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Liquidity Dynamics in the Nordic Financial Power Market

An Empirical Impact Analysis of the Liquidity at the NASDAQ OMX Commodities Exchange Following Nord Pool's 2021 Mispricing of the Nordic System Price

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Abstract

In this study, we explore liquidity dynamics in the Nordic financial power market in late fall 2021. We focus on the impact of a pricing error in the Nordic power derivatives' reference: the Nordic system price. Our objective is to analyze market liquidity changes and their causes.

Using a difference-in-differences approach, we compare liquidity changes between the Nordic and German markets, the latter serving as a control based on similar market dynamics. Our analysis centers on the bid-ask spread found in our reconstructed order books.

Following the mispricing event, we observe an increased bid-ask spread in the Nordic market, signaling reduced liquidity. This could stem from decreased investor trust and heightened caution. We also examine liquidity through volume and depth tests but face data limitations.

Keywords – Liquidity, Nordic Financial Power Market, Trust

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1 Introduction

In late November 2021, Nord Pool announced that they had been miscalculating the Nordic system price over 17 days due to a configuration error. The financial power market at the Nasdaq Commodities exchange trades in derivatives with this system price as the underlying reference. The mispricing threw a financial market that hinges on this price into uncertainty. Its repercussions extended to various market participants, including energy-producing and consuming firms reliant on hedging against volatile prices. Following the mispricing, prominent figures like Tor Reier Lilleholt from Volue Insight expressed reservations regarding Nord Pool's credibility. He contended that this event eroded trust and confidence in Nord Pool's operations (Barstad & Adolfsen, 2021). Our study is driven by the recent growing discourse around the reliability and credibility of Nord Pool's systems, as highlighted by notable finance experts like Thore Johnsen (Kværnes et al., 2023). Nord Pool has a vital role in facilitating critical infrastructure. The urgency and relevance of this topic in current energy and financial conversations make this research particularly compelling. We aim to dissect the liquidity impact on the financial markets from Nord Pool's 2021 pricing error.

Producers and large electricity consumers use financial power markets to hedge the risk of the volatile nature of electricity prices. The market facilitates efficient capital allocation, risk management, and the signaling of future supply and demand conditions (Pineda & Conejo, 2013). These functions are essential for the stability and sustainability of the power market. Power derivatives are settled against the system price, and mistakes in its calculation can lead to potentially significant losses for the market participants. The mispricing mistake from Nord Pool came at a time when the functionality of the Nordic financial power market as an instrument for hedging risk was already questioned. High demand for collateral and large deviations between the underlying asset and the actual zonal prices made it hard and expensive to hedge all price risk (Hentschel et al., 2022).

The most challenging aspect of our analysis involved reconstructing 411 order books from Nasdaq ITCH data. This gave us access to every level of all order books at any given moment in time during the three-month period. The order books provided valuable data that were used in our liquidity analysis. It allowed us to calculate a time-weighted average of both the bid-ask spread and the order book depth. Having access to all levels of the order book allows for a more comprehensive assessment of the order book depth.

Our paper details the methodologies employed to isolate and analyze the effects on market liquidity. Through bid-ask spread calculations, volume examination, and order book depth, we provide a comprehensive assessment of the liquidity shifts in response to Nord Pool's announcement of the pricing error. Using these measures in difference-in-difference estimations with German contracts as a control, we estimate the effect of mispricing on Nordic contracts' liquidity.

We find strong evidence that the bid-ask spread for Nordic contracts increased following the mispricing from Nord Pool. This indicates increased transaction costs and suggests that the incident affected liquidity. Our analysis points toward diminished trust in Nord Pool as the most plausible explanation for this phenomenon. To further assess the impact on liquidity, we analyzed the mispricing's impact on trading volume and order book depth. Due to the inherent illiquidity of the German contract, the comparability between the Nordic and German contracts is limited. Our analysis did not provide concrete evidence of an impact on these measures. We recommend exploring additional data sources that may offer more insights into this aspect.

Our findings could support Lilleholt's notion that Nord Pool's pricing mistake led to reduced market trust. The increased transaction cost can indicate that market participants seek higher compensation for an increased level of risk and that the activity from market participants is reduced. Our analysis explains how a seemingly minor mistake can have a significant impact on the Nordic financial power market.

This thesis is structured into five sections. The first part provides background information, outlining the institutional setup of the power market. In the second section, we present the Nasdaq ITCH data and describe its utilization in reconstructing the order books. The methodology section explains how we incorporate this data into our analysis. Subsequently, we present our findings and the analysis. In the fifth section, we summarize our findings and provide insights into the underlying rationale.

2 Background

In this section of our thesis, we present the institutional framework for our research. This includes providing essential background details that shed light on the motivations and rationale behind various aspects of our study.

2.1 The Physical Power Market

The physical power market is the market for the production, distribution, and consumption of electricity. Unlike the financial power market, which focuses on trading financial instruments related to electricity, the physical market is concerned with the physical aspects of electricity (Nord Pool, 2022).

2.1.1 Establishment of the Nordic Electricity Market

In the late 1980s, the Norwegian government controlled electricity prices and the development of new production capacity. A lack of cross-border interaction for electricity imports and a heavy reliance on hydroelectric power generation forced Norway to install enough generation capacity to meet demand in low influx years. The government's extensive development of electricity production facilities resulted in a production capacity that was over-dimensioned most years. When inflows to the hydroelectric magazines were at normal levels, capacity significantly surpassed the country's electricity demand. This oversized electricity production limited profits for state-run electricity producers (Bye & Hope, 2007). In response to these inefficiencies, Norway pioneered the implementation of market-based electricity pricing in 1991, a groundbreaking move that laid the groundwork for broader market liberalization across Europe and the Nordic region (Energifakta Norge, 2021). The market-based pricing and competition among producers necessitated the separation of the natural monopolist grid owner from the production entities (Bye & Hope, 2007).

In 1996, the Norwegian and Swedish electricity markets were integrated. Nord Pool was established to manage the balancing of supply and demand through the new power exchange. In 1997, the Finnish market was integrated, followed by Denmark in 2002 (Bye & Hope, 2007). The main idea behind this integration was to collaborate with other countries and utilize different production methods. Norway could export inexpensive energy to Sweden in high-influx years and import from Sweden in years with low inflow to the reservoirs. The market electricity price balances the markets, and signals the need for investments in production. (Energifakta Norge, 2021).

2.1.2 Economic Implications of Nordic Integration into the European Electricity Market

Through the Agency for the Cooperation of Energy Regulators (ACER), the European Union advocates for horizontally integrated and competitive electricity markets. They advise regulatory authorities about rules and encourage them to increase the European grid integration (European Union, n.d.). An integrated European electricity market leads to economic gain, where the prices are more stable and equal over time. Energy will flow from the area with high prices to the area with low prices (Bøhnsdalen et al., 2013).

This shift towards a liberalized power market in Europe has equalized Nordic electricity prices with the prices within the European markets (Bøhnsdalen et al., 2013). Let us think of the Nordic market as one, trading with other European markets. The size disparity between these markets is significant. Nordic prices are more susceptible to changes in European prices than the other way around. From a Nordic perspective, this results in the Nordic system price being influenced by a relatively elastic demand from European counterparts. The market size and consumption from foreign countries are much greater than the power surplus in the Nordics (Bøhnsdalen et al., 2013).

This dynamic is impactful not only when the Nordic countries actually export power. The mere possibility of exports can influence prices. In Norway, for instance, hydro reservoirs constitute around 90% of the power generation capacity. Knowing there might be a higher demand in the future influences production planning and profit maximization today (Energifakta Norge, 2021). In a situation with export possibilities, the alternative cost of holding the water and selling the power in the future is higher than without export possibilities. This is caused by the likelihood of a relatively large demand for exports in the future (Døskeland et al., 2022).

Moreover, the integration of energy markets across Europe contribute to the equaling of energy prices across different bidding zones (Døskeland et al., 2022).

2.1.3 European Energy Situation

In recent years, Europe has experienced a surge in energy prices and volatility. Notably, Germany and Britain have been reducing their reliance on fossil fuels as primary sources of power generation over the past two decades. Britain has increasingly turned to energy imports, which now make up 40% of their total energy supply (UK Parliament, 2023). Germany has undergone a similar transformation, with imports now accounting for a staggering 95% of its gas requirements, a significant departure from its previous levels of own gas production (Wettengel, 2023). Adding to the complexity, the cost of CO2 quotas has risen, and both France and Germany have steadily reduced their nuclear energy output (Pécout, 2023). This shift has reshaped the merit order in Europe to contain less gas and nuclear base load energy production.

Another critical development has been Russia's reduction in European gas exports. Historically, they have been supplying roughly 40% of the continent's gas. However, starting in 2021, President Putin initiated restrictions on gas exports, which almost came to a complete halt in 2022. This sudden change has had consequences, driving up gas prices and LNG (liquefied natural gas) carrier rates (Popkostova, 2022).

Investing in renewable energy sources undoubtedly offers many benefits. However, the decrease in investments in base load energy resources has brought about heightened price volatility within the European energy market (Døskeland et al., 2022). The integration of the Nordic and European energy markets is supposed to equal prices over time, but lately, the Nordics have imported price volatility from the EU. This, in turn, exerts an influence on the price stability of the Nordic system price with direct repercussions on future pricing dynamics within the financial markets.

2.1.4 The Merit Order

The merit order determines the electricity prices based on the marginal cost of each generation method, effectively creating the supply curve. The marginal costs for various production methods vary, influenced by factors such as fuel prices, the alternative cost of water, and general operational expenses (Appunn, 2015).

Renewable Energy Sources (RES), including river hydro, wind, and solar energy, typically have low marginal costs. These sources tend to operate at maximum output as their production increase largely depends on weather conditions rather than cost. This characteristic can lead to significant price reductions, even to the point of reaching zero during favorable weather conditions. However, it also renders the market susceptible to fluctuations when wind, sunlight, or rainfall become scarce, significantly affecting the supply curve (Figueiredo & da Silva, 2019).

The merit order ranks the production methods by marginal cost. The marginal cost includes the cost of CO2 quotas, disfavoring production based on fossil fuels (Nano Energies, 2023). Due to grid constraints, the merit order does not necessarily reflect which production method that is actually used.

2.1.5 Nord Pool

Nord Pool was founded in 1996 to support the integration between the Norwegian and Swedish electricity markets (Energifakta Norge, 2021). Nord Pool operates in 15 European countries and is the exchange for buyers and sellers of power in the Nordics. Furthermore, the "Nord Pool European Market Coupling Operator" contributes to the market coupling and integration in Europe (Nord Pool, 2020).

2.1.5.1 Day-Ahead Clearing at Nord Pool

Every day at 10 am CET, Nord Pool announces the day ahead inter-connector capacities between 15 countries and 21 bidding zones. Energy distributors, energy-intensive industries, and power producers then have until 12 pm to place bids for their day-ahead capacity or needs (Nord Pool, 2023a). The buyers' demand and willingness to pay for an extra unit of energy, also known as the marginal cost of consumption, is aggregated to determine the demand curve. Simultaneously, the producer's ability to supply electricity at different prices reflects the supply curve, in this context known as the generation cost. Nord Pool's optimizing model matches orders from all the countries (Nord Pool, 2023a). The equilibrium price is set hour by hour and reflects the hourly day-ahead power price.

All the information is published at 1 pm by Nord Pool, informing the buyers and sellers about the prices and volumes the following day. The prices are published for all bidding zones, including the Nordic system price (Nord Pool, 2023a).

2.1.5.2 Nordic System Price

The Nordic system price is a reflection of the equilibrium between power supply and demand in the Nordic region and the Baltic's, calculated independently of any physical limitations (Nord Pool, 2023b). As a result, it deviates from the observed zonal prices within the Nordics. The daily Nordic system price is the average of the hourly system prices.

Despite the existence of varied zonal prices, the system price maintains a crucial role as a reference point for future contracts. The aggregation of the futures market to the system price expands the market for these products, attracting more participants and consequently bolstering overall liquidity (Eicke & Schittekatte, 2022). This expansion is feasible due to the typical emergence of discernible patterns in the fluctuations of zonal prices relative to the system price. However, the aggregation process does have certain issues, which we will discuss in the section on the financial power market.

2.1.5.3 Nord Pool's mispricing in 2021

In November 2021, an unusual pattern emerged in the Nordic system price. The price unexpectedly aligned with the NO2 prices in South Norway. On November 26, Nord Pool disclosed that they were investigating potential inaccuracies in their Nordic system price calculations. The following day, they identified a configuration error with NO2A. NO2A is not an actual price zone, but a configuration used by Statnett to define the capacities of Norned and Nordlink, two Norwegian interconnectors to the Netherlands and Germany. The reported capacities of Norned and Nordlink had beed erroneously doubled the previous 17 days, akin to removing a constraint in an optimization problem. This led to a substantial increase in the system price (Barstad & Adolfsen, 2021).

This discrepancy in system pricing is not a concern for regular electricity consumers, as the system price primarily functions as a reference (Barstad & Adolfsen, 2021). However, this error significantly impacted various stakeholders and daily cash settlements in the financial markets, where the system price is a crucial reference point. We spoke to a trader who was active during the incident. He explained that while contracts settled at the incorrect price were later corrected, those bought and sold during the mispricing period could not be rectified. This is because it was impossible to know how crucial the value of the system price was for any decision to buy or sell contracts.

2.2 Financial Power Market

Much like other commodity markets, the financial power markets play a crucial role for various participants in the power sector, including producers, consumers, and speculators. These markets offer critical tools for managing costs and projecting revenues, essential for investments and planning in power generation and power-intensive industries (Nasdaq, 2022). At the core of these markets are derivatives – contracts whose value is derived from an underlying reference, in this case, power prices (Fernando, 2023).

There are also bilateral future markets where trades can be made, cleared by the exchange (OTC) or outside the exchange. Bilateral trades over the counter contain the same agreements as the financial agreements, and the exchange takes care of the credit risk and settlements. The difference is that these contracts are not a part of the demand and supply at the exchange, nor the order books. The market for non-cleared bilateral contracts is quite different and does not contribute to transparency. In these types of contracts, the buyer and seller set the terms of the agreement. Because these contracts are not cleared by the exchange, the buyers and sellers take on the risk of the counterpart defaulting (Hentschel et al., 2022).

There is also a market for contracts with physical delivery of power outside the exchange. Power purchase agreements (PPA) are contracts with physical delivery, and they vary when it comes to volumes and prices. Normally, the agreements are between producers and big consumers that are creditworthy. They agree to physically buy/sell a certain volume for a given price in a given period (Hentschel et al., 2022). There are also contracts with physical delivery (forwards) at the exchange, but these are standardized.

2.2.1 The Financial Electricity Market at Nasdaq

Nasdaq is a large company running several exchanges all over the world. Nasdaq European Commodities have members from 20 different countries, including energy producers, energy-intensive industries, distributors, and financial institutions (Nasdaq OMX, 2023). Nasdaq OMX commodities cover the financial power market in Europe. This is the leading exchange for trading Nordic power contracts with the Nordic system price as the underlying reference.

Typical power products traded at Nasdaq commodities are Futures, DS futures, Options, and European price area differentials (EPAD) (Nasdaq OMX, 2023). In this thesis, we will focus on quarterly base load futures, as these are the most traded products in our data set.

2.2.1.1 Activity in the Nordic Financial Market

The Nordic power market has recently experienced significant price fluctuations and volatility. These market conditions have adversely impacted the financial power market, leading to a notable decline in liquidity (Hentschel et al., 2022). One key factor contributing to this shift is the increasing disparity between zonal prices and the system price. This divergence primarily results from enhanced export capacity from the Nordics, coupled with insufficient upgrades to the internal connector capacity among different zones. Consequently, market participants, including producers and energy-intensive industries, find it more advantageous to engage in direct agreements with counterparts within the same zone and through physical contracts (Hentschel et al., 2022). The electricity price area differentials (EPAD) contract is an additional product that can be bought to hedge the difference between the system price and the zonal prices. These contracts need to be traded by participants in the given area, which constrains market size and leads to illiquidity. Due to their lack of liquidity, using these contracts for hedging purposes becomes costly, prompting market participants to seek alternative hedging options (Nasdaq, 2022). Consequently, the liquidity of future contracts with the system price as the underlying reference decreases (Hentschel et al., 2022).

In 2022, an increase in the resource rent tax in Norway for power producers was announced. The Norwegian Government mitigates the risk for the producers by covering losses and taking a more significant share of the profit. Further, this implies that if the participant has the same risk aversion, their need for financial contracts is decreased (Hentschel et al., 2022). Norwegian market participants make up a large part of the Nordic electricity market. Decreased demand from Norwegian producers can therefore significantly impact the liquidity of the Nordic system price contracts.

The market landscape has further evolved due to significant regulatory changes in 2016 concerning collateral requirements at exchanges in Europe. Previously, banks could issue guarantees, assuring credit on behalf of producers with collateral in physical capital. The 2016 regulations removed this possibility, escalating the cash collateral demands from exchanges. In the same period, the underlying price and volatility increased, making the collateral demand from the exchange even higher than usual. This led to many traders shifting from transacting financial power derivatives through exchanges to engaging in bilateral trades and Power Purchase Agreements (PPAs). As a result, the number of participants at "NASDAQ clearing" has decreased from 323 in January 2016 to 136 in January 2021 (Hentschel et al., 2022).

Most of the power producers that want to hedge against the volatile system price have their capital invested in physical property. Because of the decrease in liquidity, as mentioned above, the market regulators in the EU decided to change the rules again. Non-financial participants are now allowed to use bank collateral to meet half of the collateral demand required from the exchange (Lingjærde, 2023). This change had not yet been made in late 2021, meaning that in the period we are interested in, physical capital was not accepted as collateral.

2.2.2 Nordic and German Base Load Futures

A future contract is an agreement to buy or sell an underlying asset in the future. It is a standardized contract traded at an exchange with several standard specifications (Hayes, 2023a). Base load contracts are one common type of future contract for electricity with no physical delivery. There are daily settlements between the exchange and the buyers/sellers. One contract represents 1MW/h and is traded in Euros (Euro/MWh). The underlying price for the Nordic electricity futures is the daily Nordic system price, also listed as a price in euros for 1MW/h. The future underlying prices of German electricity are the German electricity prices, also listed in euros per MW/h (Nasdaq Oslo, 2023).

The daily underlying price observed in the spot market is subtracted from the agreed price, where one part pays the difference, and one part receives the difference. This number is multiplied by 24 because it is a base load contract, covering a continuous supply all the hours of the day (EEX, 2023). The number of delivery hours for the different contracts is found in the product calendar at Nasdaq Commodities (Nasdaq Oslo, 2023).

It is worth mentioning that German electricity derivatives are also bought at the European Energy Exchange (EEX). Spreading market participants between two markets can have a negative impact on the liquidity at Nasdaq.

2.3 Characteristics of Electricity as a Commodity

Electricity as a commodity exhibits distinctive characteristics that set financial derivatives based on it apart from those associated with other commodities. Unlike some other commodities, electricity has limited storability and transportation options, limiting opportunities for arbitrage across time and space (Lucia & Schwartz, 2002).

2.3.1 Storage of Power

Electricity stands out among commodities due to its inherent non-storability, necessitating that the amount produced should be immediately consumed within the grid (Lucia & Schwartz, 2002). This unique characteristic requires transmission system operators (TSOs) and distribution system operators (DSOs) to meticulously balance the grid's frequency (balancing demand and supply). This is done by engaging in various market transactions and agreements with significant stakeholders representing both the supply and demand side (Statnett, 2022).

For storable commodities, the spot price and the cost of carry define the value of a financial future contract. Cost of carry is the cost a seller of a future must pay for holding the commodity (Fama & French, 1987). This could be financing, insurance, and storage costs (Chen, 2020). This is known as the "theory of storage". Holding the commodity can include a "convenience yield", which is the advantage of having the commodity physically. This also needs to be taken into consideration when calculating the forward price of a storable commodity (Fama & French, 1987).

Given the non-storability of power, cost of carry considerations, common in other commodity futures pricing, do not apply to electricity (Lucia & Schwartz, 2002). However, there could be a convenience yield for energy production based on fuel. For example hydroelectric power with reservoir capabilities, which is prevalent in Nordic countries. Operators of hydroelectric reservoirs have the strategic advantage of timing their electricity production (Jansen & Østby, 2001). They can conserve water during periods of low prices or expected surplus supply. They choose to generate electricity when prices are anticipated to be higher due to increased demand or reduced supply. However, this strategy comes with risk. Overfilled reservoirs may force production at inopportune times, potentially when prices are lower, thus introducing a unique set of challenges in managing hydroelectric resources. Future contract prices play a crucial role in calculating the alternative cost of the water in the reservoirs.

While electricity is generally perceived as a homogeneous product, with one kilowatt-hour being equivalent across the board, storage—or the lack thereof—introduces a temporal dimension to its valuation. From this perspective, electricity's value can vary significantly depending on the time of production and consumption (Lucia & Schwartz, 2002). This temporal variability underscores the complexity of electricity as a commodity and the calculation of contract prices in futures markets.

2.3.2 Weather and Seasonality

Weather plays a significant role in influencing the supply and demand for electricity, consequently impacting both spot and future electricity prices (Mæland, 2021). In the Nordics, demand for electricity tends to rise during cold weather as buildings require heating. The electricity price will then increase as the demand increases. As mentioned earlier, renewable energy sources could contribute to volatile prices, especially with "rare" weather occasions. If a market has a relatively high exposure to these types of production methods, then heavy rainfall or storms will influence the supply of electricity.

Expectations of a cold winter will increase the future contract price, while, for example, expectations of a rainy fall will decrease the prices for hydro-power areas (Mæland, 2021). This insight is important, especially in geographical areas with renewable energy sources as a big share of the energy mix.

2.3.3 Fuel Cost

The cost of fuel inputs, such as gas, coal, or oil, is crucial in determining electricity spot prices where the power generation is based on fuel (Mohammadi, 2009). The type of fuel is also important, as CO2 quota prices also need to be priced in (Nasdaq, 2022). The relationship between fuel and electricity prices implies that future electricity prices could be tied to the anticipated future market prices of these fuel sources (Mohammadi, 2009).

Germany's energy sector depends on several fuel types (Wettengel, 2023). The German future electricity prices are, for example, influenced by the Title Transfer Facility (TTF) futures, a benchmark for Dutch natural gas prices (Graves & Levine, 2010). Conversely, precipitation patterns and reservoir water levels can similarly affect future electricity prices in regions where hydroelectric power is predominant, demonstrating how different energy sources uniquely influence regional electricity markets.

2.3.4 Expectation Hypothesis and Importance of Spot Prices

Fama and French (1987) suggest that there are two types of future pricing calculation methods for commodities, the theory of storage and the expectation theory. Earlier, we mentioned that there is a limited capacity for storing electricity. This means that the expectation theory is better suited for pricing power futures. The expectation theory is based on the expectation of future spot prices and the risk premium (Huisman & Kilic, 2012). The expected risk premium is, according to Fama and French (1987), the difference between the future contract prices and the expected spot prices. Lucia and Schwartz (2002) models the expected future spot prices based on: "an equilibrium long-term spot price level and a mean-reverting short-term price" (Huisman & Kilic, 2012). Other researchers try to model the expected risk premiums.

Given the unique attributes of electricity, one could argue that spot prices should not influence future electricity prices and contract values. For instance, it seems counter-intuitive that a spot price in January, influenced by a specific weather event, would dictate the price in August. However, it is often posited that the best predictor of tomorrow's price is today's price. According to Fama and French (1987) and their expectation theory, the future prices for a commodity are based on historical prices.

2.4 Market Microstructure

Market microstructure is a specialized field within financial economics that delves into how transactions are conducted in markets. The fundamental role of markets in connecting buyers and sellers has remained relatively constant over time, but the methods of trading have undergone significant changes, particularly in recent decades (Baker & Kiymaz, 2013).

The growing availability of high-frequency market data in recent years has led to many intriguing discoveries, reshaping both theoretical understanding and practical approaches in financial economics (Abergel et al., 2012).

According to market microstructure literature, there are three types of traders in the market: Liquidity traders, market makers, and informed traders. Market makers are professional traders, also called dealers (Baker & Kiymaz, 2013). Liquidity traders buy or sell for reasons exogenous to the payoffs in the market. They, therefore, do not care about the market prices or their expectations about prices, meaning that they have inelastic demand/supply (Kalay & Wohl, 2009). These traders provide liquidity to the market. The informed traders represent a group that trades based on their informational advantage. Market makers represent both sides of the order book. They try to profit on the bid-ask spread by both buying and selling (Bloomenthal, 2023).

2.4.1 Liquidity

According to Hayes (2023b), liquidity is characterized by the efficiency and ease with which an asset or security can be converted into cash without significantly impacting its market price. Liquidity is a cornerstone of market efficiency and stability. The primary role of a market is to establish a fair price for the traded assets and to offer a platform where buyers and sellers can trade (Baker & Kiymaz, 2013). Given the variability of data sources and the nature of securities, there is no universally superior method for measuring liquidity. Consequently, our analysis will employ multiple tests to detect shifts in liquidity.

A comprehensive understanding of financial market liquidity requires examining various liquidity metrics. Specific attributes consistently define a liquid market: depth, immediacy, breadth, resiliency, and tightness. *Depth* pertains to the capacity for many volume orders, reflecting the volume present in the order book. *Immediacy* denotes the speed at which orders can be executed, encompassing aspects of the exchange's system. *Breadth* indicates substantial volume for a given level. *Resiliency* relates to the market's ability to rebound swiftly from significant events, price swings, or other disruptions. Lastly, *Tightness* is associated with the costs incurred in transactions (Sarr & Lybek, 2002).

2.4.2 Limit Order Book

Most liquid markets, encompassing equities, futures, and foreign exchange, operate electronically. They primarily utilize a continuous double auction system facilitated through a limit order book (LOB). This system executes transactions when buyers and sellers reach a consensus on the price (Hayes, 2023b). Buyers and sellers place their market- and limit orders. The market orders are matched with the limit orders already in the limit order book, while the limit orders are put in the queue in the order book (Fedorov, 2021). The order book has a bid side and an ask side, where quantity per price level is represented. A market order is taking liquidity out of the order book. In comparison, limit orders provide liquidity to the market (Kenton, 2022).

2.4.3 Transaction Cost Measure

In assessing the transaction costs associated with an asset, a critical measure is the bid-ask spread, which reflects the market's tightness (Alzahrani, 2011). This spread, observable in the order book, represents the difference between the lowest price a seller is willing to accept (the ask) and the highest price a buyer is willing to pay (the bid). Seen in the context of the definition of liquidity, this implies that a higher spread gives worse liquidity. The bid-ask spread encompasses explicit costs, such as order processing fees and taxes, and implicit costs, representing indirect trading expenses (Sarr & Lybek, 2002). As highlighted by Alzahrani (2011), the bid-ask spread is a crucial indicator of market liquidity. It reflects the efficiency with which assets can be traded and the ease with which market participants can transact.

The bid-ask spread at time t is calculated in the following way:

$$\text{Bid-Ask Spread}_t = AskPrice1_t - BidPrice1_t \tag{2.1}$$

where $AskPrice1$ is the best ask price in the order book at time t, and $BidPrice1$ is the best bid price in the order book at time t.

The bid-ask spread represents the direct transaction cost incurred for an investor executing immediate buy and sell transactions. This cost is essentially the price of immediacy – the cost of executing a trade quickly without waiting for a more favorable price (Baker & Kiymaz, 2013).

Market participants who choose to delay their exit from a position may avoid this immediate cost but incur an alternative risk exposure over time—also called inventory risk. This risk necessitates compensation, which is effectively a payment for the liquidity service provided to the market. Lower trading costs are a significant factor in attracting traders, thereby enhancing market liquidity or reducing market tightness (Baker & Kiymaz, 2013).

The literature focusing on the inventory and immediacy costs claims that adverse selection costs also exist. In competitive dealer markets with risk-neutral dealers, the transaction cost still exists (Baker & Kiymaz, 2013). Baker and Kiymaz (2013) therefore suggests that this transaction cost reflects the cost of adverse selection.

Traders charge a cost for providing liquidity to the market. If there is an increased risk of being in the market, the market dealers will require higher compensation. The more market participants there are willing to trade with the dealers, the lower the transaction costs are. Increasing transaction cost decreases the demand for trades, implying that the number of market participants is reduced (Sarr & Lybek, 2002).

2.4.4 Volume Measure

Trading volume is defined as the quantity traded (Nasdaq, 2023). We wish to compare the volume of two different markets with each other, and the different contracts have individual prices. Therefore we use the size of the position in Euros as the measurement for volume. This means that the volume for a trade i is calculated as shown below:

$$\mathrm{V}_i = Q_i \times P_i \tag{2.2}$$

where V_i is the volume for trade i, Q_i is the quantity for trade i, and P_i is the price for trade i.

The volume serves as a gauge of market activity. A volume change indicates a shift in the number of transactions, price movement, or a combination of both. It reflects the monetary scale of positions that market participants are willing to enter into the market, representing the market's size or breadth. Volume levels can provide insights into the number of participants involved in the market (Nasdaq, 2022). A participant decline would likely lead to decreased volume, while an increased number of participants often result in higher volume.

2.4.5 Depth Measures

The depth represents the market's ability to absorb large orders. This measurement should reflect the volume at the different levels of the order book, and indicate the magnitude of a position it is possible to take without significantly affecting the price. A deeper order book contains a larger number of price levels, given that they are not too far from the actual price (Daigler & T., 2015).

The depth at a given order book level is calculated as shown in equation 2.3.

$$\mathrm{D}_i = BidPrice_i * BidVolume_i + AskPrice_i * AskVolume_i \tag{2.3}$$

Where D_i is the depth at order book level i. $BidPrice_i$ and $BidVolume_i$ is the price and volume for a bid order at level i in the order book. $AskPrice_i$ and $AskVolume_i$ is the price and quantity for an ask order at level i in the order book.

2.4.6 Determinants of Liquidity

Liquidity is influenced by various factors, which can exert both short-term and long-term effects. In the short term, liquidity can be impacted by immediate market stimuli such as news events, shifts in market sentiment, technical disruptions, or regulatory changes. For instance, a significant news event can instantly alter trading, either invigorating market activity or causing a retreat of traders, thereby affecting liquidity (Gu et al., 2020).

Over the long term, broader factors such as evolving market structures, global economic trends, and technological advancements play a pivotal role in shaping liquidity (Gourinchas, 2012). These long-term elements can fundamentally alter the trading landscape, influencing transaction costs, market depth, and trading volume.

Regulatory choices, such as the implementation of new tax regulations or trading fees, can consequently influence transaction costs. These costs essentially act as a barrier to trading. A rise in costs has the potential to discourage market involvement, leading to a widening of the spread (Nasdaq, 2022).

Trading volume is closely tied to investor confidence and market sentiment (Holmes & Rougier, 2005). It can be both a cause and effect of market movements. For example, a surge in trading volume spurred by positive news can enhance liquidity. Conversely, declining volumes can lead to a negative feedback loop, where traders are compelled to execute smaller trades due to concerns about market exit strategies, further diminishing liquidity.

As market depth is a measure of the market's capacity to absorb large orders without significant price changes, it is naturally dependent on the number of active market participants. The higher the number of buyers and sellers is, the larger the positions one can take without affecting the price. A notable example of this was observed at Nasdaq OMX Commodities, where regulatory changes led to a reduction of over 200 participants (Hentschel et al., 2022). This is another example of how regulatory shifts can directly influence market liquidity.

3 Data

In this section we will present the data we used in our analysis. We will start by presenting the raw data from Nasdaq, before we explain how we handled, cleaned and organized it. We will then explain how we reconstructed the order books, before we argue for the selection of the data to be analyzed.

3.1 Nasdaq ITCH Data

Our analysis is based on data from the Genium INET ITCH feed provided by Nasdaq. This is a comprehensive direct data feed that captures all public orders and trades in the auto-matched market. We have access to the data feed of Nordic and German power derivatives. There are numerous order books in the data, for example daily, weekly, monthly, and quarterly contracts.

The feed is structured as a sequence of messages, each detailing various activities within the Genium INET trading system. These activities include the addition, removal, and execution of orders. Additionally, the feed includes messages with essential reference data for each order book, such as tick size, price decimal points, and the trading currency (Nasdaq, 2017). The feed also incorporates event messages, which inform about system events like trading halts and state changes. Notably, the length of each message varies according to its type (Nasdaq, 2017).

For the purposes of our analysis, we have utilized data spanning the fourth quarter of 2021. The critical task at hand involves reconstructing the order books at each point in time for all three months. This reconstruction is based on the systematic analysis of specific message types within the feed, namely "A" messages (Add Order), "D" messages (Order Delete), and "E" messages (Order Executed). These messages have some data in common. All have data on 'Date', 'Timestamp', 'Nanoseconds since 1970-01-01', 'Order ID', 'Order book ID', and 'Side'. 'Side' indicates which side of the order book the order is placed, deleted or executed from. Note that the Order ID is unique only per order book and side (Nasdaq, 2017).

In addition to the data the messages have in common, "A" messages have data on 'Order book position', indicating what level of the order book the order is placed. This position is ordered first by price, then by time, meaning it does not accumulate quantity at the levels. We cannot use this information to reconstruct the order book properly because we want to position the orders only by price and not time. We can however use it to check that our reconstructed order books are correct. The "A" messages also have data on the quantity and price of the order being placed in the book. "E" messages include data on 'Executed Quantity' but not the execution price.

3.2 Organizing the Data

The NASDAQ-provided text files contain daily data feeds for all products. The first step was therefore to combine these files in R and transform the data into a structured format by separating the contents into columns, using commas as delimiters. This process resulted in a data frame consisting of approximately six million rows.

Upon examining the various message types in the data, we identified several irrelevant to our study. By excluding these unnecessary messages, we narrowed our focus to the following message types: 'Add Order', 'Order Delete', 'Order Executed', 'Order Executed with Price', and 'Trade'. The 'Trade' messages provide execution details for normal match events involving non-displayable order types or individual cross trades. Because these messages do not affect the displayed book, they are only used in the volume calculations and are ignored in the reconstruction of the order books (Nasdaq, 2017).

The 'Order Book Directory' messages contain crucial information. However, the uniformity of the trading currency (Euros) and the consistent two-decimal pricing across all products allowed us to simply acknowledge this information and omit these messages from our analysis. Post-filtering, our data frame was streamlined to just over 3.5 million rows, which formed the basis of our subsequent analysis.

To organize the data further, we divided it into separate data frames for each product. This step must be done because order IDs are unique only within their respective order book and side. For these data frames, 'Trade' messages were omitted as they are irrelevant to the order book reconstruction (Nasdaq, 2017). These messages will be handled separately and added to the volume calculations. Consequently, we ended up with 508 distinct files of feed data (411 order book data and 97 files with 'Trade' messages for different products).

A notable challenge we encountered was that the 'Order Delete' messages only specifies the order ID to be deleted, without providing details on price or quantity. Similarly, the 'Order Executed' messages indicates the number of contracts executed but omits the execution price.

3.3 Finding Volume and Price for Executed Orders

For further analysis of the order book data, we need to determine the execution price of contracts, and the quantity and price of deleted orders. This is the first real hurdle of our data handling process.

To address this, we developed a script that loops through all rows of the product data. When the script encounters a row with an "A" message type, it updates a list named "last A row" with the order's quantity and price information. Each order is assigned a unique key based on its 'OrderID' and 'Side'.

For every "E" message, the script identifies the corresponding 'Add Order' in the "last A row" list and transfers the price information from the 'Add Order' to the executed order. Additionally, it records the executed quantity in a separate section of the "last A row" list, labeled "Executed Quantity". This section tracks the portion of the "A" order that has been executed.

When processing a "D" message type, the script locates the relevant 'last A row' with a matching key. It then copies the price from this list to the "D" message. The script calculates the quantity for the "D" message by taking the "Quantity" from the 'last A row', subtracting any "Executed quantity", and applying this figure to the "D" message's "Quantity". In cases where the "Executed Quantity" is absent, the script treats it as zero.

By applying this function to all our data frames, we successfully generated data sets that included both price for the "E" rows and quantity and price for the "D" rows.

3.4 Reconstructing the Order Book

Our analysis required the reconstruction of order books for each product over a three-month period. To achieve this, we developed a script to process the message feed and use this data to reconstruct the state of the order books at any given point in time. The script's functionality is centered around managing and updating the order books, which are structured to reflect different levels of bid/ask prices and volumes.

Each level in the order book represents a specific price point for both the bid side and the ask side, with corresponding volumes. The script starts by creating a structured framework for these levels, setting up columns for bid and ask prices and volumes.

As the script processes each message, it identifies the type—'Add Order,' 'Delete Order,' or 'Executed Order'—and updates the order book accordingly. When an 'Add Order' message is processed, the script has to insert the order into the correct level on the correct side of the order book. This placement is based on the order's price in relation to existing orders.

For a new bid order, the script finds the first level where the price of the order is higher than the existing bid price. The script then reorganizes the order book to place this new order at the correct level, shifting other orders down as necessary. This reorganization ensures that the highest bid price is always at the top level of the bid side of the book, and other bids is placed at the correct level. Conversely, for a new ask order, the script finds the first level where the price is lower than the existing ask price. The script then moves the existing order at that level and all orders below down one level, and places the bid at the now empty level.

In cases where the new order's price matches an existing level, the script simply updates the volume at that level, adding the new order's volume to the existing one.

If the volume of either the bid or ask side ever reaches zero for any level in the order book, that level is deleted from the book, and all levels below are moved one level up. This process maintains the integrity of the price levels, ensuring that each level accurately reflects the total volume available at that price point.

The order book is wiped clean every morning, meaning we begin each day with an empty order book. This is done to avoid carryover of any unprocessed or residual data from the previous day.

3.4.1 Order Book

After running this script on all our product data, we are left with 411 reconstructed order books. These books contain all states of the order book for the entire three-month period, including all levels. Each order book has a date, a timestamp, and a state of every level of the order book at that time. A snapshot of the two best levels of the order book for the Nordic base load future q1 2022 is shown in Appendix A.

3.5 Choosing the Most Liquid Products

Our goal is to measure how the liquidity in the Nordic financial power market is affected by the mispricing from Nord Pool. To do this, we want to compare the liquidity of the Nordic contracts to the liquidity of German contracts in the same period. We therefore need to find similar contracts in both countries for a fair comparison. Initially, we thought contracts closest to their maturity date would be the most liquid. However, our data shows that the liquidity for Nordic quarterly contracts is higher than that for monthly and weekly ones. Additionally, the German monthly electricity contracts seem to have virtually no liquidity, making them unsuitable for our analysis. Consequently, we've decided to focus our study on the Q1 2022 contracts. This choice is also based on input from market participants who told us that the use of quarterly contracts is the industry standard.

With this approach, we make the assumption that the liquidity of the quarterly base load futures is a good indicator of overall market liquidity.

As the Q1 contracts approach their maturity date, their trading volume significantly decreases. Conversations with market participants revealed that producers, consumers, and speculators tend to roll over from Q1 to Q2 contracts as the former near maturity. This shift becomes evident as the volume for Q2 contracts starts to exceed that of Q1 contracts about two weeks before January. Based on this observation, we've chosen to 'roll' our contracts on December 17th. This means our analysis will be based on data from Q1 contracts until December 17th, and data from Q2 contracts from the 18th to provide a more comprehensive understanding of the market dynamics.

4 Methodology

In this part of our thesis, we outline the methods applied to analyze our data. First, we'll describe the process of calculating various liquidity metrics. Our measures for liquidity are trading volume, the bid-ask spread, and order book depth. Following this, we introduce the difference-in-difference estimation as our empirical method of choice. We will also discuss the critical assumptions necessary to ensure the validity of our analysis.

4.1 Bid-Ask Spread

With the reconstructed order books, we can pinpoint the bid-ask spread for each product at any given moment during the quarter. The bid-ask spread, however, is subject to significant fluctuations throughout the day due to the dynamic nature of financial markets. To extract a meaningful and consistent measure over time, we need to adopt a metric that captures these variations while offering a stable basis for comparison.

Initially, computing the daily average spread for each product seems like a viable approach. This method would help smooth out the intra-day volatilities, thereby offering a clearer view of the market conditions over an extended period. However, a simple daily average could disproportionately emphasize brief periods of exceptionally high or low spreads. To address this, we use the time-weighted average spread, calculated by multiplying the spread by the duration for which that spread is maintained. We then average these values over the total duration when a spread is present in the order book for that day. This approach ensures that the measure reflects the duration for which each spread is actually in effect, providing a more accurate and representative view of market conditions.

Furthermore, when comparing the spreads of different products in different markets, it becomes essential to use the relative spread instead of the absolute spread. The relative spread, expressed as a percentage of the mid-price, normalizes differences across various price levels, allowing for a more equitable product comparison. This is important for our analysis, as the different financial products often have significantly different price levels. A relative spread provides a percentage-based comparison, reflecting the proportional trading costs and offering a more consistent measure of liquidity and market depth across diverse assets (Ødegaard, 2023). Using the time-weighted average of the relative spread, we can accurately assess and compare the trading costs and market conditions of different financial products, regardless of their individual price levels. The relative spread at each moment t is calculated as:

$$S_t = \frac{\text{AskPrice1}_t - \text{BidPrice1}_t}{\frac{\text{AskPrice1}_t + \text{BidPrice1}_t}{2}} \tag{4.1}$$

Where $AskPrice1_t$ and $BidPrice1_t$ are the best ask price and bid price at time t.

Duration for each moment is defined as the difference between the next- and current timestamp:

$$\text{Duration}_t = (t+1) - t \tag{4.2}$$

The weight for the state of the order book at time t is calculated as:

$$W_t = \frac{\text{Duration}_t}{\sum_{t=1}^{n} \text{Duration}_t} \tag{4.3}$$

Finally, the daily weighted average spread relative to mid-price is the sum of the weighted spreads over the day:

$$\text{Daily Weighted Average Spread Relative to Mid Price} = \sum_{t=1}^{n} W_t \cdot S_t \tag{4.4}$$

4.2 Volume

Using the data feed on our products of interest, we proceeded to calculate the trading volume for each order book. Our approach involved isolating the 'E' messages, which represent executed orders, from the data feeds. We then added a new column labeled 'Volume' to these messages. This 'Volume' column was calculated by multiplying the quantity of each executed order by its respective price. Next, we organized these 'E' messages by date, and summed the volume for each day. We handled 'Trade' messages in a similar manner, and summed the daily executed orders and the executed non-displayable trades. We now have access to the daily volume for all products for the entire period.

The daily volume is calculated as:

$$\text{Daily Volume}_t = \sum_i P_{it} \times Q_{it} \tag{4.5}$$

where P_{it} is the Price for trade i during day t, and Q_{it} is the Quantity for trade i during day t.

4.3 Depth

We aim to use order book depth as another indicator of market liquidity. Order book depth refers to the quantity of buy and sell orders present at various price levels within the order book (Daigler & T., 2015).

We apply the daily weighted average method to compare Nordic contracts' liquidity with German contracts. We multiply the price and volume at each relevant book level for both the bid and ask sides and then sum these products. This calculation is performed for all states of the order book throughout the day. Moreover, we monitor how long each depth level is maintained in the book and calculate a weighted average for the entire trading day.

We calculate two different depth measures: the depth at the best bid and offer price (BBO), and the depth at the top two levels. The latter is found by summing the products of volume and price for both bid and ask sides for both the two best levels. This approach provides us with measures of how much one can trade before affecting the price at the best levels, and before causing a significant price change.

We define a price change exceeding two levels as significant, a choice influenced by the limited liquidity in the German contract, which typically extends no further than two levels. While we would have preferred to include more levels, opting for, let's say the top five levels would have provided us with a good metric for the Nordic contract. However, due to the limited depth in the German contract, measuring the five best levels essentially encompasses the entire order book.

The Depth at time t (best level) is calculated as follows:

$$Depth_t = Bidprice1_t * Bidvol1_t + Askprice1_t * askvol1_t \tag{4.6}$$

where $Bidprice1$ is the price for the best bid in the order book at time t, and $Askprice1$ is the best ask price in the order book at time t. $Bidvolume1$ is the volume for the best bid in the order book at time t, and $Askvolume1$ is the volume for the best ask in the order book at time t.

The depth at the top two levels is calculated similarly, just adding the second levels to the calculation.

Duration for each moment is defined as the difference between the next- and current timestamp t:

$$\text{Duration}_t = (t+1) - t \tag{4.7}$$

The weight for each moment t is calculated as:

$$W_t = \frac{\text{Duration}_t}{\sum_{t=1}^{n} \text{Duration}_t} \tag{4.8}$$

$$\text{Daily Depth} = \sum_{t=1}^{n} W_t \cdot Depth_t \tag{4.9}$$

4.4 The Difference-in-Difference Model

Difference-in-difference (DID) estimation is one of the methods used most frequently in impact evaluation studies (Fredriksson & Oliveira, 2019). The aim of our empirical analysis is to estimate the impact the mispricing from Nord Pool had on the liquidity in the Nordic financial power market.

If we were to run a standard Ordinary Least Squares (OLS) regression to analyze our liquidity measures, including a variable for the period after the event, we wouldn't be able to isolate the specific impact of the mispricing. This is because other factors also influence the liquidity and these can change over time.

A difference in difference analysis allows us to compare the effect of a 'treatment' in the Nordic market with a control group - in this case, German contracts. We treat these German contracts as the 'counterfactual', and the announcement of the mispricing on November 26th as the 'treatment'. The counterfactual is what would have happened, or what the outcome would have been, for a group in the absence of the treatment (Gertler et al., 2016). In our case, the counterfactual is how the different liquidity measures would have developed without the mispricing.

By comparing the Nordic market (which experienced the mispricing) with the German market (which did not), we can more accurately measure the impact of the mispricing. We do this by calculating the difference in volume, bid-ask spread, and depth after the mispricing in the Nordic market and then subtracting any similar change that occurred in the German market in the same period. This helps us account for other factors that might have influenced the liquidity (Gertler et al., 2016).

This approach assumes that the liquidity of the Nordic and German futures is affected by the same factors to the same extent. If this assumption of parallel trends holds true, and Germany is a valid counterfactual for the Nordic market, then our difference-in-difference estimation will reveal the causal effect of the mispricing. Essentially, if the only difference between the two markets is the mispricing, then any difference in the liquidity changes after the mispricing can be attributed to the mispricing.

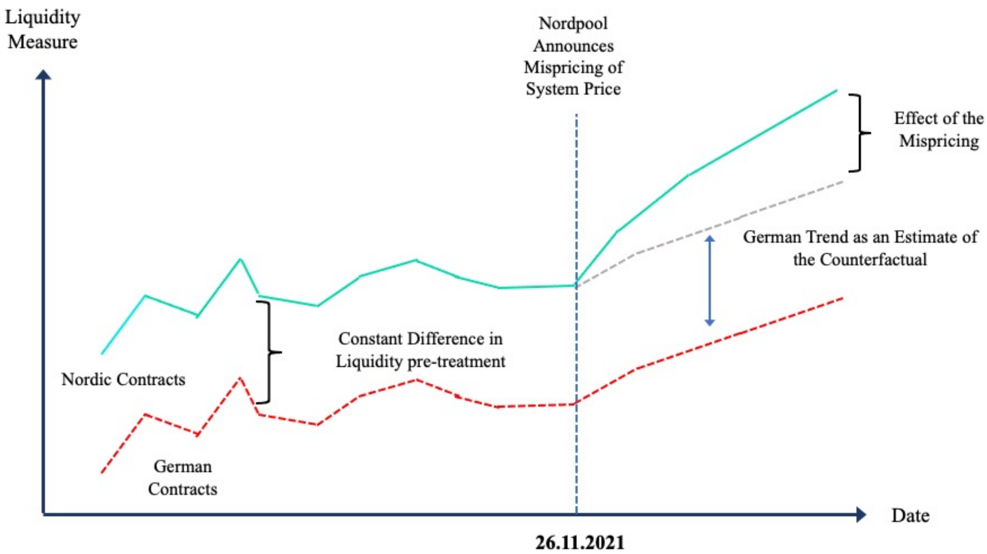

Figure 4.1: Difference-in-Difference Model

Figure 4.1 visualizes the difference-in-difference model. In this example, the trends of the Nordic and German contracts are parallel pre-treatment. After the treatment, or the mispricing, the Nordic contract trend increases while the German contract trend remains unchanged. In the figure, the German trend is plotted as the Nordic counterfactual. The difference-in-difference is the distance between these two.

$$\text{Dif-in-dif estimator} = (\text{y}_{\text{treat,post}} - \text{y}_{\text{treat,pre}}) - (\text{y}_{\text{control,post}} - \text{y}_{\text{control,pre}}) \tag{4.10}$$

To find an estimate of this difference, we regress the different liquidity measures on binary dummy-variables for the treatment group (Nordic) and the period after the mispricing (Post Mispricing), and an interaction term between the two. This interaction multiplies the two dummies and becomes a dummy variable for the observations of the Nordic contracts in the period after the mispricing.

$$\text{Liquidity measure} = \beta_0 + \beta_1 \cdot \text{Nordic} + \beta_2 \cdot \text{Post Mispricing} + \beta_3 \cdot \text{Interaction} + \epsilon \tag{4.11}$$

The β_0 represents the intercept and is the baseline liquidity level in the control group before the treatment. β_1 estimates the main effect of being in the treatment group. β_2 estimates the main effect of the post-treatment period. The difference-in-difference estimator is represented by the β_3. This is an estimation of the effect the treatment had on the treated group. ϵ is the error term, capturing random variation (Fredriksson & Oliveira, 2019).

4.4.1 The Parallel Trends Assumption

The fundamental assumption underpinning the difference-in-difference estimation is parallel trends (Gertler et al., 2016). The parallel trend assumption is crucial because it forms the basis for attributing any observed differences post-treatment to the effect of the treatment itself, rather than to pre-existing trends. In our case, this assumption implies that without the mispricing, the liquidity measures for both Nordic and German contracts would have followed similar trajectories over the period. Consequently, this means they would be influenced by the same factors to the same extent.

In the post-treatment period, we can only observe the liquidity of the Nordic contracts when they were affected by the mispricing. This prevents us from determining what the liquidity measures would have looked like without the mispricing. As a result, the parallel trends assumption remains fundamentally untestable (Fredriksson & Oliveira, 2019). However, we can find support for this assumption's validity by examining data from the period preceding the announcement of the mispricing. Observing a similar pattern between the treatment and control groups in these pre-treatment periods provides reasonable support for the presence of parallel trends (Fredriksson & Oliveira, 2019). An important note on this approach is that while the presence of parallel pre-trends may suggest that the outcomes have parallel trends, it is not sufficient to conclusively confirm this as fact (Borusyak et al., 2023).

Another assumption that must hold is the the 'stable unit treatment value assumption' (SUTVA), which posits that an individual's potential outcome is independent of the treatment status of other individuals (Duflo et al., 2008). In our case, this implies the absence of spillover effects, which would be the case if mispricing caused a shift from the Nordic contract to the German contract. Given the distinct nature of these contracts and the necessity for Nordic power producers and consumers to use Nordic contracts for price hedging, we do not consider this a significant concern for our analysis. However, we acknowledge the possibility that traders dealing in both Nordic and German contracts, if they exist, might increase their positions in the German market while reducing them in the Nordic market. Such behavior would violate the SUTVA assumption, potentially affecting the robustness of our analysis.

Given the inherent untestability of the parallel trends assumption, we will present graphical representations of pre-trends and engage in qualitative discussions regarding this assumption for all liquidity measures in the analysis section of our paper.

5 Results and Analysis

In this section of our thesis, we will present our findings and examine them in the context of economic theory. Utilizing the methods described in the previous section, we will attempt to visualize our findings and provide evidence that the liquidity in the Nordic financial power market was affected by the mistake made by Nord Pool. As discussed, the fundamental assumption at the root of our analysis is that of parallel trends. While we will delve into the comparability of pre-treatment trends as we present our analysis, we'll commence with a qualitative discussion about the validity of using German contracts as a control for the Nordic market. We will then present our findings for the different liquidity measures before discussing the findings and the intuition behind them.

5.1 Germany as a Control

In assessing whether the German financial power market serves as an appropriate control for the Nordic financial power market, it is crucial to examine how liquidity determinants may have diverged between these two markets.

One key aspect to consider is the integration of European power markets, facilitated by interconnectors and the efforts of the Agency for the Cooperation of Energy Regulators (ACER) in integrating the European power market. This integration implies that Germany could serve as a viable control. The Nordic and German markets are subject to similar regulatory changes, as both regions adhere to ACER's guidelines and rules. Our analysis confirms that there were no significant internal regulatory changes in either market during the period under study, reinforcing the suitability of Germany as a control.

5.2 Bid-Ask Spread Analysis

We started our analysis by plotting the bid-ask spread for the two quarterly contracts, rolled from Q1 to Q2 on December 17th, for the entire period. This plot is shown in Figure 5.1. On November 26th, we marked the announcement of the mispricing with a line on the plot.

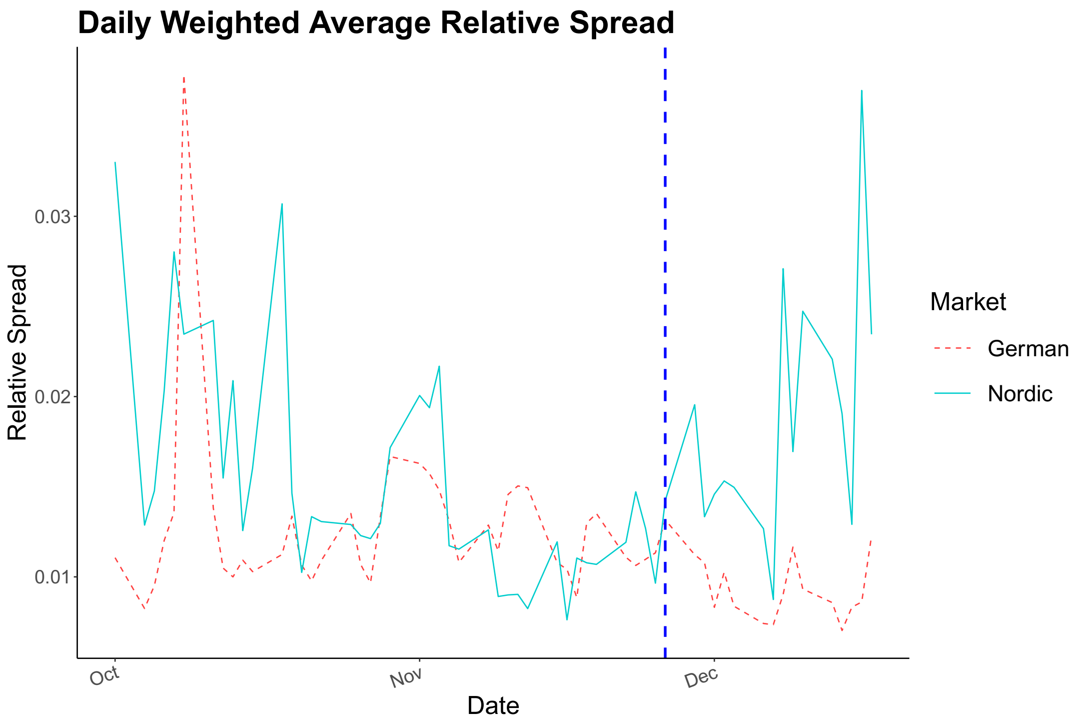

Figure 5.1: Relative spread for the entire period

We conduct our pre-trend analysis visually by examining the graphs. Specifically, we assess pre-trends in the plot to determine if the spread of the two contracts exhibits parallel trends. The plot shows that the spread for the two products is quite similar in the period leading up to the mispricing event.

On October 8th, there was a significant spike in the spread of the German contract, leading to a noticeable divergence between the two products both before and after this spike. Nevertheless, after this period, from mid-October onward, the spread of the contracts seems to converge, with both following a relatively similar trajectory. Although they are not perfectly parallel, there is a consistent alignment in spread trends relative to each other leading up to the announcement of the mispricing. These observations provide confidence in the validity of the parallel trends assumption, supporting a difference-in-difference estimation.

Following the mispricing event, indicated by the dashed line in the plot, a distinct pattern emerges. The spread of the Nordic contract increases rapidly, while the spread of the German contracts remains relatively stable, with a slightly negative trend.

Considering the consistent alignment in spread trends in the period leading up to the mispricing announcement and the subsequent divergence in trends post-mispricing, the plot suggests that the mispricing had an effect on the Nordic bid-ask spread.

5.2.1 Bid-Ask Spread DiD

To further assess this effect, we conducted a difference-in-difference regression analysis on the spread. The regression is shown in equation 5.1 and the output is shown in table 5.1.

$$\text{Relative Bid-Ask Spread} = \beta_0 + \beta_1 \cdot \text{Nordic} + \beta_2 \cdot \text{Post Mispricing} + \beta_3 \cdot \text{Interaction} + \epsilon \quad (5.1)$$

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.0127	0.0008	15.34	0.0000
Nordic	0.0024	0.0012	2.03	0.0446
Post Mis-pricing	-0.0035	0.0016	-2.17	0.0322
Interaction	0.0072	0.0023	3.19	0.0019

Table 5.1: Bid-Ask Spread DiD Entire Period

The difference-in-difference estimator is represented by the coefficient of the interaction term, which has a value of 0.0072 and a p-value of 0.0019. This p-value indicates that in only 0.19% of repeated samples, we would expect to observe a DiD estimator as large or larger if the mispricing actually had no effect. Consequently, we can assert that the coefficient is statistically significant at the 99% significance level.

The coefficient value of 0.0072 suggests that the mispricing event had a statistically significant positive impact on the relative bid-ask spread in the Nordic market. The coefficient implies that the Nordic relative spread increased by an average of 0.0072 units more than the German relative spread as a result of the mispricing event. With a relative spread of approximately 0.01 on the day of the mispricing, this represents a significant increase. Due to the pre-trends not being perfectly parallel, it's important to acknowledge that the coefficient serves as a close estimate rather than an exact measure of the treatment effect. The reason is that there may still be some lingering influence from pre-existing differences between the two markets, which the analysis cannot fully account for. While the coefficient signifies a significant change attributable to the mispricing event, it might not capture all the intricacies of market dynamics.

In an effort to discern the specific impact of mispricing, we conducted regression analyses using shorter time frames. By employing shorter periods, we aim to reduce the influence of extraneous factors and enhance our ability to isolate the effect of the mispricing. Additionally, by using shorter periods, we exclude the early October period when we observed diverging pre-trends. This eliminates any potential bias stemming from non-parallel pre-trends at the beginning of the period.

Table 5.2 displays the results of a regression spanning two weeks before and after the mispricing announcement, while Table 5.3 presents the findings for a regression covering just one week before and after the announcement.

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.0114	0.0010	11.36	0.0000
Nordic	0.0002	0.0014	0.11	0.9143
Post Mis-Pricing	-0.0020	0.0014	-1.42	0.1656
Interaction	0.0073	0.0020	3.63	0.0009

Table 5.2: Bid-Ask Spread DiD two Weeks Before and After

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.0114	0.0008	14.48	0.0000
Nordic	0.0012	0.0011	1.08	0.2982
Post Mis-Pricing	-0.0016	0.0011	-1.48	0.1596
Interaction	0.0046	0.0016	2.89	0.0108

Table 5.3: Bid-Ask Spread DiD one Week Before and After

The tables reveal interesting insights: reducing the period to two weeks before and after yields a lower p-value of 0.0009, whereas the one-week interval before and after results in a slightly higher p-value of 0.0108. Because the effect of the mispricing remains significant when shortening the period, these difference-in-difference estimations provide compelling evidence that the mispricing had a detrimental effect on the bid-ask spread, consequently impacting transaction costs in the Nordic market.

Danielsson and Payne (2001) claims that the majority of empirical work on liquidity measures focuses on the bid-ask spread. Building upon the findings presented, which strongly indicate an increase in bid-ask spreads after the mispricing announcement, we can say with a high degree of certainty that the liquidity in the Nordic financial power market was weakened as a result of the incident at Nord Pool in 2021.

The specific cause behind the reduced liquidity remains uncertain and could be attributed to various factors. We consider the possibility that the mispricing eroded trust in Nord Pool and the system price, prompting market participants to either exit the market or reduce their positions, or require more compensation for being in the market.

If our intuition that market confidence has decreased holds true, we anticipate observing a reduction in trading volume subsequent to the announcement. Consequently, we will examine the trading volume during this period to gather evidence supporting the notion of diminished liquidity.

5.3 Volume Analysis

Just like we did for the relative spread, we started the analysis of executed volume by plotting the volume for the two contracts for the entire period. This plot is shown in Figure 5.2. This reveals that trading volume is consistently higher in the Nordics compared to Germany. In fact, there are numerous days when the German contract records no trading volume at all. Even on days with trading activity, the volume in Germany is significantly lower than in the Nordics. While the plot suggests a downward trend in Nordic volume following the mispricing announcement, there are days post-announcement when the volume surpasses that of the earlier period.

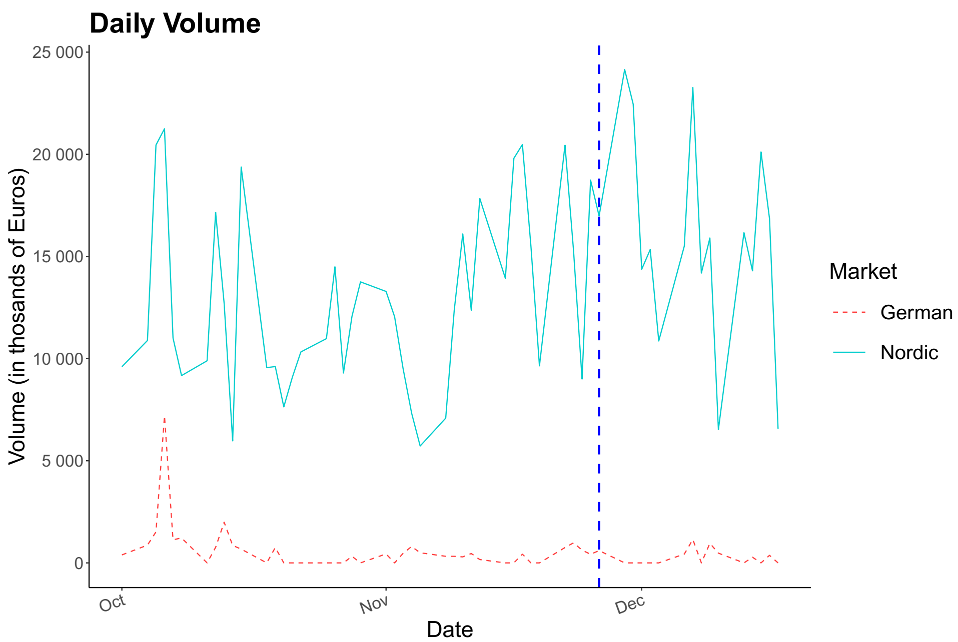

Figure 5.2: Daily Volume over the entire period

The pre-trends for volume, depicted in Figure 5.2, present some challenges in their assessment. Due to the disparities in volume levels between the two contracts and the prevalence of zero values, discerning clear evidence of parallel pre-trends is difficult. While there appear to be occasional spikes that align between the two products, the volume levels are too different to provide any substantial evidence that the pre-trends are parallel.

The low volume of German contracts also leads to other problems in the comparison. The volumes close to zero inherently limit the extent to which they can decrease. This means the same factors causing a significant drop in Nordic volumes might also affect German volumes. However, since German volumes are already minimal, they cannot decrease much further, unlike the Nordic volumes. Therefore, if we observed a substantial decrease in Nordic volumes, the German volumes, constrained by their already low baseline, would not exhibit a similar extent of decline. This potential discrepancy in volume changes between the Nordic and German markets could represent a limitation in the findings of our analysis.

5.3.1 Volume DiD

Despite the absence of clear evidence for parallel pre-trends, we conducted a difference-in-difference regression on the executed volumes to investigate whether the data could have captured any effect from the mispricing if the assumption holds. Equation 5.2 outlines the regression, and the results are presented in table 5.4.

$$\text{Volume} = \beta_0 + \beta_1 \cdot \text{Nordic} + \beta_2 \cdot \text{Post Mispricing} + \beta_3 \cdot \text{Interaction} + \epsilon \tag{5.2}$$

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	616053	527326	1.17	0.2453
Treated	12255053	745751	16.43	0.0000
PostTreatment	-371749	1018889	-0.36	0.7159
Interaction	3270524	1440928	2.27	0.0252

Table 5.4: Volume DiD Entire Period

The difference-in-difference estimator is represented by the interaction coefficient. This indicates that following the mispricing announcement, the daily Nordic volume increased by over three million Euros more than in Germany. The p-value of the coefficient is 0.025.

This indicates significance at the 5% level. However, the comparison between the countries is, as discussed, problematic.

To further isolate the event, we mirror our approach with the bid-ask spread. We run the regression using shorter periods before and after the announcement of the mispricing. With a shorter period, there are less factors that affect the volume, enabling us to isolate the effect of mispricing to a greater extent. Table 5.5 presents the results of a regression spanning two weeks before and after the mispricing announcement, while Table 5.6 displays the results for a regression encompassing just one week before and after the announcement.

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	381069	1109435	0.34	0.7332
Treated	15598950	1568978	9.94	0.0000
PostTreatment	-79518	1568978	-0.05	0.9599
Interaction	356284	2218870	0.16	0.8733

Table 5.5: Volume DiD two Weeks Before and After

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	676788	1601362	0.42	0.6782
Treated	15411680	2264667	6.81	0.0000
PostTreatment	-676788	2264667	-0.30	0.7689
Interaction	2022934	3202723	0.63	0.5365

Table 5.6: Volume DiD one Week Before and After

These regression outputs reveal that the statistical significance of the difference-in-difference estimator diminishes when we restrict the time period. The estimator's value decreases substantially when we narrow it down to two weeks, and the corresponding p-value rises to 0.87. This means that in a large portion of repeated samples, we would expect to observe the increase that we observe even if the mispricing had no effect. When we further limit the analysis to just one week before, and after the mispricing event, the estimator value decreases less, but the high p-value of 0.54 means that there is no conclusive evidence that the mispricing had an effect.

The analysis of executed volume in the period following the announcement fails to provide evidence that the mispricing had an effect on trading volume. The challenges related to near-zero volume levels cast doubt on the reliability of the volume analysis. Given the limitations of the executed volume data, we can explore another measure to assess potential reduced market activity resulting from the mispricing, namely order book depth.

5.4 Order Book Depth

Because of the limited number of orders being executed for the German contract, we want to analyze the depth of the order book. This is motivated by the fact that we have relatively more data on orders being placed in the books rather than those actually executed. Our aim is to utilize order book depth to detect any shifts in market activity following the announcement of the mispricing. A shallower order book due to the mispricing could indicate fewer active market participants, strengthening our theory of reduced trust.

Just like for volume and bid-ask spread, we initiate our examination of order book depth by visualizing its evolution over time. We chart the order book depth for both the best bid and offer levels (BBO), the top two levels, along with the depth for the five best levels. The depth plot for the best bid and offer level is shown in Figure 5.3. Figure 5.4 illustrates the depth for the two best levels, while Figure 5.5 displays the five best levels.

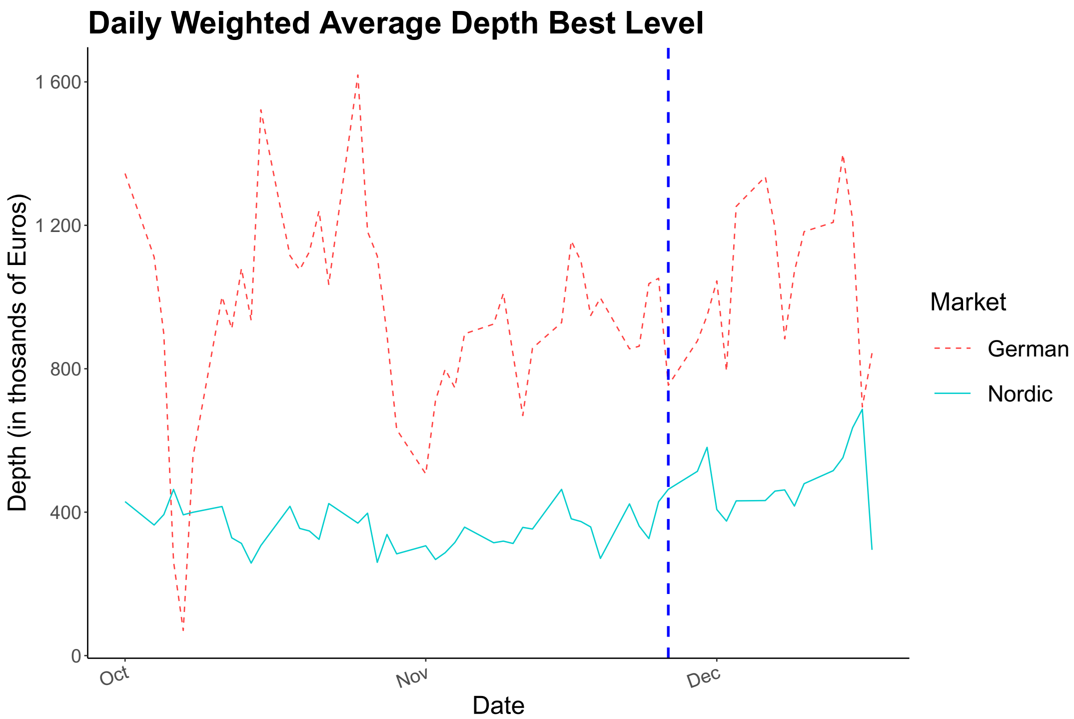

Figure 5.3: BBO Depth

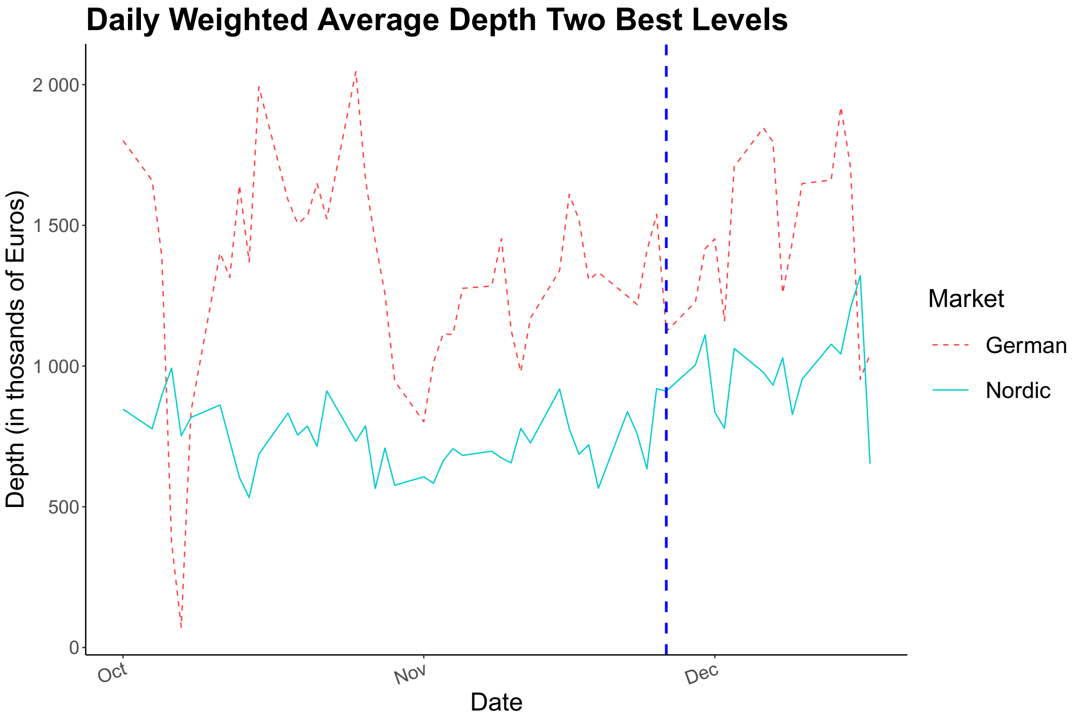

Figure 5.4: Depth Top two Levels

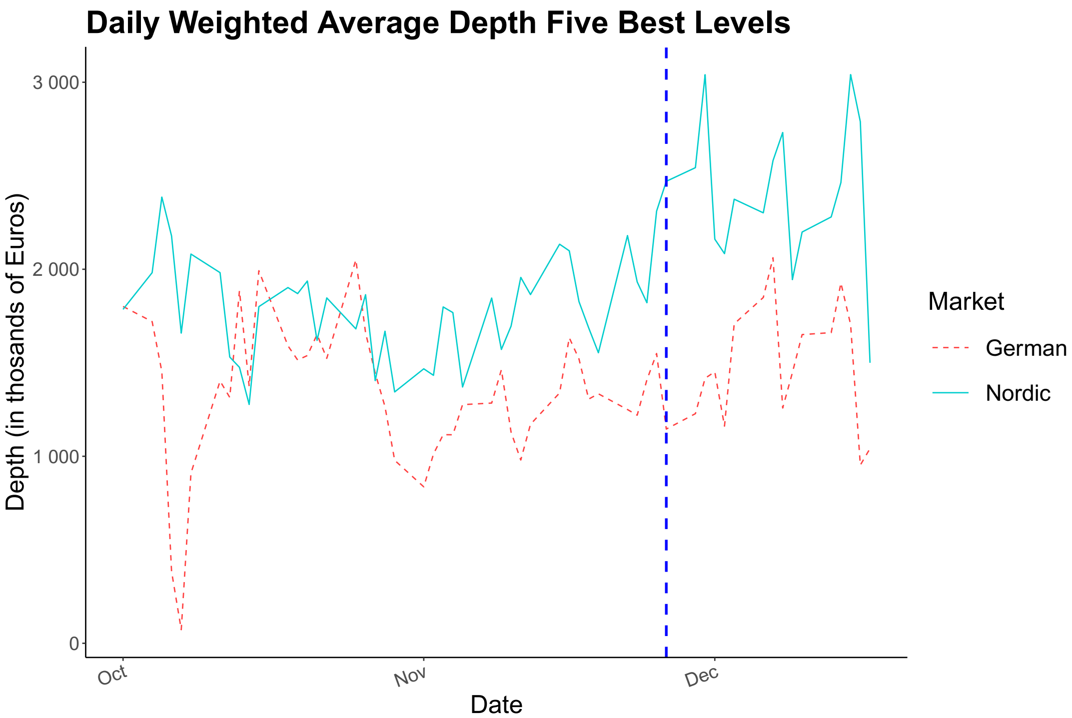

Figure 5.5: Depth Five Best Levels

As outlined in the methodology section, the German order book typically contains no more than two filled levels. This observation becomes apparent in Figure 5.5, where the German depth exhibits minimal variation compared to the plot of the top two levels. Consequently, when analyzing the best five levels, we would, in essence, be comparing the best five levels of the Nordic book to the entirety of the German book. As a result, our analysis will concentrate on the depth of the BBO and the two best levels.

The graphs also highlight a shallow order book for the German contract, as the addition of the second level leads to a notably larger increase in depth for the Nordic contracts compared to the German one. Note that the reason for the substantially lower depth levels compared to volume levels is due to a high number of non-displayable order, which does not provide order book depth.

The pre-trends in both plots do not appear to be parallel, especially when considering the entire period. Similarly to what we observed for the bid-ask spread analysis, the trends diverge at the beginning of the period, and just like the spread trends, they converge to a greater extent by the beginning of November.

5.4.1 Depth DiD

We see no clear difference in post-mispricing trends for either plot. To test this formally, we again run difference-in-difference regressions on the entire period in an attempt to estimate the effect, even with the apparent mismatch in the pre-trends. The regression is shown in equation 5.3. Table 5.7 shows the output of a DiD regression on the best bid and offer level, and table 5.8 shows the output of the top two levels.

$$\text{Depth} = \beta_0 + \beta_1 \cdot \text{Nordic} + \beta_2 \cdot \text{Post Mispricing} + \beta_3 \cdot \text{Interaction} + \epsilon \tag{5.3}$$

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	936039	30814	30.38	0.0000
Treated	-579361	43577	-13.29	0.0000
PostTreatment	126643	59538	2.13	0.0357
Interaction	-417.8	84199	-0.00	0.9960

Table 5.7: Depth BBO DiD Entire Period

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	1316730	41905	31.42	0.0000
Treated	-575870	59263	-9.72	0.0000
PostTreatment	165908	80968	2.05	0.0429
Interaction	80940	114506	0.71	0.4812

Table 5.8: Depth Top two Levels DiD Entire Period

Table 5.7 shows that the mispricing had no statistically significant effect on the BBO depth. The p-value close to 1 gives support to the hypothesis that the mispricing had no effect on the depth of the order book. When we include the second level, the p-value reduces to 0.48. This means that the effect is still not significant, and we find no evidence the depth of the order book is affected by the mispricing.

Due to the non-parallel pre-trends, these difference-in-difference estimations are inherently biased and cannot serve as an indication of either evidence or the lack thereof regarding the mispricing's impact on order book depth. Therefore, we aim to conduct regressions for limited periods to isolate the effect of the mispricing, aligning with our method for examining volume and spread. This approach also helps us circumvent the issues associated with non-parallel trends at the start of the period. The regression outputs for periods limited to two weeks before and after are displayed in Table 5.9 and 5.10. The outputs for regressions limited to one week before and after are shown in Table 5.11 and 5.12.

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	969246	37107	26.12	0.0000
Treated	-584023	52477	-11.13	0.0000
PostTreatment	88896	52477	1.69	0.0989
Interaction	-18274	74213	-0.25	0.8069

Table 5.9: BBO Depth DiD two Weeks Before and After Mispricing

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	1364502	52518	25.98	0.0000
Treated	-591605	74272	-7.97	0.0000
PostTreatment	131385	74272	1.77	0.0854
Interaction	46987	105036	0.45	0.6573

Table 5.10: Top two Best Levels Depth DiD two Weeks Before and After Mispricing

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	912359	53802	16.96	0.0000
Treated	-511659	76088	-6.72	0.0000
PostTreatment	71022	76088	0.93	0.3645
Interaction	-9968	107604	-0.09	0.9273

Table 5.11: BBO Depth DiD one Week Before and After Mispricing

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	1307399	73622	17.76	0.0000
Treated	-495089	104119	-4.76	0.0002
PostTreatment	85862	104119	0.82	0.4217
Interaction	60313	147246	0.41	0.6875

Table 5.12: Top two Best Levels Depth DiD one Week Before and After Mispricing

These outputs show that the effect of the mispricing remains statistically insignificant, both for the best and top two levels. We, therefore, find no evidence that the order book depth was affected by the mispricing.

The comparability between the Nordic and German depth is overall problematic. When calculating the depth at the top two levels, the German depth exceeds that of the Nordic contracts. This indicates that the German order book is deeper than the Nordic one at the top levels. This approach assumes that a shift of more than two levels indicates a significant price movement in both markets. This assumption does not hold, as the Nordic order book usually has more levels. It's possible to take a position in the Nordic contract exceeding two levels and still not make a significant impact on the price. On the other hand, it's not possible to exceed two levels in the German contract. This, in total, indicate that the Nordic order book is deeper than the German one. As in the volume test, more data for the German order book would have made it easier to compare the markets using depth measures.

5.5 Intuition behind Findings

Transaction costs serve as a critical liquidity indicator. Therefore, our findings strongly support the assertion that Nord Pool's error had an adverse impact on liquidity. We can observe a clear and immediate deterioration in the bid-ask spread following the announcement. We argue that such a pronounced and sudden market shock is likely closely linked to issues of trust. Market participants could require higher compensation for providing liquidity due to the increased immediacy- and inventory risk. As mentioned earlier, higher transaction costs decrease the demand for trades and, thereby, the number of market participants (Sarr & Lybek, 2002).

During our discussions with market participants, one individual shared that their trust in the system price as a reliable reference remained unchanged after the event. They expressed confidence that the error in the system price was an isolated incident and did not raise concerns about its recurrence. According to their perspective, the mispricing, on its own, did not significantly impact liquidity. However, they suggested that the Nord Pool mispricing may have been "the straw that broke the camel's back" for certain investors. What they meant by this was that the system price had already been a suboptimal reference point, and market participants had been exploring alternative hedging options to the financial power market at NASDAQ.

On the other hand, figures like Andreas Thon Aasheim, commercial director of Cloudberry, and Tor Reier Lilleholt from Volue Insight expressed reservations regarding Nord Pool's reliability in the aftermath of the incident. They contended that this event eroded trust and confidence in Nord Pool's operations (Barstad, 2021). Our research suggests that the mispricing, either by itself or as a final blow, may indeed have had such an effect, at least in the short term.

Because trust issues could be proved by decreased market activity or number of active participants, evidence of the mispricing's impact on market volume and depth would have further bolstered this hypothesis. Our data did, however, not reveal such effects. We, therefore, can not conclusively argue that the mistake led to decreased trust. Nevertheless, we consider this argument compelling, and it emerges as the predominant narrative in our findings. In the period after the event, Nord Pool's trust was challenged by the media. A mispricing, in its nature, is something that could affect trust. When we observe decreased liquidity through the transaction cost, we find trust to be the most rational intuition behind the result.

5.6 Limitations

The depth- and volume measures limit our analysis. These tests do not give conclusive evidence of decreased volume and depth. If they did, we could have concluded with a high degree of certainty that trust issues led to a decrease in market activity, further influencing the liquidity.

There are substantial disparities in general liquidity between the Nordic and German financial power markets at Nasdaq. We observe a significantly higher volume of executed trades in the Nordic market, and the Nordic order book generally exhibits greater depth. This results in inconclusive findings regarding the market activity in the period.

With access to additional data, or the utilization of an alternative control group, we might have been able to provide a more comprehensive and nuanced assessment of the impact of mispricing on liquidity. One potential avenue is to access data on volume and depth for the German market from other exchanges, like for example the European Energy Exchange (EEX).

Another limitation of our analysis is that it is based on the assumption of parallel trends. Because we can not observe the counterfactual, we can not prove that the German market is a valid control. Our analysis of the pre-trends can give support to the validity of the assumption, but not prove that it holds. A violation of the parallel trend assumption would invalidate our analysis.

6 Conclusion

In this thesis, we have measured the liquidity changes in the Nordic financial power market as a result of Nord Pool's mispricing of the system price. The system price is used in the settlement of derivative contracts, and is therefore of crucial significance for the financial power market. Our analysis, grounded in reconstructed order books, has unveiled compelling evidence that transaction costs in the Nordic markets witnessed an increase after the mispricing. This is evident from an increase in the bid-ask spread following the announcement. Our data indicates a significantly larger increase in the spread trend for the Nordic contract compared to the German one on the day the mispricing was announced. We propose that Germany is a suitable control, providing a reliable estimate of the Nordic counterfactual. Our examination of the pre-event trends in Nordic and German bid-ask spread shows that they are sufficiently similar to conclude that the shock observed on the day of the mispricing was significant. Given the importance of transaction costs in the measuring of liquidity, we argue that the increased bid-ask spread proves that liquidity was reduced immediately following the announcement of the mispricing.

The increase in transaction costs can be attributed to various factors, but we argue that the costs are increased due to market participants seeking higher compensation because of decreased trust. In conversations with active market participants during the mispricing, we were told that they believed the mispricing itself did not deter investors from hedging at Nasdaq. They posed that instead, maybe some market participants saw this as the final blow in an already dysfunctional market. In this case, investors who were already considering alternatives to hedging at Nasdaq made the switch when the mispricing was announced. This is in line with our findings of increased transaction costs.

Our investigation of volume and order book depth did however not definitively demonstrate a decrease in market activity. While there are some indications of a downward trend in volume post-announcement, the limited data on executed trades for German contracts prevents definitive conclusions. Conclusive evidence of a decrease in trading volume and order book depth could have further supported the notion of diminished liquidity. However, we contend that the rise in transaction costs alone is adequate to demonstrate a reduction in liquidity.

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Appendices

A Order Book Snapshot

Date	Timestamp	Bid price 1	Bid volume 1	Ask price 1	Ask volume 1	Bid price 2	Bid volume 2	Ask price 2	Ask volume 2
2021-10-01	06:00:01.801655000			6755.00	7000.00				
2021-10-01	06:02:46.263168400	5800.00	1000.00	6755.00	7000.00				
2021-10-01	06:05:09.003965500			6755.00	7000.00				
2021-10-01	06:05:09.003965500	5800.00	50000.00	6755.00	7000.00				
2021-10-01	06:05:14.387562200			6755.00	7000.00				
2021-10-01	06:05:36.475457000	5500.00	1000.00	6755.00	7000.00				
2021-10-01	06:06:11.388469300	5600.00	3000.00	6755.00	7000.00	5500.00	1000.00		
2021-10-01	06:06:50.062067600	5600.00	3000.00	6755.00	7000.00				
2021-10-01	06:06:50.062067600	5600.00	4000.00	6755.00	7000.00				
2021-10-01	06:10:06.157058100	5700.00	1000.00	6755.00	7000.00	5600.00	4000.00		
2021-10-01	06:22:49.066001800	5800.00	2000.00	6755.00	7000.00	5700.00	1000.00		
2021-10-01	06:27:58.470092700	5900.00	1000.00	6755.00	7000.00	5800.00	2000.00		
2021-10-01	06:28:32.911697400	6000.00	5000.00	6755.00	7000.00	5900.00	1000.00		
2021-10-01	06:31:25.075368000	5900.00	1000.00	6755.00	7000.00	5800.00	2000.00		
2021-10-01	06:32:03.639900700	5900.00	1000.00	6755.00	7000.00	5800.00	2000.00		
2021-10-01	06:32:03.639900700	5900.00	1000.00	6755.00	7000.00	5800.00	5000.00		
2021-10-01	06:36:19.874099800	5900.00	1000.00	6755.00	7000.00	5800.00	2000.00		
2021-10-01	06:36:19.874099800	5900.00	4000.00	6755.00	7000.00	5800.00	2000.00		
2021-10-01	06:46:09.979942100	6000.00	1000.00	6755.00	7000.00	5900.00	4000.00		
2021-10-01	06:49:36.852461000	6000.00	1000.00	6755.00	7000.00	5900.00	4000.00		
2021-10-01	06:50:09.287431500	6000.00	1000.00	6755.00	7000.00	5900.00	4000.00		
2021-10-01	06:50:09.287431500	6000.00	1000.00	6755.00	7000.00	5900.00	4000.00		
2021-10-01	06:50:27.373727800	6000.00	1000.00	6755.00	7000.00	5900.00	4000.00		
2021-10-01	06:50:27.373727800	6000.00	1000.00	6755.00	7000.00	5900.00	4000.00		
2021-10-01	06:50:32.266683900	6000.00	1000.00	6755.00	7000.00	5900.00	4000.00		
2021-10-01	06:51:31.412625500	6000.00	1000.00	6700.00	5000.00	5900.00	4000.00	6755.00	7000.00
2021-10-01	06:51:52.986236900	6000.00	1000.00	6650.00	1000.00	5900.00	4000.00	6700.00	5000.00
2021-10-01	06:57:16.696273300	6000.00	2000.00	6650.00	1000.00	5900.00	4000.00	6700.00	5000.00
2021-10-01	07:00:17.090358600	6000.00	3000.00	6650.00	1000.00	5900.00	4000.00	6700.00	5000.00
2021-10-01	07:00:24.654859800	6000.00	3000.00	6700.00	5000.00	5900.00	4000.00	6755.00	7000.00

Figure A.1: The top two levels of the first 30 rows in the Nordic orderbook