticity means that consumers become more price sensitive, making Cournot bids less effective as a method of profit maximization as less electricity will be demanded. A shift toward greater demand elasticity could therefore change the conditions for Cournot players' ability to influence prices. One could then suspect market power to decrease, thus moving electricity markets closer towards price competition and more optimal market outcomes.

A paper by Vesterberg (2018) looks at Swedish households' electricity contracts. Electricity contracts naturally influences demand elasticity for electricity since the type of contract incentivizes certain behaviors (Vesterberg, 2018). A variable price contract will for example incentivize higher consumption during low prices and vice versa, while a fixed price contract makes consumers insensitive to changes in spot prices as they, indeed, pay their contracted price per MWh regardless of the spot price. Vesterberg (2018) found that consumers' decision-making when signing electricity contracts is greatly influenced by the contract type they had previously, implying some level of inertia. Hence, the more popular contract type, fixed price contracts, is likely to be signed even if other contracts may be more economical. This finding is consistent with Borenstein’s (2007) analysis of commercial and industrial electricity consumers in the US. These electricity consumers are due to risk aversion likely to purchase fixed price contracts even if variable price contracts would lead to lower prices over the long-term (Borenstein, 2007). One could therefore suspect some level of consistency in the low elasticity of demand, as both industrial and household consumers seem to prefer fixed rate contracts.

Contracts on the demand-side are not the only contracts to consider. Electricity producers are equally inclined to reduce risks caused by price volatility and forward contracts are therefore often signed. Allaz and Vila (1993) theorize that forward contracts in Cournot competition improves market efficiency. The reason, they point out, is that producers’ have less incentive to set quantities that maximize short-term profits if the goods’ price is already set by the forward contract. The authors argue that firms will determine what quantities to be sold on the forward market and that the specified quantity will therefore not be used as part of the firm’s output strategy. If a producer has agreed to sell a set quantity of a good for €10 on the forward market, they receive no benefit by bidding the quantity allocated for the forward contract at a higher price. Quantities sold on the forward market will therefore reduce firms’ Cournot behavior by reducing the quantity with which they (can) exercise market power (Allaz and Vila, 1993). Allaz and Vila’s (1993) theory is often applied to electricity markets. Willems, Rumiantseva and Weigt (2009), and Lundin and Tangerås (2020) for example only use the share of electricity production not covered by forward contracts when analyzing firms’ Cournot behavior.

Recent expansions of renewable electricity production also affect firms’ ability to exercise market power. Do et al. (2021) point out that firms base their bidding decisions not on the total demand, but on the residual demand. Residual demand is total demand netted for renewable production. Due to the difficulties in storing electricity, a higher share of renewable production will lead to a more volatile residual demand, making it difficult for firms to make precise forecasts (Do et al., 2021). Similarly, Haas et al. (2013) point out that an increase in renewable production causes increased spot price volatility. It is therefore likely that a greater share of total production from renewables will make it more difficult for producers to exercise market power via Cournot strategies, as such strategic decisions ultimately depends on firms’ predictions. Another related factor is that less non-renewable production is required to meet total electricity demand, thus reducing the scope for Cournot bids to influence price-setting.

Early Cournot literature on electricity markets focused on quantity competition in the context of transmission constraints (Cardell, Hitt, and Hogan, 1997; Cunningham, Baldick, and Baughman, 2002), something that has increased in frequency and severity over the analysis period (Energinet et al., 2021). Cardell, Hitt, and Hogan (1997) show that producers could in some situations optimize their generators' market power by strategically bidding production to cause congestion. Congestion is when transmission lines are at capacity and cannot transmit more electricity. A potential benefit to producers with congestion is that it causes electricity markets to temporarily split into several, smaller markets due to the inability to import and export. The smaller electricity markets caused by congestion, Cardell, Hitt, and Hogan (1997) find, allows producers to increase their sell bids above marginal costs since competition from imports decreases in the affected areas, giving producers greater market power. A related paper by Cunningham, Baldick, and Baughman (2002) shows how market power maximization becomes more difficult when transmission constraints are introduced to electricity market Cournot models. Firms able to influence market prices via their output are less likely to optimally exercise market power under transmission constraints due to forecasting difficulties (Cunningham, Baldick, and Baughman, 2002).

The findings of the early Cournot literature on electricity markets implies that transmission constraints have an important but somewhat ambiguous effect on market performance. It can on one hand be used to exercise greater market power by means of congestion (Cardell, Hitt, and Hogan, 1997), while it on the other hand makes it more difficult for power producers to estimate what output would maximize market power as decisions from competing producers becomes less predictable (Cunningham, Baldick, and Baughman, 2002).

The literature thus suggests that forward contracts, consumer contracts, demand elasticities, renewable production, and transmission constraints are key factors to how (and if) electricity producers may exercise market power. Since this thesis analyzes a market which has historical evidence of market power (Fogelberg and Lazarczyk, 2019; Lundin and Tangerås, 2020; Tangerås and Mauritzen, 2018), it is important to be mindful of the development of the factors that affect firms' ability to exercise market power, as they are likely to determine market performance. This thesis will contribute to the existing literature by providing an updated estimate of market power in the Nordic electricity market, which has seen increasing penetration of renewable production and transmission constraints. It will also provide estimates on how Cournot players' strategic behavior is affected in turbulent energy markets.

3. Data

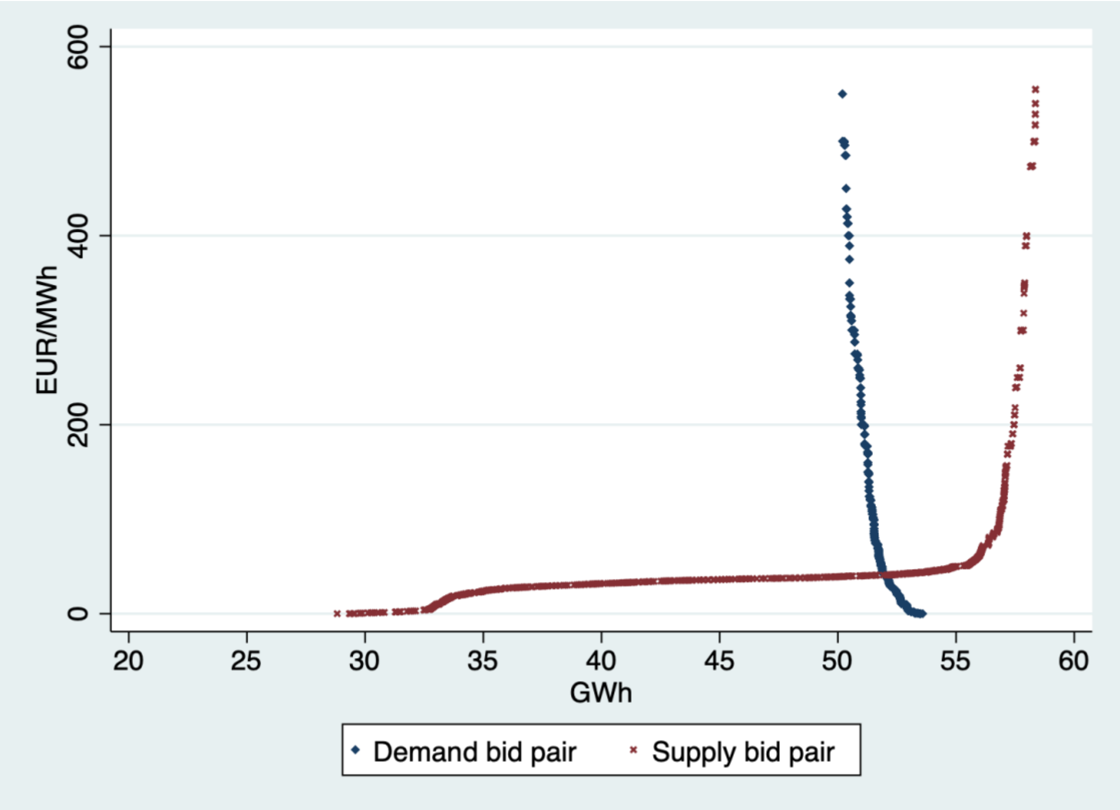
The purpose of this section is to describe the data used in the empirical analysis as well as from where it was obtained. Some variables, the Cournot output, the semi-elasticity variable, and the transmission constraints proxy, are described in greater detail to elaborate on the theory behind them and their purpose in the regression model.

3.1 Sources

Data has been collected from a variety of sources. Data on system price, bidding zone spot prices, forecasted demand, electricity consumption and production, and system price bid curves were obtained from the Nord Pool FTP-server. All data on prices is from the Nord Pool day-ahead market, where roughly 80% of all electricity produced in the Nordics is traded. Price data should therefore be representative of the Nordic electricity market in general. Forecasted demand for the following day is reported to Nord Pool by each country's respective transmission system operator, from where it is shared to market participants (Nord Pool, 2020a). The system price bid pairs from producers and consumers are based on aggregated and anonymized bids made by buyers and sellers on the bidding zone level. The bids from the individual bidding zones are recalculated by Nord Pool to generate bid pairs at the system price level (Nord Pool, 2020a). The system price bid pairs for every hour are reported in the Elspot directory, from where the data was acquired. A bid pair represents the amount of output a bidder is willing to sell (supply) or buy (demand) at a given price. Figure 3.1 shows an example of these bid pairs combine to create supply and demand curves. Nord Pool calculates the demand and supply curves using linear interpolation between the bid pairs, where the intersection of the two curves determines the system quantity, and more importantly, the system price. Besides being used as the price variable in this analysis, the system price is commonly used as the reference price for financial products (Nord Pool, 2020a).

Figure 3.1

System price bid pairs on March 17th, 2018, 18:00.



Note: Every point in the graph represents one bid pair. A supply bid pair represents the output a seller would accept at a given price. Similarly, a buy demand bid pair represents the output that a buyer is willing to accept at a given price.

Data on renewable output and hydroelectric production (Cournot output) has been compiled from national sources. Data for Swedish hydroelectric production as well as renewable output, which includes solar power production and wind power production, was downloaded from SvK (Swedish National Grid System). The same data was downloaded from Fingrid, the Finnish national transmission system operator. Finnish solar production was not included however, as their generation from solar power was negligible during the entire sample period. Data on Danish electricity production was downloaded from the national transmission system operator, Energinet. Norway has no national source that provides hourly statistics so Norweigan electricity production data was downloaded from Entso-e's transparency platform. Data on the stored energy value of Swedish, Norweigan, and Finnish hydro reservoirs was also downloaded from Entso-e. (Denmark has no hydroelectric power production). Since Elspot trades 80% of all electricity production in the Nordics, all values have been multiplied by 0.8 to reflect the actual amount traded on the Nord Pool marketplace. Finally, data on temperature was downloaded from the Swedish Meteorological and Hydrological Institute's database. Temperature corresponds to the temperature in Stockholm. The choice of Stockholm is motived by its central location in the Nordic region. Table 3.1 provides summary statistics for all variables that will be used in the empirical analysis.

Table 3.1

Summary statistics of variables.

Variables.	Mean	Sd	Min	Max
System price	62.0	71.5	0.06	563.7
Temperature	9.2	8.2	-13.5	28.7
Semi-elasticity	25.5	31.4	0.15	720.0
Cournot output	22.2	4.192	11.7	31.9
Forecasted demand	45.4	9.281	31.1	69.4
Hydro reservoir	75,634	22,745	28,173	117,959
Transmission constraint proxy	11.1	19.1	0	157.5
Renewable production	5.7	3.4	0.3	18.6
Total consumption	47.2	8.6	33.1	68.8

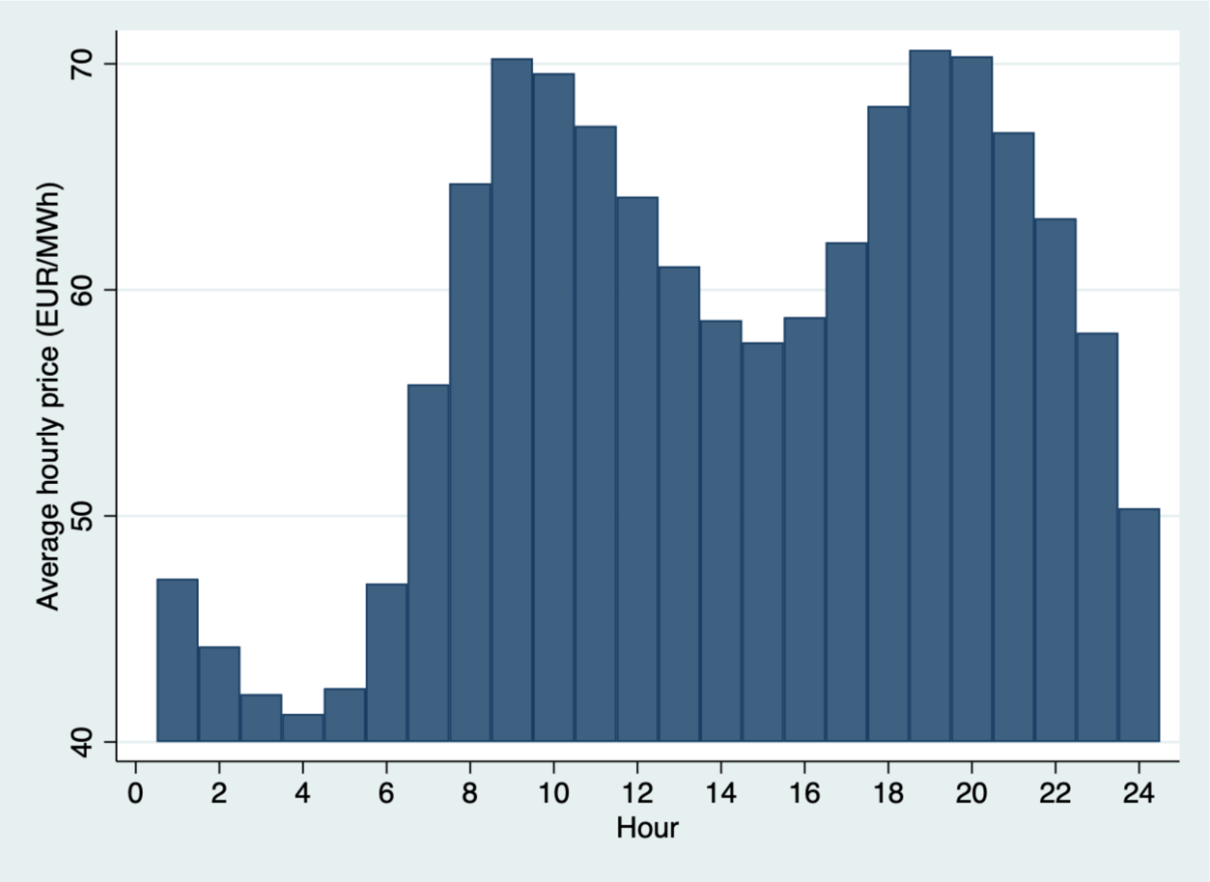
Note: Price and the transmission constraint proxy is measured in EUR/MWh. Temperature is measured in centigrade. All other variables are measured in GWh, except semi-elasticity which is Price/GWh.

3.2 Sample

To analyze the sample period (2018-2022) using daily observations rather than hourly observations, which most of the raw data consists of, only data points for 18:00 were used in the analysis. Every daily data point therefore corresponds to the hourly value for 18:00, unless specified. The decision of which hour to use to approximate the daily value is somewhat arbitrary as any hour could reasonably approximate the trends of the electricity market on a day-to-day basis if the same hour is compared over the entire period. The average hourly system price over the analysis period can be seen in Figure 3.2, and 18:00 is notably among the hours with the highest price. Only 09:00, 10:00, 19:00, and 20:00 have higher average prices. The figure also illustrates how night-time hours, when electricity consumption is low, have significantly lower prices than the rest. It is likely that if one of these hours was used for the analysis, the results would lead to a worse approximation of the actual trends in the electricity market. If the off-peak hours from 21:00 to 07:00 are excluded, it becomes clearer how 18:00 represents a medium among the non-off-peak hours. It would also be possible to take the average of all hourly prices to calculate a mean price, but mean prices would not match the hourly demand and supply curves that are used to calculate demand elasticities. Averaged buy and sell bids would therefore not represent the actual demand and supply curves of which market participants base their decisions.

Figure 3.2

Average hourly prices in the Nordic electricity market, 2018-2022.



Note: Prices are based on the average hourly system price over the analysis period, 2018-2022..

3.3 Cournot output

The purpose of the Cournot output variable is to test whether market participants set output to influence prices. The variable was first modelled by Lundin and Tangerås (2020), where it represented sell bids from plannable generators on the Nord Pool day-ahead market that were lower than the calculated system price for any hour. This specification means that Cournot output represents the output from plannable production sources with marginal costs low enough to always be accepted in the hourly auctions. Cournot output will in this analysis be wholly represented by hydroelectric power production, and it approximates the Cournot output variable used in the mentioned paper.

Hydroelectric power production represents roughly 55% of total generation sold on Nord Pool (Nord Pool, 2018; Nord Pool, 2019; Nord Pool; 2020c), is plannable, and has marginal costs low enough to ensure that its producers can make price-independent bids. Price-independent bids refers to sell bids from sources that have marginal costs low enough to enable sell bids lower than the system price, so that the output bid is accepted in the hourly auction. Hydroelectric power production, or Cournot output, is thus used as the dependent variable in this analysis, to estimate how Cournot players set output depending on market conditions. All data collected on the Nordic countries' hydroelectric power production was multiplied by 0.8 to account for the share of electricity produced not traded on the Nord Pool day-ahead market.

3.4 Semi-elasticity

Both the theory behind and the calculation of the semi-elasticity variable is based on the method used in Lundin and Tangerås (2020) to create a variable that approximates Cournot market behavior. The somewhat ambiguous name comes from the fact that it is a combination of the slope of the demand curve and the share of electricity production which is not covered by forward contracts. Hence, only half of the variable consists of demand elasticity, even if all of the variable's variation comes from changes in the slope of the demand curve. The calculated value of the slope of the demand curve is negative for all observations. However, the slopes are converted into absolute values to simplify the analysis of regression results, where the regression coefficients then represent how Cournot output changes depending on the value of the semi-elasticity.

The combination of the elasticity factor and the factor on the share of production not covered on the forward market creates a variable that approximates Cournot players' incentive to strategically withhold production. If we imagine that a firm with the potential to influence market prices has sold all their production on the forward market, it would be reasonable to assume that their incentive to influence prices is non-existent. They have, after all, nothing to gain by it. A firm which has sold nothing on the forward market will, on the other hand, be incentivized to set output to influence prices and maximize profits for every hour. The other half of the semi-elasticity variable, the elasticity factor, is exogenous to the producer since it is dependent on the price elasticity of demand. It is however likely, as Lundin and Tangerås (2020) argue, that the decision to bid a certain amount of production depend on demand elasticity, as it affects how much price changes when output is withheld. Roughly 200,000 hourly auctions have taken place on Nord Pool since the marketplace's inception in 1996, which should indicate that producers are cognizant of the effect that demand elasticities have on price formation. The authors point out that for this reason combined with the low variability in short-term elasticity of demand, Cournot players are likely to have good estimates on how their production will affect prices at different levels of forecasted demand. Put together, the semi-elasticity variable represents how Cournot players will act based on a combination of their percentage of quantity sold not on the forward market, and the effect that their produced quantities have on price formation.

The calculation of the semi-elasticity was a two-step process. The elasticity of demand portion of the variable was first calculated for every day (this paper uses the auction for 18:00-19:00 to approximate each day's auction). The slope of the daily demand curves was calculated by regressing price demanded over volume demanded to generate an estimate of the slope between bid pairs at a given interval. As can be seen in the example of the demand curve given by Figure 2.1, the demand curve is non-linear, most notably at the lower priced demand bids where the curve becomes more elastic. Cournot producers should however be most cognizant of the demand elasticity near the equilibrium point, as it is around that location on the demand curve that the price is formed. It is therefore not optimal to calculate the elasticity based on the entire demand curve, but rather around the equilibrium point. Besides, the greater concentration of buy bids at lower prices would lead demand elasticity to become overestimated.

The intervals used to estimate the slope of the demand curve were calculated as a percentage of the system price (which is the same as the equilibrium point). A benefit of the percentage method compared to using absolute values around the system price were that they were able to compute elasticities at both high and low system prices. The absolute interval had to be large, at over ±20 MWh/EUR of the system price, to be able to perform regressions on all demand curves in the sample, due to the significant gaps between bid pairs at high prices (these gaps can clearly be seen in the example provided in Figure 3.1). Three different intervals were calculated: one at ±75% of the system price, one at ±90% of the system price, and one at ±95% of the system price. The correlations between the elasticities were high at between 0.94 and 0.97, indicating that any of the intervals produces robust estimates. The elasticity calculated using the interval of ±90% of the system price is used for the purposes of the empirical analysis.

The other half of the semi-elasticity variable, the share of production not sold on the forward market, was evaluated by looking at the two of the largest market players Vattenfall, and Fortum's price hedge rates on the Nordic market over the period. The average hedge rate was 72% between the two firms over the period (Vattenfall, 2019; Vattenfall, 2020; Vattenfall, 2021; Vattenfall, 2022; Fortum, 2018; Fortum, 2019; Fortum, 2020; Fortum, 2021; Fortum, 2022); the share of production not sold on the forward market is therefore calculated as 28%. This assumption is reasonable since the hedge rates between the two companies were similar, with the largest difference being ten percentage points in 2019. Vattenfall's and Fortum's hedge rates are hence assumed to approximate the price hedge rates of producers in the electricity market in general.

The combination of the demand elasticity and the share of output not covered on the forward market generates a variable that approximates Cournot players' incentives to exercise market power via strategic reductions in output. A negative value on the regression coefficient for the semi-elasticity variable indicates that Cournot output (the dependent variable) is lower when demand is more inelastic, which would be consistent with the findings from previous literature (Fogelberg and Lazarczyk, 2019; Lundin and Tangerås, 2020). A positive or statistically insignificant coefficient estimate means that the null hypothesis fails to be rejected and that Cournot players do not set output to increase prices.

3.5 Transmission constraint proxy

Increased European electricity market integration, and EU-goals of reducing fossil fuel consumption has expanded the market for Nordic electricity (Grigoryeva, Hesamzadeh, and Tangerås, 2018). The recent energy market turbulence in the wake of the Russian war in Ukraine has only deepened the demand, as European electricity consumers seek to substitute away from natural gas in their electricity production (Holmberg and Tangerås, 2022). The heightened share of intermittent electricity production from renewable generation has meanwhile increased the importance of transmission capabilities within the Nordic electricity system, since electricity cannot be stored in any greater capacity (Grigoryeva, Hesamzadeh, and Tangerås, 2018).

All of these developments have put pressure on an already strained transmission network. The occurrence of transmission constraints has therefore become an important factor to consider when analyzing market behavior in recent years. All national transmission system operators report the capacity available for transmission for every hour in the following day to Nord Pool at 10:00, which is then shared to market participants (Nord Pool, 2020a). This information combined with information on estimated consumption for the following day makes it reasonable to assume that market players take transmission constraints into consideration when deciding how to bid their production into the day-ahead market. Furthermore, the price variable for this analysis, the system price, does not incorporate the price effect of transition constraints as it is calculated with transmission capacity set to infinity (Nord Pool, 2020a), and does not directly incorporate the price effects of congestion. The purpose of the transmission constraint proxy variable is therefore to approximate the effect that constraints in the transmission system has on Cournot output.

The transmission constraint proxy variable uses the difference between the actual spot prices in the bidding zones and the system price to evaluate the severity of congestion in the transmission system. Because system price is calculated with the assumption of infinite transmission capacity, it is possible via the deviation of actual prices from the system price to gauge the extent of transmission constraints. In fact, if technical issues hinder the calculation of system price via the algorithm, system price is calculated using the spot prices from the bidding zones weighted by volumes sold, with exports and imports excluded (Nord Pool, 2020a). The emergency system price calculation thus approximates the system price that would have been calculated by the algorithm. The transmission constraint proxy uses the emergency system price calculation to model an hourly ‘system price’, with price differences caused by transmission constraints included.

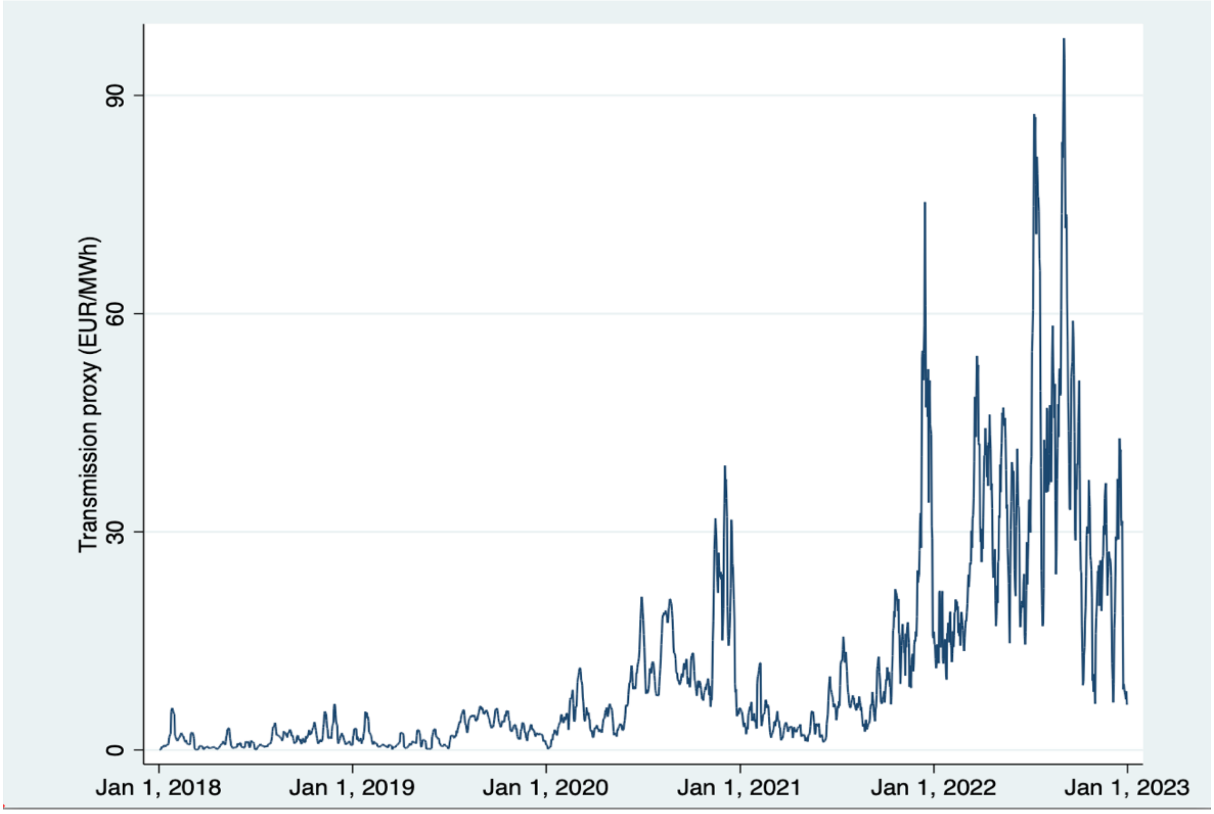
Since data on volumes sold is unavailable for the individual bidding zones, consumption weights are instead calculated using the daily average electricity consumption at 18:00 in every bidding zone. All consumption from the individual bidding zones were then added to calculate the average Nordic electricity consumption, with which the hourly consumption in every bidding zone was divided, to obtain their share of total electricity consumption. The aggregate value of the weighted bidding zone price should therefore approximate the system price, although with transmission constraints priced in. The difference between the system price and the aggregated bidding zone price is thus the value of the transmission constraint proxy. The correlation between the aggregated bidding zone price and the system price is 0.96 over the analysis period. Equation 1 shows how the proxy variable was calculated, where t represents daily value, and i represents the individual bidding zones.

(1) $Proxy_t = (price\ in\ bidding\ zone_{i,t} \cdot\ share\ of\ total\ consumption_i)$ - $system\ price_t$

Figure 3 shows a plot of the value of the transmission constraint proxy over the analysis period, using weekly moving averages. The trend looks as you would expect with relatively modest values until 2020. One can also see an explosion in the severity of transmission constraints in 2022, which seemingly coincides with the ramping up of Russian natural gas and oil embargo on the EU in the wake of the invasion of Ukraine. This makes intuitive sense as the shortfall of electricity generated from natural gas on the continent must be substituted from elsewhere, with some of the replacement coming from the Nordics. The increased flow of electricity from the Nordics to the continent would therefore put greater strain on the transmission system, increasing the severity of congestion and hence price differences between the aggregated spot price and system price.

Figure 3.3

Transmission proxy values over the analysis period, using weekly moving averages.



Note: The transmission proxy variable is calculated as the difference between the aggregated average spot prices in the bidding zones weighted for consumption and the system price.

4. Methodology

The research model can be divided into two parts. The purpose of the first part is to estimate whether there is evidence of Cournot competition Nordic electricity market using a two-stage least squares (TSLS) regression. The second part of the model constitutes of calculating Lerner indexes using the regression results to evaluate the level of price-cost markups caused by market power, in the case that there is evidence of market power. Both stages are modified versions of the method used in the Lundin and Tangerås (2020) paper, which analyzes market performance on the Nordic electricity market for the period 2011-2013.

4.1 Two-stage least squares model

The first sub-goal of the analysis is to evaluate whether there is evidence of Cournot competition in the Nordic electricity market. Our regression model can be seen in Equation 2. If the estimates of β_2 is statistically significant, we can reject the null hypothesis that the Nordic electricity market is perfectly competitive. A TSLS model is preferred over a general OLS model due to the risk of reverse causality between the Cournot output variable (Q_t) and the price variable (p_t). Although the model assumes that changes in Cournot output may cause changes in price, it is also likely that changes in price will affect Cournot output. An instrumental variables approach using TSLS is therefore used to ensure that any reverse causality is isolated, to lower the risk of omitted variable bias due to endogeneity. Estimates on the semi-elasticity variable ($\left|P_Q^t\right|(1-\eta)$) are also likely to suffer from reverse causality for similar reasons. $|P_Q^t|$ represents the demand elasticity portion of the semi-elasticity variable, whereas the $(1-\eta)$ portion represents the share of output not sold on the forward market, where η is the hedge ratio. As can been seen from the demand curve in Figure 2.1, the elasticity of demand depends on price, which can be seen by how the slope of the demand curve changes as price becomes higher or lower. Reverse causality between the Cournot output variable and semi-elasticity is therefore likely for the same reasons as for price. An instrumental variable is therefore also used to estimate the coefficients of the semi-elasticity.

$$Q_t = \beta_0 + \beta_1 p_t + \beta_2 \left|P_Q^t\right|(1-\eta) + \beta_3 C_t + \beta_4 HR_t + \beta_5 TC_t + \varepsilon_t \tag{2}$$

Lundin and Tangerås (2020) applied forecasted demand and wind power production as instrumental variables in their analysis of the Nordic electricity market. Kim and Knittel (2006) used forecasted demand in a similar capacity when analyzing oligopolistic competition on the

Californian electricity market, pointing out that forecasted demand is based on weather and economic activity, without taking price into consideration. The exclusion restriction should therefore hold. The second instrumental variable for the purposes of this analysis is total renewable generation, which is slightly different from the previously mentioned wind power production instrument. The decision to use renewable generation rather than to only use wind power production is due to the substantial growth of solar power production, which increases from 0.06% to 2.4% of renewable production over the analysis period. An instrument for renewables that includes both power sources is therefore to preferred. Renewable generation is exogenous to both price and the semi-elasticity due to its dependence on weather conditions, ensuring that the exclusion restriction is met. Both instruments have high F-statistics in the first-stage regression with values above 70, and both instruments are statistically significant with respect to either the semi-elasticity variable (forecasted demand), or the price variable (renewable generation). Forecasted demand and renewable generation are therefore robust instruments and will be used to address the endogeneity problem.

The final three variables in our regression model were added to control for factors that are likely to affect Cournot output, to reduce the risk of omitted variables bias. The storage value of hydro reservoir, HR_t, measures the productive potential of the stored water at Nordic hydroelectric power plants. Since Cournot output is assumed to be entirely made up of hydroelectric power production, it is important to account for the productive potential of the plants that generate the electricity. One would after all expect plant managers to be inclined to produce more electricity if hydro reservoirs are close to being full, and vice versa if hydro reservoirs are low. The second control variable, TC_t, is a proxy variable that measures transmission constraints. As can be seen in Figure 3.1, transmission constraints increase in importance over the analysis period. It is highly likely that Cournot players will bid production differently depending on if it can be transported to neighboring bidding zones or not. Transmission constraints are therefore likely to produce omitted variables bias if not controlled for in our model. Finally, the last variable in the model, ε_t, is the econometric error term. The index t refers to time, which is measured in days.

4.2 Lerner index

Lerner indices measures the level of market power in a market using the percentage of markup over price, also known as the price-cost markup. These price-cost markups can be estimated without the knowledge of marginal costs if elasticities are known, assuming that marginal costs are linear (Kim and Knittel, 2006; Lundin and Tangerås, 2020). Equation 3 shows the general equation for Lerner indices, and alternative methods of calculating it. The first two parts of Equation 3 are the general formula for Lerner indices using either prices and marginal costs, or demand elasticity. P_t represents price, MC_t is marginal cost, and E_D^t is demand elasticity. The final part of Equation 3 is theorized by Lundin and Tangerås (2020), where they assume that all Cournot players have the same, linear marginal cost structures and that each Cournot player has the same incentive scheme in terms of maximizing profits. Marginal costs of hydroelectric power production are unlikely to be non-linear since it represents the cost of water, which is essentially zero. The second condition is less certain to hold since many of the largest hydroelectric power producers are owned or partially owned by their respective government, meaning that profit-maximization may not be their only motive (Lundin and Tangerås, 2020). Electricity as utility could reasonably be a more important incentive than profit-maximization for state-owned producers. There could therefore be a disconnect between government-owned and privately owned Cournot players in terms of profit maximizing behavior. However, since the values from the regression coefficients are based on the aggregate behavior of Cournot players, it is reasonable to apply the same assumption to the calculation of Lerner indices, even if individual Cournot players may act under different incentives. The potential difference in incentives would imply that some companies exercise more market power than what the Lerner indices measure.

$$L_t = \frac{P_t - MC_t}{P_t} = \frac{1}{-\frac{I}{E_D^t}} = -\frac{\beta_2}{\beta_1}\frac{|P_Q^t|(1-\eta)}{p_t} \tag{3}$$

If we apply the assumption used by Lundin and Tangerås (2020) on linear marginal costs and the incentive schemes of Cournot players, we can apply the third equation in Equation 3 to calculate the Lerner indices. Lerner indices can thus be calculated for every day using the coefficients β_1 and β_2 from our regression model, and semi-elasticity and price for every day (indexed as t). It should be noted that both coefficients' estimates must be statistically significant for Lerner indices to be calculated, as they are otherwise interpreted as zero. Non-significance would suggest that the Nordic electricity market is perfectly competitive and that there are no price-cost markups caused by strategic withholding of supply.

The benefit of using Lerner indices is that it enables us to quantify the level of market power on the Nordic electricity market and if it has changed over the period. Kim and Knittel (2006) used Lerner indices based on measured marginal costs to test predicted market power from the New Empirical Industrial Organization (NEIO) technique. Lundin and Tangerås (2020), as previously mentioned, applied Lerner indices to measure the general market performance in the Nordic electricity market from 2011 to 2013. Lerner indices produced in this paper will be used to indicate whether there has been a change in market power on the Nordic electricity market since 2013, and if market power has systematically changed within our analysis period, 2018-2022.

5. Empirical Analysis

This section provides results from the methods specified in the methodology section. The data is first analyzed using the general regression model provided by Equation 2. The same regression model is then used to analyze market behavior before out cut-off point in 2020, when energy markets became increasingly turbulent. Finally, Lerner indices are calculated and shown in a time-series over the analysis period.

5.1 Results

The regression results for the whole analysis period are shown in Table 5.1. Our variables of interest, system price and semi-elasticity are statistically significant over all regressions, except for in (1), where the coefficient estimate for system price is statistically insignificant. However, the results, when all specifications are considered, allows us to confidently reject the null hypothesis that prices on the Nordic electricity market are perfectly competitive. Furthermore, both variables' coefficients show the expected sign. Cournot output is positively affected by system price as higher prices incentivize greater production, consistent with upward sloping supply curves. The negative sign for semi-elasticity over the entire sample indicates Cournot behavior. Since the portion of production not sold on the forward market is fixed over the analysis period, all variation in the semi-elasticity variable is due to differences in the demand slope. A negative sign indicates that Cournot players withhold output when demand curves are steeper, when prices are more sensitive to changes in output. The coefficient value for semi-elasticity would be insignificantly different from zero if there was perfect competition. These findings are consistent with the findings from Lundin and Tangerås (2020), who found statistically significant negative estimates for the semi-elasticity variable. Fogelberg and Lazarczyk (2019) and Kwoka and Sabodash (2011) had similar findings, where electricity producers were more likely to decrease output at times with highly inelastic demand.

Table 5.1

Main TSLS-regression results on Cournot output, 2018-2022.

	(1)	(2)	(3)	(4)
System Price	0.0979	0.0950**	0.113***	0.167***
	(0.120)	(0.0410)	(0.0378)	(0.0394)
Semi-elasticity	-0.461***	-0.467***	-0.450***	-0.627***
	(0.129)	(0.0668)	(0.0616)	(0.136)
Temperature		0.00263	-0.0256	0.117
		(0.0784)	(0.0740)	(0.104)
Hydro reservoir			6.01e-05***	5.79e-05***
			(1.34e-05)	(1.78e-05)
Transmission constraint proxy				0.190**
				(0.0902)
Constant	27.93***	28.24***	22.37***	20.31***
	(10.63)	(2.767)	(2.330)	(2.467)
Observations	1,824	1,824	1,824	1,824

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Note: Forecasted demand and renewable electricity generation were used as instrumental variables for system price and semi-elasticity. (1) measures regression results using only the two key variables, system price and semi-elasticity; (2) introduces temperature as control; (3) adds the storage value of Nordic hydro reservoirs; finally, (4) introduces a proxy for transmission constraints.

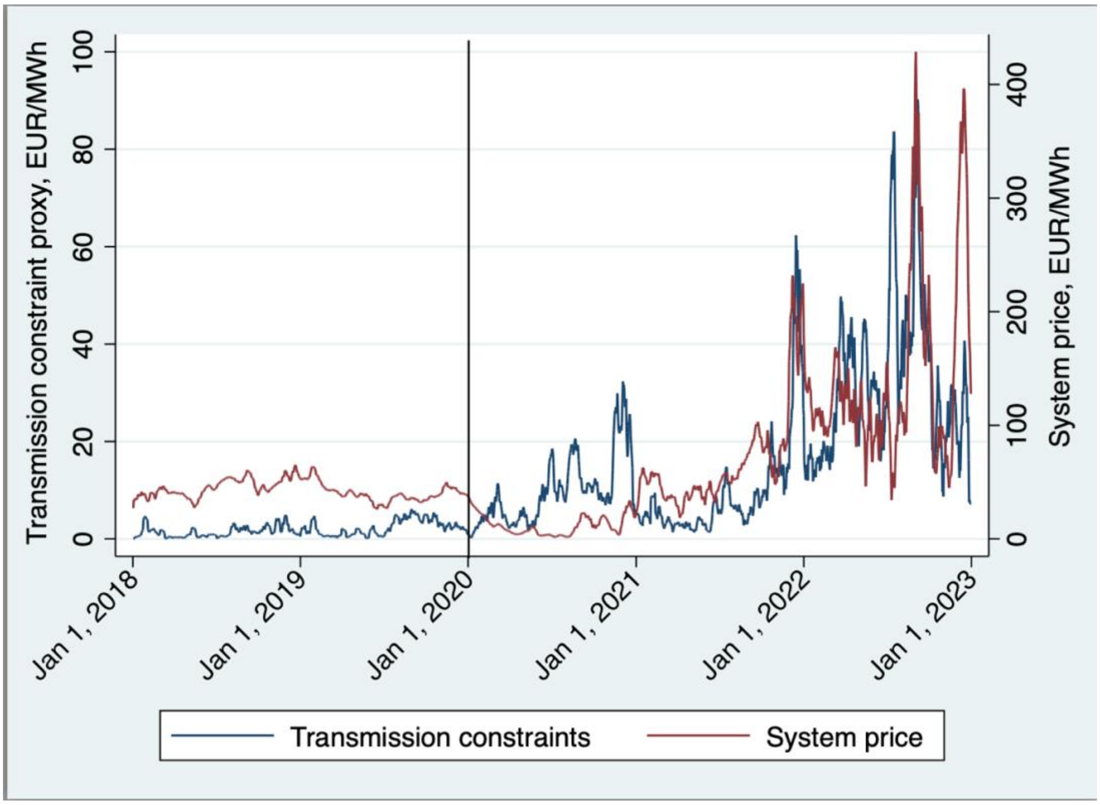
Control variables for temperature, the storage value in Nordic hydro reservoirs (which represent the productive potential of water at hydroelectric power plants), and the transmission constraint proxy were also tested. Only temperature was statistically insignificant, although it improved the precision of the estimates on system price and semi-elasticity. Similarly, the addition of stored capacity in Nordic hydro reservoirs in specification (3) improves the coefficient estimates for our variables of interest, while itself being statistically significant in all specifications. A relation between Cournot output, which is based on hydroelectric power production in the model, and the stored capacity of water in the reservoir is expected due to its role as a production input. Finally, we can see in specification (4) that the regression results change slightly when the transmission constraint proxy is introduced. The transmission constraint proxy coefficient is positive and statistically significant, suggesting that Cournot players increase output when transmission constraints increase. This result is consistent with the findings of Cardell, Hitt, and Hogan (1997), who found that Cournot players increase output to cause congestion, which can allow for greater market power in affected bidding zones.

5.2 Before and after 2020

The regressions in the Table 5.1 provide evidence of market power in the Nordic electricity market for the whole analysis period. However, it fails to consider the significant shift in both prices and transmission constraints after 2020, which is illustrated by Figure 5.1. There is a clear trend shift before and after 2020, where prices are relatively stable and transmission constraints are low. A decrease in system prices can be seen in 2020, while transmission constraints become more common. A likely explanation for this is the covid-19 pandemic. Research on the pandemic's effect on electricity market indicate a trend of reduced prices as electricity demand decreased during lockdowns (Bento et al., 2021; Halbrügge et al. 2021; Ruan et al. 2021). Furthermore, prices start to rise again around the period when pandemic lockdowns were eased. Both prices and transmission constraints, which is measured as the difference in the system price and the aggregated bidding zone prices weighted by share of total consumption, become dramatically more volatile in 2022 which seems to correlate in time with the Russian invasion of Ukraine. The clear differences between the periods before and after 2020 provides an interesting cut-off point for our analysis.

Figure 5.1

System price and the value of the transmission constraint proxy, 2018-2022.



Note: A clear difference in system price volatility and higher values in the transmission proxy variable can be seen after 2020.

Regression results for pre-2020 and post-2020 are shown in Table 5.2. The coefficients for the semi-elasticity variable are negative and statistically significant in all specifications, with the main difference between the two being that Cournot players withhold more output when demand is more inelastic in the post-2020 period. The coefficients on system price are positive and statistically significant, consistent with an upward sloping supply curve. Cournot output follows system price more strongly in the pre-2020 period, as indicated by the higher coefficient values. Higher coefficient values are likely an artifact of systemically lower system prices in the pre-2020 period. The average price of electricity increased from 42.8 EUR/MWh in the pre-2020 period to 74.8 EUR/MWh in the post-2020 period.

Table 5.2

Two-stage least squares for two periods, 2018-2019, and 2020-2022.

Independent variables.	(1) Cournot output Pre-2020	(2) Cournot output Post-2020	(3) Cournot output Pre-2020	(4) Cournot output Post-2020
System price	0.401***	0.138***	0.407***	0.160***
	(0.0900)	(0.0324)	(0.0909)	(0.0415)
Semi-elasticity	-0.366*	-0.470***	-0.359*	-0.595***
	(0.188)	(0.101)	(0.189)	(0.185)
Temperature	-0.186***	0.224	-0.187***	0.337*
	(0.0299)	(0.137)	(0.0301)	(0.205)
Hydro reservoir	2.03e-05**	5.47e-05***	2.23e-05**	6.01e-05**
	(9.78e-06)	(2.08e-05)	(1.00e-05)	(2.69e-05)
Transmission constraints			-0.0542	0.153
			(0.0627)	(0.0930)
Constant	10.88*	20.73***	10.51*	18.97***
	(5.957)	(2.731)	(6.017)	(2.959)
Observations	730	1,094	730	1,094

Standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Note: Forecasted demand and renewable electricity generation were used as instrumental variables for system price and semi-elasticity.

Coefficient estimates for temperature are consistently negative for the pre-2020 period, with ambiguous results for the post-2020 period. The negative coefficient for temperature in the pre-2020 period can be explained by the relationship between electricity consumption and temperature, which is -0.85 over the analysis period. A negative relationship between Cournot output and temperature is therefore reasonable. The weakly statistically significant positive relationship between Cournot output and temperature found in specification (4) should therefore be taken with caution. The storage value of Nordic hydro reservoirs is, as expected, positively correlated with Cournot output. Lastly, the relationship between Cournot output and the transmission constraint variable is insignificant in both specifications, contrary to the estimate in specification (4) of Table 5.1 and the findings of Cardell, Hitt, and Hogan (1997). Statistically insignificant estimates for the pre-2020 period is reasonable due to the low levels of transmission constraints over the period, as can be seen in Figure 5.1. Transmission constraints were, in other words, unimportant to market participants. Transmission conditions changed considerably after 2020, yet no statistically significant relationship between Cournot output and transmission constraints could be established. These findings are contrary to the estimates for the whole period, where transmission constraints were statistically significant.

5.3 Market power

Evidence of Cournot behavior in the Nordic electricity market were found in all periods analyzed. The null hypothesis of perfect competition is therefore rejected. However, the coefficients for both system price and semi-elasticity were notably different across periods. It should also be noted that this analysis looks at market power from hydroelectric power producers on the Nord Pool day-ahead market, since they form the theoretical framework for Cournot output in the analysis. With that said, there is evidence of hydroelectric power producers exercising market power before (Tangerås and Mauritzen, 2018), and hydroelectric power producers are as previously discussed the market participants with the greatest ability to influence prices via Cournot bids.

The method of quantifying market power is based on the calculations made by Lundin and Tangerås (2020), which is shown in Equation 3. The calculated Lerner values, which represents the percentage markup of price over marginal cost (Kim and Knittel, 2006; Lundin and Tangerås, 2020), are shown in Table 5.3. A lower value indicates better market performance, as prices are closer to the prices that would be found in perfect competition, where no market power can be exercised.

Table 5.3

Implied Lerner values before and after 2020, and for the whole period (2018-2022).

Period	Obs.	Mean	Sd	Min	Max
Pre-2020	730	0.35	0.16	0.13	1.48
Post-2020	1,096	3.38	13.24	0.10	382.60
Whole period	1,826	2.64	10.44	0.11	387.30

Note: Lerner values were calculated using Equation 3, the regression results were taken from specification (4) in Table 4.1, and specifications (3) and (4) in Table 4.2.

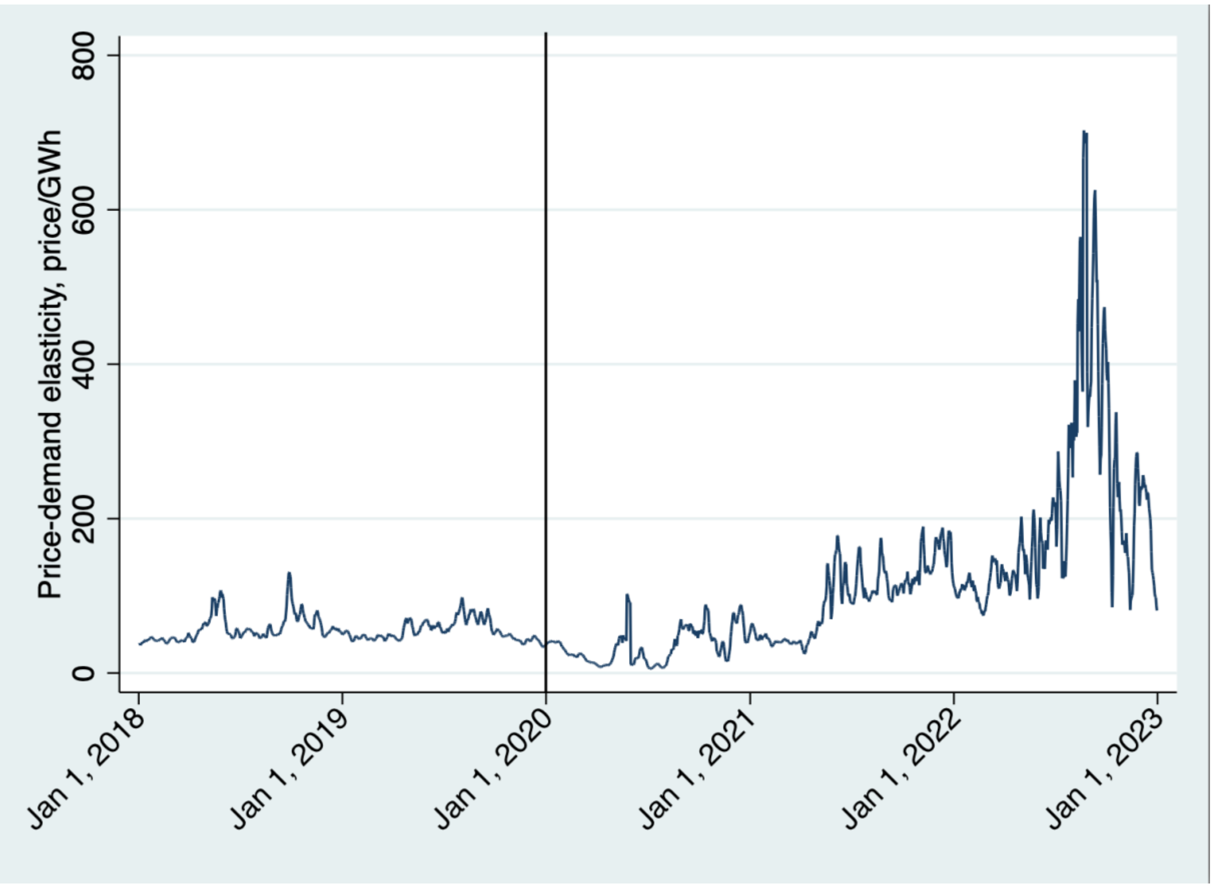
Lerner values are consistently low in all periods, except for a few outliers. If the highest 5% of values are omitted, average Lerner values for both post-2020 and the whole period decrease to 2.41 and 1.70, respectively. The pre-2020 period's mean of 0.35 implies that there was no economically significant exercise of market power in the period. Estimated Lerner values for the post-2020 period are notably higher, suggesting greater exercise of market power after the onset of the covid-19 pandemic. If general price increases are considered in the post-2020 period, a rough estimate on the additional costs to consumers can be calculated.

With an average price of 42.8 EUR/MWh in the pre-2020 period, the average cost of market power to consumers was 0.1 EUR/MWh. The same estimate for the post-2020 period is 2.53 EUR/MWh, as average prices increased to 74.8 EUR/MWh. A more representative method of calculating the absolute price-cost markups is to match the daily Lerner values to daily system prices. Using this method, the price-cost markup changes to 0.14 EUR/MWh in the pre-2020 period, and to 1.19 EUR/MWh in the post-2020 period. The significant difference between the two markups in the post-2020 period can be explained by Lerner values being higher when prices are low. This trend is confirmed in Figure 5.2, which shows that Lerner values tend to be higher in the summer, when prices are lower. A related factor for price-cost markups in our model is the slope of the demand curve, which on average doubled in steepness after 2020, from 15.8 to 31.2. Demand was thus more sensitive to price increases in the latter period and is therefore a potential explanatory factor to the increase in market power.

Higher demand elasticity in the post-2020 period was found to correlate with higher average system prices. This finding is consistent with the results in the Yan and Folly (2014) paper, where the steepness of the demand curve greatly affects spot prices. Both system prices and the steepness of the demand curve were on average lower in the pre-2020 period. Figure 5.2 shows a time-series of demand slope steepness, $|P_Q^t|$ - which is part of the semi-elasticity variable - over the analysis period. The values reflect how much price is predicted to increase by a 1 GWh decrease in output. Extreme values can be explained by the highly inelastic portion of the supply curve becoming price-setting (see Figure 2.1). Pure profit-maximizing behavior would mean that Cournot players withhold output when the demand slope is particularly steep, since prices will increase significantly. Price-demand elasticity is noticeably higher in the post-2020 period, consistent with the results in the Yan and Folly (2014) paper where inelastic demand leads to higher prices. Correlation between system price and the steepness of the demand curve does indeed change notably after 2020. System price and demand curve steepness have a correlation of -0.19 in the pre-2020 period, and 0.54 in the post-2020 period.

Figure 5.2

Estimated (negative) slope of the demand curve, 2018-2022.

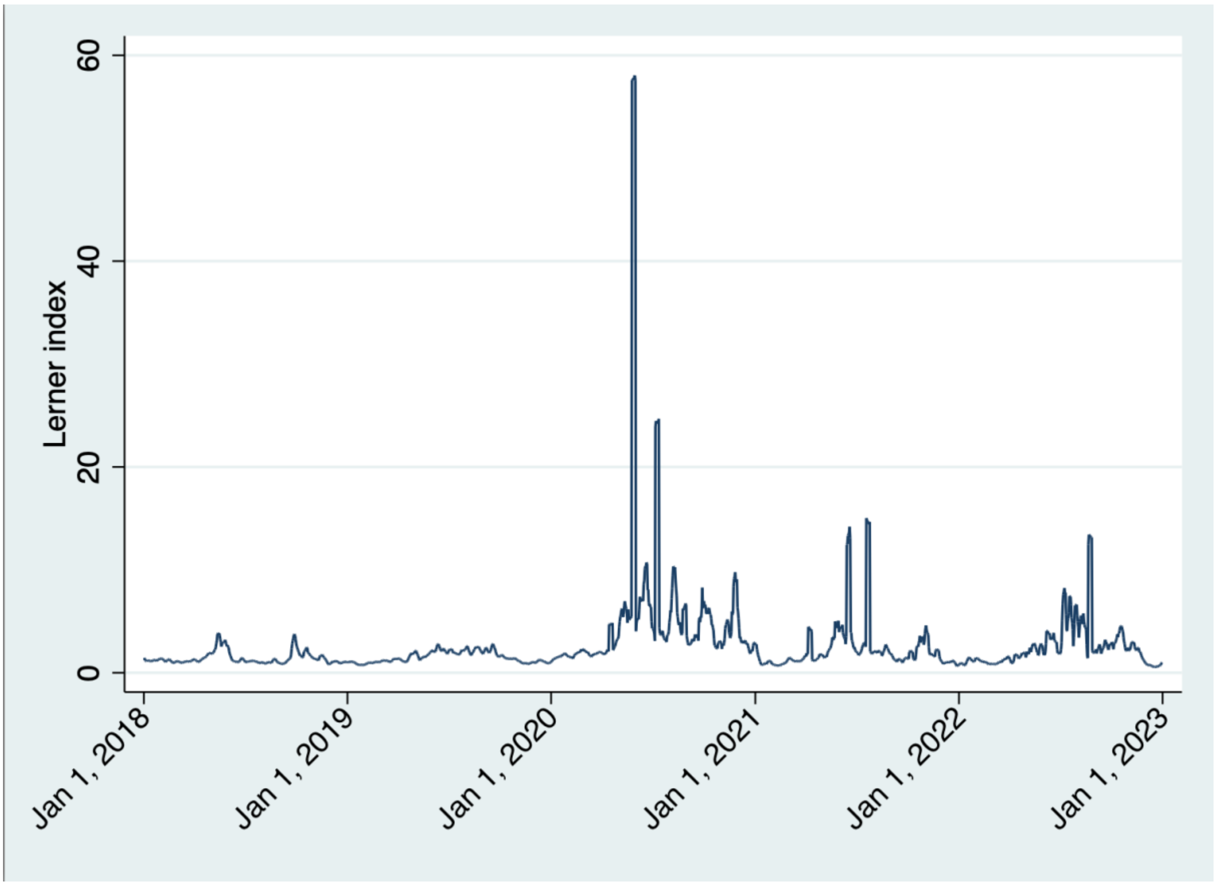


Note: The value indicates by how much price would increase if output was decreased by 1 GWh. All slope values are based on the demand curves for Nord Pool's 18:00-auction, for each day.

The estimated Lerner values can be compared to the Lundin and Tangerås (2020) estimates of 4%, in the 2011-2013 period. Given the methodological similarities between this paper and theirs, it is possible to argue that market power has decreased since 2013. One should however be careful in interpreting these results as an indication of a better performing electricity market in general due to the high and volatile prices after 2020. The results of higher Lerner values when prices are low, and vice versa, is contrary to the findings of Fogelberg and Lazarczyk (2019) and Kwoka and Sabodash (2011), who found that strategic withholding of supply is more likely when prices are already high.

Figure 5.3

Implied Lerner index with weekly moving averages, 2018-2022.



Note: The Lerner index is a time-series graph of the values for the whole period in Table 3X.

6. Discussion

The purpose of the thesis is to analyze the market performance on the Nordic electricity market, and whether recent market turbulence has translated into greater exercise in market power by electricity producers. This section will discuss how the empirical findings can be interpreted and put them in relation to related literature. Implications and limitations of the study will also be discussed.

A summary of the empirical findings is that there is evidence of Cournot behavior, and that the null hypothesis of competitively set prices can be rejected. Market power became more prevalent after 2020, as indicated by the increase in Lerner values, also known as price-cost markups. Measured as percentage markups of prices over marginal cost, price-cost markups increased from an average of 0.35 in the 2018-2019 period, to 3.38 in 2020-2022 period. Higher prices in general in the post-2020 period also caused the absolute price-cost markups to increase: the average price-cost markup increased from 0.14 EUR/MWh to 1.19 EUR/MWh. An interesting finding was systematically higher price-cost markups in the summer when prices tend to be lower.

6.1 Research findings and related literature

Related literature shows that firms will pick output to increase prices (Fogelberg and Lazarczyk, 2019; Kwoka and Sabodash, 2011). The findings in the previous section are, however, ambiguous. While firms did indeed increase their price-cost markups as prices increased in the post-2020 period, they also had lower price-cost markups on average during winter periods, when prices were on average higher. Cournot players did in other words not always seek to increase prices when setting their output. If that was the case, price-cost markups would have been highest in winter periods. A plausible explanation is that Cournot players set absolute price-cost markups, rather than as a percentage as calculated by the Lerner index. Figure A3 in the appendix graphs absolute price-cost markups over time. Absolute price-cost markups were stable, just above zero before 2020, after which they increased to around 1 EUR/MWh. An exception is 2022, when the mean absolute price-cost markup was 2.2 EUR/MWh, mainly driven by a surge in the summer period. These results could indicate that Cournot players bid their output to ensure a somewhat stable absolute price-cost markup.

There are three potential explanations for higher price-cost markups during the summer compared to in the winter. Firstly, regulators are arguably more likely to investigate market power during periods when prices are high. It may therefore not be strategic to withhold output during periods when prices will increase significantly, as market regulators are more likely to take notice. A strategy of constant price-cost markups, which there is some evidence of, could therefore be a profit maximizing strategy with lower regulatory risk. Secondly, several of the largest electricity producers in the Nordics, such as Fortum, Vattenfall, and Statkraft, are state-owned. Parts of the profit made from price increases caused by strategic withholding will therefore negatively affect the shareholders, the public, via higher electricity prices. This fact would likely disincentivize strategic withholding of output. Finally, it may not be profit-maximizing behavior to strategically withhold production during the winter period, as any output withheld cannot be sold. Profit-maximizing plant managers will therefore have to also consider the opportunity cost of not selling additional output. A potential explanation is hence that the opportunity cost of withholding supply is comparatively lower during the summer period.

Continuing, Do, Lyócsa, and Molnár (2021) found that residual demand, which is total demand subtracted by renewable production, becomes more variable as renewable sources takes greater production share. They argue that the market consequently becomes harder to predict, thus increasing the risk of market participants misestimating residual demand. The higher price-cost margins during summer could therefore be caused by Cournot players misestimating residual demand, causing price-cost markups via unintentional withholding of output due to forecasting errors. Production from renewable sources is dependent on the weather, which is exogenous to total demand. One could therefore predict that renewable production has a higher percentage of total production during summers, when electricity production is 23.6% lower, thus increasing the variability in residual demand. However, renewables share of total production was surprisingly slightly lower during summers. Higher price-cost markups during the summers from forecasting errors caused by more volatile residual demand due to comparatively higher shares of renewable production cannot be confirmed by the data.

Statistically significant results for semi-elasticity and system price are consistent with the findings in Lundin and Tangerås (2020) as well as the broader horizontal shifts literature (Wolak, 2003; McRae and Wolak 2014). There was in other words evidence of horizontal shifts in the aggregate supply function from Cournot bids, which is when Cournot players strategically bid output to affect prices. The corresponding Lerner values were however low in both periods analyzed and the evidence of Cournot bids should therefore be taken with caution. Absolute price-cost markups were not significantly different from zero in the pre-2020 period, while remaining small, at around 1 EUR/MWh, in the post-2020 period. Average system prices, meanwhile, increased from 42.8 EUR/MWh to 74.8 EUR/MWh. Horizontal shifts from Cournot bids are thus only a minor factor behind the recently surgent electricity prices.

Transmission constraints did not affect the decision-making of Cournot players when the analysis period was split into periods before and after market turbulence. Findings from Cardell, Hitt, and Hogan (1997) suggests that Cournot players increase their market influence as congestions in the grid system occurs due to its balkanizing effect on the electricity market. Smaller electricity market, they argue, create greater opportunity for market power abuse. However, the transmission constraint proxy variable did not generate statistically significant results in the post-2020 period when transmission constraints became more common and increasingly severe. The results thus suggest that a balkanized electricity market has little effect on market power, even if it greatly affects prices in particular bidding zones as more expensive generators are switched on. This can potentially be explained by the fact that Cournot players are as previously pointed out less inclined to exercise market power when prices are high, and a similar effect could explain why they do not decrease output when transmission constraints are high, despite the potential to greatly affect prices.

6.2 Implications

The results imply that the majority of the price increases are explained by factors outside the output decisions of electricity suppliers. Only 1.6%, or 1.19 EUR/MWh, of the system prices in the post-2020 period can be explained by output decisions from Cournot players. The corresponding share for the pre-2020 period is 0.2% and is therefore economically insignificant. Higher average system prices after 2020 are evidently due to factors beyond market power, as it only explains a small portion of the general price increases. Such factors would include the Russian oil and natural gas embargo on the EU and the subsequent increase in demand for Nordic electricity (Holmberg and Tangerås, 2022).

A key implication of the findings is how they can guide policymaking on how lawmakers and regulators best can alleviate consumers from high electricity prices. Identifying the exact tools is nevertheless beyond the scope of this paper. However, most of the resources used to improve the performance of the electricity market should clearly be mobilized to decrease price-effect from exogenous factors, such as the European demand for Nordic electricity. The relatively small price effect caused by market power from Cournot producers is most notable during the summer period, when price-cost markups were shown to be systematically higher. Greater regulatory oversight of bidding behavior during the period could therefore be effective, even if the absolute price effect is relatively small.

6.3 Limitations

There are a few factors that limit the generalizability of the findings in the study, beginning with the methodological assumptions. Firstly, Cournot output represents the output from hydroelectric power producers, and while they represent the only major electricity source with negligible marginal costs that is plannable, it is possible that other producers from other plannable sources exercise market power when the market conditions allow it; when prices are consistently and predictably high enough for them to reliably cover their marginal costs. These producers are omitted as they cannot systematically influence prices, even if they can exercise market power intermittently. Secondly, the transmission proxy variable assumes that price differences between bidding zones reflect the lack of capacity in the transmission system. While price differences occur because of congestion, it is less clear that the extent of transmission constraints is perfectly translated into greater price divergence between bidding zones. The transmission constraints proxy will tend to overestimate the extent of transmission constraints when price differences between bidding zones are large, if cheap production becomes isolated.

A related limitation is that the regression model estimates all Cournot players indiscriminately, even if different power producers have different profit incentives. State-owned power companies are, as previously argued, in theory less inclined to exercise market power via strategic withholding as their shareholders, the public, is ultimately affected by the price effects. A privately owned power company would on the same token be more inclined to exercise market power. The findings of the paper cannot therefore reasonably be applied to any one type of producer but represents a mean across all Cournot players.

It should be noted that the analysis uses the Nord Pool system price, which is a derivative of the spot prices that are set in the individual bidding zones. The system price does in other words not represent the prices actually paid by the end consumer, nor the necessarily the spot price in the bidding zones that they reside in (if transmission constraints are severe). The findings from this paper can therefore only explain market behavior in terms of bidding strategies from electricity producers, where the estimated price-cost markups represent an approximation of aggregate price effects. Price effects have not been measured on the bidding zone level due to data constraints, as Nord Pool only share bid data for the system price.

7. Conclusion

The objective of the thesis was to examine if there is evidence of market power in the Nordic electricity market, and whether the increases in price volatility and transmission constraints over the analysis period (2018-2022) caused behavioral change from producers. Using a two-stage least squares model based on Cournot competition, the null hypothesis of perfect competition was rejected across all periods analyzed. The findings indicate that Cournot players, or hydroelectric power producers, decreased their output when electricity demand was more inelastic. Output being withheld as demand becomes more inelastic demand implies that the behavior is strategic, as the price-effect of withholding is greater.

The main findings are that the implied price-cost markups increased after 2020, but that the overall effect on prices were comparably small in both periods. Only 0.2%, or 0.14 EUR/MWh, of the system price could be explained by price-cost markups due to market power in the pre-2020 period. The influence on price formation increased to 1.6%, or 1.19 EUR/MWh in the post-2020 period. Furthermore, price-cost markups were found to be systematically higher during summer when prices are lower, suggesting that Cournot players' strategy revolves around consistent, absolute price-cost markups. The estimated price-cost markups were just above zero in the pre-2020 period and increased to vary around 1 EUR/MWh in the post-2020 period. Furthermore, transmission constraints could not explain the increase in market power after 2020, even if average system prices and the severity of transmission constraints jointly increased. Put together, it is evident that factors external to Nordic electricity market participants drive price increases and price volatility after 2020, when the average system price rose from 42.8 EUR/MWh to 74.8 EUR/MWh.

The thesis contributes to economic literature on electricity markets in three main ways. Firstly, the transmission constraint proxy introduced in this paper allows Cournot behavior to be tested under congestion. Furthermore, the general model can easily be modified for other electricity market (given they have a system price) due to its reliance on easily obtainable data, consisting of consumption share per bidding zone and local spot prices. Secondly, the use of hydroelectric power production as the Cournot output variable highlights the importance of hydroelectric power plant managers on market performance in the Nordic electricity market. This finding suggests that other bid-based hydro dominated electricity market may be analyzed using hydroelectric power production as the Cournot output variable. Finally, the finding of higher price-markups during the summer period introduces opportunity for future research to gain a better understanding on how Cournot bids are made and when profits are maximized.

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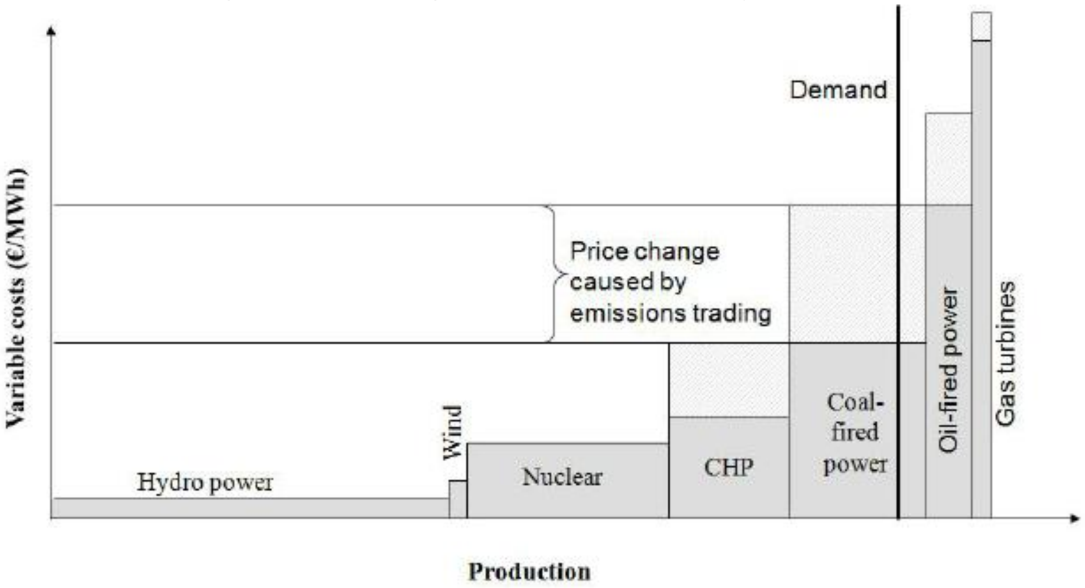
Appendix

Figure A1
Map of Nordic bidding zones as of 2011.

Note: The Baltic bidding zones are not included in the calculation of the Nordic system price.
Source: Nord Pool.

Figure A2
Illustration of marginal cost pricing in the Nordic electricity market.



Note: The price is decided by source with the marginal cost required to meet demand, in this illustration coal fired power. Greater production from low marginal cost sources will cause prices since a cheaper sources will be required to meet demand. Source: Jablónska et al. (2012)

Figure A3
Calculated absolute price-cost markups before and after 2020.