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An analysis of bidding strategies in the Danish wind power market

En analyse av strategisk budgivning i det danske vindkraftmarkedet

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I want to dedicate this work to my mother.

She has been my strength and my biggest encouragement.

Preface

This Master thesis is a final project towards my Master's degree in Business and Administration at the Norwegian University of Life Sciences. The topic of this thesis is selected in accordance to my major programme, Energy economics.

I want to sincerely thank my supervisor Olvar Bergland for his guidance. His advice and support has been very helpful to me, and he has been available for me during the whole process and considered all my questions.

I want to mention my family and my fiancé Farid Esam and thank them for their continuous support. I also want to thank my friend at the university, Senyonga Livingstone for all the meaningful discussions during the process.

Ås, 15th May 2014

Nabeela Qureshi

Summary

In 2013 the wind turbines in Denmark accounted for approximately 30 % of Denmark's total electricity supply (Jensen and Sørensen 2014). The 2020 goal necessitates wind supply increase from 30% to 50 % (Lentz and Strandmark 2014). The expansion of the wind power sector raises several questions regarding its strategic effect on the spot and the regulation market. The suspicion is that increased amount of wind power will trigger systematic use of the regulation market. The area of focus is West-Denmark and the problem for discussion is stated in this manner: *How does deviation between predicted production and actual production of wind-power in West-Denmark affect the bidding in the spot market*?

The interest is to use the regulation market and wind prognosis to find the deviations between the supply bids made to the spot market, and actual delivery. The bids made to Nord Pool are confidential. The analysis is done without this information. Two hypotheses are formulated in order to answer the problem of discussion, and two models are developed in order to test these hypotheses Model 1 and Model 2.

In Model 1 the effects of up and down regulation are tested on price for balancing regulation. The goal in this model is to reveal the relationship between up and down-regulation price to check for asymmetries in the regulation market. In Model 2 wind power production is tested, as an exogenous predictor of total regulation. The data used to test Model 1 and Model 2 is downloaded from energinet.dk, except the data on wind prognosis. The data on wind prognosis is downloaded from Nord Pool´s website. The data downloaded is from 01.01.2012 to 31.12.2013. The estimation strategy in Model 1 is the use of OLS, and the estimation strategy in Model 2 is based on regression analysis with possible measurement error, where wind prognosis is used as an instrumental variable. The findings in Model 1 suggest that there is difference in price for up-and down regulation, and that the use of the regulation market is slightly asymmetric.

The findings in Model 2 rejected the second hypothesis, and wind power production is an endogenous predictor of total regulation. The deviation between planned and actual production of wind power can be used as an incentive to place the supply bids strategically on the spot market, to obtain a better price in the regulation market.

Significant measurement error in Model 2 can be regarded as indirect evidence of systematic action.

Sammendrag

I 2013 stod vindkraftsektoren for 30 % av den totale kraftproduksjonen i Danmark, (Jensen og Sørensen 2014). Et mål for år 2020 er en økning fra 30% til 50% (Lentz og Strandmark 2014). Den planlagte utvidelsen av vindkraftsektoren reiser flere spørsmål rund strategisk budgivningsadferd i spot og kraftreguleringsmarkedet. Det mistenkes at ved økt vindkraft i kraftsystemet vil det utløse systematisk bruk kraftreguleringsmarkedet. Denne analysen begrenser seg til Vest-Danmark og problemstillingen er formulert som følgende: *Hvordan vil et avvik mellom planlagt og faktisk produksjon av vindkraft i Vest-Danmark påvirke budgivning i spotmarkedet?*

Hovedmålet er å bruke reguleringskraftmarkedet og vindprognose for å finne avvik mellom bud i spot markedet og faktisk levert produksjon. Budgivningen i Nord Pool regnes som konfidensiell og problemstillingen besvares uten denne informasjonen. For å besvare problemstillingen er det i hovedsak formulert to hypoteser, og hypotesene ble testet basert på to modeller, modell 1 og modell 2.

I modell 1 blir effekten av opp -og nedregulering testet mot prisen i kraftreguleringsmarkedet. Målet er å klargjøre forholdet mellom opp –og nedreguleringsprisen for å gjennomskue potensielle asymmetrier i kraftreguleringsmarkedet. I modell 2 blir vindkraftproduksjon testet som en eksogen variabel til å predikere den totale reguleringen i kraftreguleringsmarkedet. Begge modellene er basert på data som er hentet fra energinet.dk, bortsett fra data for vindprognose, som er hetet fra hjemmesiden til Nord Pool. Dataen gjelder fra 01.01.2012 til 31.12.2013. OLS metoden ble brukt til å estimere modell 1. Estimerings strategien til modell 2 faller under 2SLS der vindprognosen ble brukt som en instrumentell variabel. Modell 2 ble testet for systematiske målefeil.

Hovedfunnene i modell 1 indikerer en prisforskjell mellom opp -og nedregulering. I tillegg er det hint av asymmetrier når det kommer til bruken av kraftreguleringsmarkedet. Funnene i modell 2 indikerer at vindkraftproduksjon er en endogen variabel i sammenheng med total regulering. Avviket mellom planlagt og virkelig produksjon av vindkraft kan brukes som et insentiv systematisk vis anlegge bud på spotmarkedet. Betydelig målefeil i Modell 2 kan anses som indirekte bevis på systematisk handling for å få en bedre pris i reguleringskraftmarkedet.

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1 Introduction

An analysis of bidding strategies in the Danish power market

"This asymmetric cost may encourage bidders with fluctuating production to be more strategic in their way of bidding on the spot market. By using such strategies the extra costs for e.g. wind power needed to counter unpredictable fluctuations may be limited"
(Skytte 1999)

How does deviation between predicted production and actual production of wind-power in West-Denmark affect the bidding in the spot market?

1.1 Background

This thesis is inspired by the quote presented above, taken from Klaus Skytte's article "*The regulating power market on the Nordic power exchange, Nord Pool*" published in 1999. His research and findings suggest that the cost of using the regulation power market is dependent on the spot price level at the Nordic power exchange. He discovered that the regulation cost was more correlated to the spot price in an event of down-regulation, compared an event of up-regulation. With expected fluctuation of supply and demand, the actor in the market is able to jointly optimize his total bids at the spot market and in the regulation market (Skytte 1999). His research targeted Norwegian hydropower producers.

Skytte's article was written before Denmark joined the Nordic power exchange, Nord Pool, in year 2000 (NordPool 2013). Today Denmark's wind power production covers 30 % of the country´s energy production. An analysis of the current effects of the wind power supply bids submitted in Nord Pool may provide insights that can determine the hidden cost or as Skytte described, strategic bidding behaviour related to fluctuating power supply. Within year 2020 wind energy production is planned to increase, and will account for 50 % of the total energy production in Denmark (Danish Wind Industry Association 2014). According to these plans the amount of wind power in the system will increase. A research on wind power production in West-Denmark and up- regulation was published in 2007, the article concluded the relation as significant (Forbes et al. 2007). By using updated data from 2012-2013 and modified version of the model discussed in Skytte's article the goal of this thesis is to detect any indication of strategic behaviour in the Danish wind power market, by analysing the bidding strategies related to wind power supply. The bidding area of interest is West-Denmark, and their use of regulation services.

It seems like that the suspicion of strategic behaviour lies in the bidding behaviour of the wind power producers. The suspicion is that they systematically bid less wind power supply than the predicted amount, and then use the regulation market to down regulate the excess supply. If asymmetries are found in the regulation market, further analysis of this thesis will test the regression model for systematic measurement error. Whether systematic behaviour is an economic burden or has any spillover effects on other actors in the market will depend on the magnitude of the problem, and is not discussed in this thesis. This thesis will focus on indirect evidence of strategic behaviour in the bidding area of West-Denmark.

1.2 Problem for discussion

How does deviation between predicted production and actual production of wind-power in West-Denmark affect the bidding in the spot market?

The interest here is to use the regulation market and the wind prognosis to find the deviations between supply bids made at the spot market, and actual delivery. There is no official data on the bids submitted into Nord Pool, as the data is confidential. Therefore problem stated will be answered without using this data, and the problem for discussion will be answered based on these hypotheses:

Hypothesis one: There is no systematic relationship between regulation price, and up or down- regulation.

The alternative hypothesis is that there is a systematic relationship between regulation price and up or down-regulation.

Hypothesis two: Wind power production is an exogenous predictor of total regulation

The alternative hypothesis will reject hypothesis two and state that wind power production is endogenous and measured with error.

1.3 Structure

The first chapter of this thesis reveals the problem for discussion and the related hypotheses to be tested. The second chapter provide an overview of Nord Pool, earlier research on strategic behaviour in the power market, and the Danish bidding areas. In the third chapter, the two models behind the analysis are introduced with the relevant indication of the theory behind them. The data and variables used in the analysis of the models are given in chapter four. In chapter five the estimation, strategy and the analysis structure are given. The results are specified and discussed in chapter six before concluding remarks in the final chapter.

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2 Nord Pool and strategic behaviour

This chapter is divided into four sections. Firstly the conceptual framework behind the Nordic electricity market is presented. Secondly the Danish power market, bidding areas and their future investment plans is discussed in the second part. In the third part of this chapter, the earlier research on strategic behaviour is discussed before a brief chapter summary is provided.

2.1 The Nordic electricity exchange

Nord Pool is the Nordic electricity exchange with member countries Denmark, Norway Sweden, Finland, Estonia, and Lithuania. Electricity Producers, retailers, traders, and large end users meet in the Nord Pool spot exchange to trade electricity. The producers need to pay a fee to the grid owner for each kWh they pour into the grid, and the consumers need to pay a fee for each kWh they draw from the grid. This is known as the point tariff system. This system is relevant for understanding the key balance between production and consumption in the system every hour (Nord Pool 2014a).

Each hour somewhere in the system the producer has to produce a certain amount of electricity to the grid, and that same amount has to be consumed by the retailer´s customers. Electricity grids transport the power, and for each local grid, there is a local grid operator who handles the local low voltage grid. The TSO owns and operates the high voltage grid for the respective country. Because the TSO own and operates the grid, it is solely responsible for the assurance of supply in the country they are operating. The Danish TSO is Energinet.dk, and it is a state-owned grid-company for both gas and electricity (Nord Pool 2014a).

2.1.1 Elspot

Electrical power in Nord pool is traded in a day-ahead auction market, Elspot. At noon, the day before all supply and demand bids are cleared and transported to the grid. Both producers and consumers meet in this market. At Nord Pool Spot in Oslo all the bids are received electronically from market actors. (Nord Pool 2014a).

On an hourly basis the market price is given as the intersection between the aggregated supply and demand curves. Price calculation is done and published by Nord Pool Spot. This price is regarded as the system price, a theoretical price without any bottlenecks in the system. The published information is then used by the TSO in the Nord Pool Spot area to calculate the balancing power for producers and consumers. Both buyers and sellers have to pay a trading fee to the market (Nord Pool 2014a).

In a competitive market a producer´s profit maximising outcome when price is equal to marginal cost. Wind power producers have a marginal cost very close to zero if costs of maintenance are not considered. Wind power is produced when the market price is positive because the producers produce the amount above or equal to marginal cost of production. In theory this is the structure of the supply bid for wind power producers. Marginal cost of thermo-based power plants is not equal to zero and they have different marginal cost at different capacities. This is how their bidding structure of production differentiates from wind power producers (Nord Pool 2014b).

2.1.2 Imbalance in the power market

In the wholesale electricity market the process balancing the power at every hour depends on all of the actors in the market. The TSO must ensure a balance between producers and consumers. The storage possibilities with electricity are limited and in addition, it is challenging to forecast the exact amount for production and consumption. A producer must commit to the contract it has signed with the consumer. For example if a producer has a contract of providing 100 MWh, and is only able to provide 90 MWh, the producer trades with the TSO for the remaining 10 MWh, because the aim for the TSO is to always restore a balance between the production and consumption (Nord Pool 2014a).

The imbalance in the power market is regulated by the TSO. Imbalance occurs when consumption exceeds generation or generation exceeds consumption. To obtain a stable frequency in the transmission grid, for instance if the stable frequency amount is 50 Hz, the TSO has to make sure that the producers alter their production to obtain this level. When the frequency in the system falls below 50 Hz, one or more producers will be asked to produce more power to the grid, in other words TSO is regulating up the power supply. The TSO regulate down when frequency exceed 50 Hz. To keep the frequency at 50 Hz, the TSO has to trade the electricity in the market, and that electricity is called regulated power. The power orders submitted into TSO under up or down regulation periods are ranked by increasing price (Nord Pool 2014a).

2.1.3 Regulation market

Producers of fluctuating power make offers on the daily spot market in such way that they can combine their production offers at the same price as generators of conventional power sources. If the producers deviate from the commitment made to the daily spot market in that exact moment for actual delivery, the producers will face an extra cost. The extra cost is linked to the regulation expenses related to maintain the balance between demand and supply in the spot market (Skytte 1999).

The regulating power market controls the entries that deviate from the power balance in the market. This market closes two hours before the actual trade. When it is only 15 minutes until market closure, the clearing is settled in the regulation market. When buyers increase their purchases by buying of the excess supply, or when suppliers buy the excess supply to increase their own supply, the actual payments of these transactions are made to the regulating market. The payment is based on the balancing price for regulating power. The spot market takes payment for all the commitments made to the spot market so therefore limited attention is paid to the actual trade by the spot market (Skytte 1999). There is a fee for using the regulation market called premium of readiness, and in addition, a fee is paid to the spot market if the producer fails to keep the promises made to the spot market, i.e. the bidding amount (Skytte 1999).

2.1.4 Implicit auctions and trade

When surplus and deficit of power occurs across the bidding areas, implicit auctions takes place to obtain the welfare maximizing solution. There will be a price difference between the surplus and deficit bidding areas. In theory, both areas are dependent on trade, and by trading power the welfare-maximizing price will be obtained. Without trade, the area with surplus will have a low price and the area with deficit will have a high price. Trade is only possible if there is available transmission capacity in the transmission grid (Nord Pool 2014a).

Without transmission capacity, a price difference will occur due to the power imbalance. When transmission capacity is available, implicit auctions are used to balance the price differences. The price might not be the same, but with the electricity trade through the implicit auction, the price difference will be reduced. If power trade was to happen cross-border between two exchange areas due to bottlenecks in the system, both parties must give their bid to a central organ to calculate the price. This is known as market coupling and this happens between the Nordic, Central Western European and German exchange areas (Nord Pool 2014a).

2.1.5 Electricity contracts in the financial market

There are several rules and regulations regarding trade of power in the exchange areas. The players must be located in the same bidding area in order to trade electricity with each other. Any trade across bidding areas is handled solely by Nord Pool Spot. Through the financial electricity market, the players in different bidding areas have the opportunity to trade with each other. The settlement is then regulated by a financial contract (Nord Pool 2014a).

A futures contract in the financial market regulates price and volume during the delivery period. The average system price for the delivery period is compared to the hedge price of the contract. If there is a deviation in price, that price difference times the volume is the money amount transferred between the parties. In futures contracts the retailer compensates the producer if the price is lower than the contract-regulated price, and the producer compensates the retailer if the price is higher. Financial contracts regard only money and no actual power is transferred between the parties (Nord Pool 2014a).

2.2 Wind power and Danish bidding areas

West Denmark (Jylland and Fyn) and East Denmark (Skjælland) are the two bidding areas where the electrical system is divided in Denmark. West Denmark is interconnected with East Denmark, Norway, Sweden and Germany (Energinett.DK 2014). The boundaries and number of bidding areas are decided by the TSO. This trade that occurs between the bidding areas, the orders must be submitted to Nord Pool Spot. (Nord Pool 2014a).

In 2013, the wind turbines in Denmark accounted for approximately 30 %, (94466/GWh) of Denmark's total electricity supply (Jensen & Sørensen 2014). In December 2013 the installed wind capacity was 4569 MW, and offshore wind power with a capacity of 517 MW. The total number wind turbines in Denmark in December 2013 were 5176. The 2020 goal necessitates wind supply increase from 30% to 50 % (Lentz & Strandmark 2014). Figure 1 gives an overview of the growth of renewable energy from year 1990 to 2012.

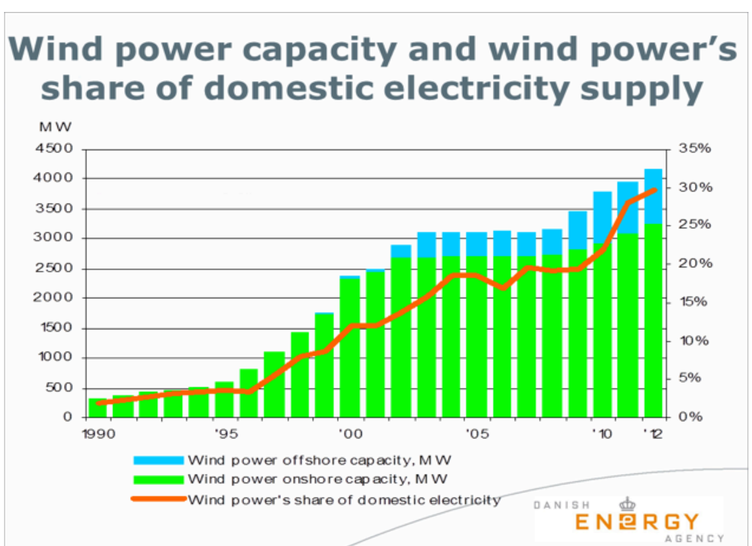

Figure 1: Wind power capacity and wind-power's share of domestic supply (Jensen & Sørensen 20014).

2.2.1 Future investments

As earlier indicated, the Danish government has an ambition of expanding the renewable energy to account for half of the country´s energy demand. There might be some obstacles related to the plan. The necessary storage capacity needs to be developed to avoid negative price periods and other complications. There are required technology related investments that will be able to handle the intermittency and volatility when being dependent of renewable resources (Kanter 2012). In addition, large investments are required to expand the offshore wind –power compared to onshore energy sources. Improved weather forecasting is relevant in order to anticipate the power production (Kanter 2012). Investments related to the improvement could also affect the price due to increased cost.

2.3 Bidding and strategies

Detecting and classifying what is regarded strategic behaviour is not a straightforward task. Every commodity market behaves differently, and each markets has its own rules and regulation methods. Some findings from the Dutch and German market are given in this section. The article by Klaus Skytte (Skytte 1999) is used to create the first model in the analysis to detect any strategic- like behaviour. His findings will be highlighted in this chapter, and his main analysis will create the base of Model 1 in chapter three.

2.3.1 Market power

Earlier research provides insight in strategic bidding models to identify gaming behaviour (Dr. Petrov et al. 2003). This research paper focuses on the German and the Dutch power market. When bidding at marginal cost, the bidding is regarded perfectly competitive. The marginal cost in the competitive market is an aggregation of the marginal cost curves of all participants in the market. The strategies were different in each market, and as a result, the impacts of strategic behaviour were different. Taken the level of market share of the company in consideration, two factors indicate to what extent strategic behaviour can be profitable. First, it depends on how sensitive the market demand is to price, and second how sensitive the firm is to a price change due to the supply of other companies in the market. This can be narrowed down to two common strategies, capacity withdrawal and mark-up pricing (Dr. Petrov et al. 2003).

In the Netherlands, the capacity from major power plants was withdrawn during peak demand and price increased excessively. To be precise the price could be up to several hundred Euros per MWh. Another significant finding in that market was that mark-ups only increase with increased market demand. The sudden rise of mark-ups was linked to substantial market power for some actors. The main result in the article was that there exists a possibility of exercising market power both in the Dutch and German power market (Dr. Petrov et al. 2003).

2.3.2 The regulating power market on the Nordic power exchange

Klaus Skytte's work is the inspiration behind the analysis in this thesis. All of the information and arguments below is meant as a summary of his work. The link between the spot market and the regulation market is explained in detail. The theory behind model 1 in chapter 3.1 is collected from this article, and is based on the same assumptions.

The fluctuations in price between the markets are of interest to traders on the spot market and suppliers of regulation services. Wind-power producers may in general face more uncertainty in their production compared to hydropower producers. Hydropower producers have higher storage facilities and a more predictable production compared to wind power producers. When a wind power producer announces its production on the spot market, the producer is unaware if the variations related to the actual wind power delivery, (Skytte 1999).

The main focus in the article is to find the relationship between the price on the spot market and the price in the regulation market. This relationship might be of interest to traders on the spot market who have fluctuating demand or supply, for example wind power generation and suppliers of regulation services (Skytte 1999).

The uncertainty of the actual delivery of power may encourage the producer to pursue joint optimization both in the spot market and the regulation market. The idea is to increase the revenues from the sales on the spot market, and minimize the costs faced in the regulation market. The producer will increase total revenue by looking at both markets at the same time and by considering the revenue on the spot market against the cost of using the regulation market. As a result, of this mind-set, the producers place a bid on the spot market in order to maximize total profit from at power exchange (Skytte 1999).

Another idea introduced in the article was that partial optimization is pursued when the producers will seek to maximize the revenues from sales on the spot market, and minimize the use of regulation services. Revenues are maximized based at the announcement on the spot market. According to the article, the optimal announcement at the spot market is given by a linear relationship between the price level and the expected delivery at the spot market. The cost associated with the use of regulating services for an actor is a quadratic function of the amount of regulation (Skytte 1999).

The article describes the asymmetric cost as an encouragement to producer with fluctuating production to be more strategic in the way they place their bids on the spot market. The price difference between the spot and regulated power market is of interest to wind power producers. When the producers use this price difference in order to maximize their revenues, the bids they place are strategically put to preserve their interests. Further, it is assumed that the power firms do not have any market power and they act like price takers on the spot market (Skytte 1999).

Skytte's conclusion is that the premium of readiness for down-regulation was strongly influenced by the level of the spot price, while up-regulation was less correlated to the spot price. When it comes to regulation amount, it affects the price of up -regulation more than for down- regulation (Skytte 1999).

2.4 Summary

This chapter provides understanding of how Nord Pool operates and works as a power exchange. The background behind the problem of discussion is given in this chapter to make it easier to understand the challenging task of market balance at every hour, and how this provides scopes for deviations. It is important to distinguish between the responsibilities of the spot market compared to the responsibilities of the regulation market. This will benefit the understanding of the models given chapter in three. This background material will help specify the relevance of the results from the analysis.

Current and future investment plans for wind power production in Denmark is introduced in this chapter to evaluate how relevant this problem for discussion is in the future.

Earlier research on strategic behaviour in the electricity market is useful when understanding the impact of such behaviour and it is also a useful reference point for future research. In this case, earlier research in particular done by Klaus Skytte is used to form the first part of the next chapter.

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3 Theory and Model

Two models are introduced in this chapter, and this is a short-run analysis. The results and findings in Model 1 creates the basis for Model 2 and when combined both models are used to answer the questions raised earlier. The analysis is emphasised on the supply side of the market while the demand side is given by the deviations in providing the contracted supply to the spot market. This deviation is given by the amount of total regulation in the analysis.

3.1 Balance equation

The equations represented below are based on theoretical assumptions and in equation (1) W_t^P represents the planned wind power production at time t, and the assumption here is that this is equal to the wind power supply bid made into Nord Pool W_t^B. In addition to the bid, the strategic element W_t^S is added to the equation. If no sign of strategic element exists, then in the equation, W_t^S is 0. The important point here is that this equation describes what happens 12 hour before the actual delivery of power, i.e. when the spot market is cleared at noon.

$$W_t^P = W_t^B + W_t^S \tag{1}$$

Actual delivery is given by W_t^{AC} and the error term ε_t^W, is added to the equation (2). This error term is related to actual wind power production. This equation represents the period when actual delivery takes place 12 hours after the bids are cleared, and continues for the next 36 hours (Nord Pool 2014a).

$$W_t^{AC} = W_t^B + W_t^S + \varepsilon_t^{Wind} \tag{2}$$

Equation (3) represents the planned market balance equation. In this equation the energy demand, D_t^P, and net exports X_t^P, is equal to total energy production and wind power production. The subscript P indicates that all variables in the equation are not the actual production delivery, but the planned supply and demand of the power delivery.

The variable W_t^P is taken out of the total production variable because it is relevant for the upcoming analysis. The planned market balance equation is given as:

$$D_t^P + X_t^P = Q_t^P + W_t^P \tag{3}$$

In equation (4) the subscript *AC* stands for actual, and this equation represents when actual demand of power is equal to actual supply. Equation (4) represents the actual values from equation (3). The actual market balance equation is given as:

$$D_t^{AC} + X_t^{AC} = Q_t^{AC} + W_t^{AC} \tag{4}$$

The data on the energy supply and demand bids made into Nord pool is not available. Therefore there is no direct way of proving that equation (1) and (2) hold at time t. The equations above will be used as a part of a model to detect any systematic behaviour in the market. The main idea is to see if eq. (4) deviates from the planned amount in eq. (3). In specific the variable of interest in these equations are W_t^P and W_t^{AC}. The two upcoming models will be used to analyse the effects of deviations between these two variables and their effect.

3.1.1 Model 1

The first part of the analysis is based on an analysis developed by Klaus Skytte (Skytte 1999), where he uses the following hypothetical relationship to analyse the regulation market price:

$$\begin{aligned} PR(P_t, S_t, D_t) = \emptyset P_t &+ 1_{[S_t < D_t]}[\lambda P_t + \mu(S_t - D_t) + \eta] \\ &+ 1_{[S_t > D_t]}[\alpha P_t + \gamma(S_t - D_t) + \beta] \end{aligned} \tag{5}$$

PR is the price of regulating power, $P_{t,}$ is the spot price, S_t is the announced bid and D_t is the actual delivery, therefore theoretically amount regulated is given as $(S_t - D_t)$. When the regulating power prices are known, the values of $P_{t,}$ and S_t are known, because the spot market closes 12 hours before the actual delivery. D_t , is the only unknown variable in this regression model. When $S_t < D_t$ there is excess demand for power, and when $S_t > D_t$ there is excess supply. The key point in this hypothetical relation is that when there is an absence of regulation, the regulating power price is equal to the spot price scaled by a factor.

Skytte estimates this factor to be equal to 1. The coefficients μ and ϒ are regarded as the marginal regulating power price per unit of regulated power, and the coefficients λ, α, and β are assumed to be unrelated to the amount of regulation. In the model these are interpreted as determining, the premium paid to the regulators. This premium is paid because the regulators have to regulate within 15 minutes of notice. Which is relatively quick compared to the spot market, where the interval between acceptance of the bids and actual trade is at least 12 hours.

Equation (5) is used in the article to show that the optimal announcement at the spot market is linearly dependent on the price level at the spot market and the expected delivery.

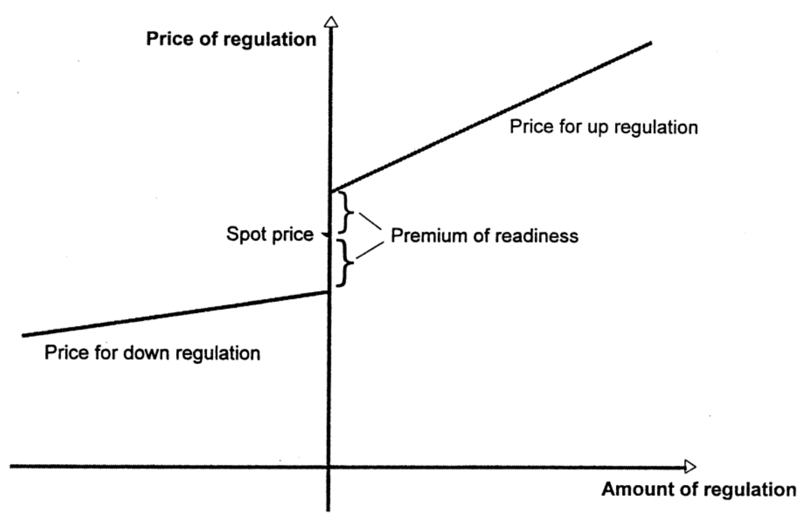

Figure 2: Price of regulating power (Skytte 1999).

This model was developed to analyse the Norwegian power market. Hydropower based electrical markets are different than wind power based electrical markets. The use of regulating services might have different incentives in the Norwegian market compared to the

Danish market. The main reason is that hydropower can to some extent be stored but such possibilities are limited in the wind power market. This model is applied on the Danish power market, to detect any strategic behaviour with updated data from 2012-2013. Hereafter the model will be referred as model 1. Any asymmetries related to up and down – regulation will be used in context with equation (1) and equation (2), and any hint of systematic behaviour will be regarded as the variable W_t^S, the strategic element in wind power production.

3.1.1.1 Modification of Model 1

The dataset and the generated variables used in the models is described in detail, see chapter four. In line with the main purpose of this thesis, Model 1 is modified to approach the analysis of the Danish market. Two dummy variables are created to modify the equation so equation (5) can be written:

$$PR(P_t, S_t, D_t) = \emptyset P_t + \begin{cases} [\lambda P_t + \mu(S_t - D_t) + \eta] & if\ S_t < D_t \\ 0 & if\ S_t = D_t \\ [\alpha P_t + \gamma(S_t - D_t) + \beta] & if\ S_t > D_t \end{cases} \tag{6}$$

The dummy variable for down- regulation is given by:

$$d_t^d = \begin{cases} 1 & if\ S_t < D_t \\ 0 & otherwise \end{cases}$$

The dummy variable for up- regulation is given by:

$$d_t^u = \begin{cases} 1 & if\ S_t > D_t \\ 0 & otherwise \end{cases}$$

With the dummy variables one has now:

$$\begin{aligned} PR(P_t, S_t, D_t) = \emptyset P_t + d_t^d[\lambda P_t + \mu(S_t - D_t) + \eta] \\ + d_t^u[\alpha P_t + \gamma(S_t - D_t) + \beta] \end{aligned} \tag{7}$$

Equation (7) can be rewritten as:

$$PR(P_t, S_t, D_t) = \emptyset P_t + \lambda\left[d_t^d P_t\right] + \mu\left[d_t^d (S_t - D_t)\right] + \eta\left[d_t^d\right] + \alpha[d_t^u P_t] + \gamma[d_t^u (S_t - D_t)] + \beta[d_t^u]$$

Equation (7) in form of the regression model and ready for estimation becomes:

$$P_{Rt} = \alpha_0 + \alpha_1 P_D + \beta_0 D_{up} + \beta_1\left(P_D * D_{up}\right) + \beta_2\left(V_{up} * D_{up}\right) + \gamma_0 D_{do} + \gamma_1 (P_D * D_{do}) + \gamma_2 (V_{do} * D_{do}) + \varepsilon \qquad (8)$$

Here, P_{Rt} is the regulation price for balancing regulation and V is the actual volume of regulation. Subscripts *up* and *do* stand for up and down- regulation. More information about the variables is provided in chapter four.

Finally, equation (9) is studied through creating a graph. Here the change in price of balancing regulation is given as the difference in price of up and down-regulation in the relevant time period.

$$\Delta P_t^r = P_t^{up} - P_t^{do} \qquad (9)$$

This modified version of Skytte's model is regarded as model 1 hereafter, because this version of the model is relevant for the analysis.

3.1.2 Model 2

Model 2 is based on econometric theory of measurement error in the model. The estimation method is used because there is a suspicion of endogeneity in the model. The use of proxy variable and the use of an instrumental variable are methods used to correct for endogeneity, given that the OLS[1] estimation may not produce good results. In this case there is a suspicion of endogeneity in the model, related to the variable of wind power production. The objective is to check the model for endogeneity and signs of systematic measurement error that can be linked to strategic behaviour. In Model 2, the dependent variable in the regression

[1] The method of ordinary least squares

is total regulation, and the independent variables are net exports, wind power production and total power production. The failure of meeting total demand at the time of actual delivery is reflected in total regulation. The goal is to extract the effect of planned wind power production on total regulation.

When there is endogeneity in the independent variables, the results will be produced with bias estimates. Endogeneity can be caused by omitted variables, measurement error or simultaneity. Possible ways to correct for unobserved endogeneity is to find a suitable proxy for the unobserved variable. The instrumental variables regression approach can also be applied. The use of OLS in presence of endogeneity will lead to a correlation between the explanatory variables and the error term, and results will be biased. In this case, the unobserved part of the model is the strategic element added to the planned wind power production. The assumption is that this strategic element will be detected through the endogeneity in the independent variable and this can be classified as systematic measurement error (Reichstein 2011).

The assumption in the classical linear regression model is that the model is being measured with an error term ε. The problem of measurement error distinguishes from the error term ε, because the assumption here is that in addition to the error term of the model, the independent variable is being measured with an error. The models with measurement errors follow, the key assumption that the response variable and the predictor variables are subject to additive measurement errors. The regression model in this case is subject to an unknown constant, which classify the model to become a functional measurement error model (Young 2014).

In presence of a measurement error the estimation method of 2SLS[2] can be applied to correct for the error. In the model X is an independent variable, Y is dependent variable and Z is the instrumental variable. The instrumental variable Z affects the dependent variable Y, only through its effect on the independent variable X. (Young 2014). Two properties must be satisfied in order to for the instrumental variable to be consistent. The instrumental variable must be relevant and strong. In order to be relevant, there must be a strong correlation

[2] Two-stage least-squares

between the IV and the independent variable it is instrumenting for. The IV must be uncorrelated with the error term, and by that, the IV is exogenous (Young 2014).

The Hausman test is a specification test for measurement error with the null hypothesis of no measurement error. Under this hypothesis, both the OLS estimator and the instrumental variable estimators are consistent estimators in the model. The OLS will be efficient, and the instrumental variable estimator will be inefficient if the null hypothesis is valid. On the other hand, if the null hypothesis is rejected, the instrumental variable estimator will be consistent, and not the OLS estimator. In brief, the Hausman test is used to compare the result from the OLS and the 2SLS (Green 1990).

To improve OLS results, the OLS can be estimated using a proxy variable. There is difficulties related to the measure corresponding to the variable W_t^P, but still this variable is defined in the regression. There are observable indicators for this variable, and in this context the variable wind prognosis, W_t^{Prog}, will be regarded as an indirect measure of W_t^P. Theoretically, it is highly unlikely that an improvement in the measurement will bring the proxy closer to the variable, which it is a proxy for (Green 1990).

In context of the theory given above, Model 2 is designed. The objective of Model 2 is to find the effect of W_t^P on the total regulation amount. The unobservable variable W_t^P from equation (1) will be measured indirectly as this information is missing. What is known is that wind power production is solely dependent on the amount of wind that enters the system. To analyse what happens when the supply bid is planned, wind fluctuations are considered. The effect of planned wind power production on total regulation is the basis for the regression estimation in Model 2.

Without the strategic element in the model, the assumption is as following:

$$W_t^P = W_t^{AC} = W_t \tag{10}$$

Ideally, total regulation should be regressed against all the independent variables from equation (4) to obtain the effect of planned wind power production on total regulation:

$$R_t = \beta_0 + \beta_1 Q_t + \beta_2 X_t + \beta_3 W_t + \varepsilon_t \tag{11}$$

The introduction of an instrumental variable will attempt to solve the missing variable problem, and the variable wind power prognosis is used as an instrument in the 2SLS:

$$R_t = \alpha_t + Q_t + X_t + W_t^{Prog} + \varepsilon_t \tag{12}$$

To be able to compare the OLS estimation with planned wind power production included, wind prognosis is tested as a proxy variable for actual wind power production, and equation (13) becomes the following:

$$w_t^{AC} = \alpha + w_t^{prog} + \varepsilon_t \tag{13}$$

The OLS estimation with a proxy variable is as showed in equation (14):

$$R_t = \beta_0 + \beta_1 Q_t + \beta_2 X_t + \beta_3 W_t^P + \beta_4 W_t^{Prog}{}_t + \varepsilon_t \tag{14}$$

Lastly, the Wu-Hausman test for endogeneity is applied to compare OLS and 2SLS results. The OLS estimation and the OLS estimation with a proxy are compared using the Likelihood ratio test. This test shows the improvements in the estimation by using a proxy variable.

3.1.3 Hypotheses and model summary

Hypothesis one: There is not a systematic relationship between regulation price, and up or down regulation

Hypothesis two: Wind power production is exogenous predictor of total regulation

Model 1 and Model 2 is applied in order to answer the problem of discussion. Model 1 is estimated first, and if the results suggest that asymmetries are found, Model 2 continues the research by specifically testing the relationship between total regulation and wind power production, because the suspicion is that the asymmetries in the regulation market is caused by the deviations between planned and actual wind power production. Hypothesis one is tested in Model 1, and after the results are conducted from Model 1, hypothesis two is tested in Model 2. To sum up, to state the problem for discussion the deviations between actual and planned wind power production will be tested by the effect of wind power prognosis on total regulation. Further, the direct effect on the bidding strategy cannot be obtained, as the data on the actual bid is confidential. The way of analysing the bidding structure in this research will be done by examining if there are any incentives for wind power producers to systematically use the regulation market to preserve their interests in the spot market. Significant measurement error may be indirect evidence on systematic action and therefore Model 2 is tested for endogeneity.

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4 Data

The data used in the model 1 and model 2 is downloaded from energinet.dk, except the data on wind prognosis which is downloaded from Nord Pool´s website. Energinet.dk updates the homepage twice each day, and uses the latest data in update. The measurement unit and currency unit for price is Euro per MWh. The data downloaded is from 01.01.2012 to 31.12.2013. Which is a total amount of 24 months and 17544 observations on an hourly basis.

In general, the dataset the observations regard for 24 hours per day, but there is one particular day in March reported with 23 hours. This happens because the time changes from wintertime to summertime (Nielsen 2010). In the time period from 01.01.2012 to 31.12.2013, these dates occur at 25th march 2012, and 31st March 2013, which lead to that the 3rd hour was blank on these dates. The blank area in the data set is corrected for by filling in the data from hour four. The mean value of hour 2 and 4 could also have been used, but the values of these hours were very similar, so the mean value was not used to fill in for the missing hour.

When summertime changes to wintertime, in general one day will be calculated as 25 hours, because the 3rd hour will be calculated twice (Nielsen 2010). In the dataset all of the observations fit the time series setting from 1 to 24, therefore no 25th hour was observed.

4.1 The variables

All the observable variables used in Model 1 and 2 are in the dataset. The Elspot price for DK-West (West-Denmark) is used as the price variable for DK-West bidding area. DK-West primary and local production generates the variable of total production in DK-West. DK-West wind production is treated as one variable, and not as a part of total production.

Upward and downward regulation for DK-West, both amount and price are important and included in the dataset. In addition there is a price for balancing power consumption, which in the analysis is shortened to price for balancing regulation, and this is regarded as the regulation price. Down regulation values are given with a negative sign, and up regulation values are given with positive signs. DK-West trades power with Norway, Sweden and Germany, and data on trade with all the three countries is included to create one net export variable in the analysis. The trade with East-Denmark is not considered in this variable. Observations have either positive or negative values to distinguish between import and export. A detailed description of how these variables are generated is given in chapter five.

4.2 Descriptive statistics

Descriptive statistics of all variables is presented in table 1. The standard deviation of total regulation, net exports, wind prognosis and wind production is high compared to the other variables. There are huge differences between the minimum and maximum values for all variables. Up and down regulation have fewer observations than the other variables, because the observation is done only for those hours when up and down -regulation takes place. Total production has the highest mean value, and the mean value of the wind power production and wind prognosis is very similar. The coefficient of variance is equal for wind power production and wind prognosis. Total regulation has the highest value of the coefficient of variance. The mean value of price for up-regulation is higher compared to down- regulation. DK-West area price has a mean value between the mean values of up and down regulation price.

Table 1: Descriptive statistics of the variables.

Variable	N	Mean	Std-dev	Median	Min	Skewness	CV	Max
Total regulation	17544	1.51	93.09	0.00	-704.70	0.21	61.58	714.90
Total production	17544	1498.32	662.59	1397.70	355.80	0.61	0.44	4062.40
Net exports	17544	135.83	660.31	174.80	-2226.30	-0.31	4.86	1896.30
Wind prognosis	17544	919.09	739.63	709.00	11.00	0.92	0.80	3323.00
Price of balancing	17544	37.21	23.90	34.36	-217.01	3.73	0.64	499.93
Wind production	17544	929.37	744.33	738.50	0.60	0.84	0.80	3871.10
Down regulation	5230	-82.51	80.51	-55.00	-704.70	-2.12	-0.98	-0.50
Up regulation	4492	101.97	89.48	81.10	0.40	1.57	0.88	714.90
Price for down regulation	17544	32.78	14.99	32.95	-217.01	-1.74	0.46	183.39
Price for up regulation	17544	42.08	39.31	37.67	-199.99	33.00	0.93	1999.89
Spot price DK-West	17544	37.66	35.24	36.15	-200.00	44.92	0.94	2000.00

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5 Estimation and analysis

All statistical analysis was conducted using the STATA[3] software version 13. The data described in chapter four was divided into two datasets, one for each model. Some variables are repeated and appear in both datasets. For model 1 data is analysed in STATA as hourly time series with time variable hour running from 1 to 17544. The results are established on based on these 17544 hours only. Time series variable are tested for stationarity using the Augmented Dickey- Fuller (ADF) unit root test are found to be stationary, see appendix 1 for details

Model 1 is estimated first. Two dummy variables are generated one for up- regulation and the other for down- regulation. The dummy variables are multiplied with the area price of DK-West to generate two new variables as required in the model. The dummy variable for up-regulation is multiplied with up-regulation volume, and similarly the down-regulation dummy is multiplied with down-regulation volume. Model 1 requires all of these variables for the regression analysis.

At first Model 1 is estimated using ordinary least square (OLS). Specification tests conducted on OLS results indicate the need to control for autocorrelation and heteroscdasticity. To control for autocorrelation and heteroscedasticy, the model was re-estimated twice following the Newey-West procedure with HAC[4] standard errors –first with 24 lags and later with 48 lags.

The difference between up-regulation and down-regulation prices is computed to determine the spread in these prices. The distribution of these prices and their spread are graphed to show the asymmetries in their distribution. The graph is showed in chapter 6.1

The analysis for Model 2 requires the variables total production, wind power production, net exports, and total regulation, all of which are generated except wind power production. Total regulation is generated as an aggregated value of up and down regulation. The variable net export is generated as an aggregated value of imports and exports of DK-West with Sweden,

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[3] Data analysis and statistical software version 13

[4] Heteroscedasticity and Autocorrelation consistent Standard Errors.

Norway and Germany. To generate the total power production primary production and local production added together.

Total regulation is regressed against wind power production, total production and net exports. Specification tests the Ramsey-Reset, the Linktest, White´s test and the Breusch-Pegan test are applied to estimated OLS models one excluding and the other including wind power prognosis. All specification test results indicate that OLS estimation without wind prognosis misspecified. A second OLS model is estimated with wind power prognosis as proxy to correct the potential missing variable problem suspected to be causing the detected misspecification. The same four tests are applied on the OLS estimation with a proxy and misspecification is detected to persist

Model 2 is further estimated using instrumental variable two stage least squares approach using wind prognosis as an instrument for wind production, which suspect to be measured with error. Tests for a good instrument F-tests and correlation are conducted on wind prognosis assuming total production and net exports to be exogenous. Results from the Durbin and Wu-Hausman tests in the first stage of the 2SLS approach indicate that the instruments used are strong and relevant.

In the 2SLS total regulation is regressed against net exports, total production as exogenous variable and wind power prognosis as an instrument for wind production as discussed in the first stage. To compare the results of the OLS and the OLS with the proxy the likelihood ratio test is applied. Likewise OLS results are compared with 2SLS results to detect a difference, which points the possibility of measurement error by applying the Wu-Hausman test.

6 Results and discussion

This chapter provides detailed results obtained from estimation and analysis described in chapter five. Results from Model 1 are presented first, and results from Model 2 second. Results from both models are discussed at the end of this chapter.

6.1 Results Model 1

Table 2 provides the overview of the estimated parameters on Model 1.

Table 2: Estimated parameters model 1.

	OLS	NEWEY: 24 lags	NEWEY: 48 lags
Dependent variable: Price of balancing regulation			
	b/se	b/se	b/se
Area price West Denmark	0.933***	0.933***	0.933***
	(0.009)	(0.011)	(0.011)
Up regulation dummy	-15.295***	-15.295*	-15.295*
	(5.042)	(8.061)	(8.316)
Up regulation price	0.468***	0.468**	0.468**
	(0.115)	(0.181)	(0.185)
Volume traded on up regulation	0.148***	0.148***	0.148***
	(0.009)	(0.017)	(0.017)
Down regulation dummy	26.844***	26.844***	26.844***
	(0.782)	(1.569)	(1.588)
Down regulation price	-0.885***	-0.885***	-0.885***
	(0.020)	(0.040)	(0.041)
Volume traded on down regulation	0.048***	0.048***	0.048***
	(0.004)	(0.006)	(0.007)
Constant	0.981***	0.981***	0.981***
	(0.283)	(0.367)	(0.373)
Number of observations	N = 17544	N = 17544	N = 17544
F –Statistics	3165.81	1467.90	1438.33
	(0.000)	(0.000)	(0.000)
R-Squared	0.5990		

***, ** and * implies significant at 1%, 5% and 10% critical levels respectively

The OLS, Newey (24) and Newey (48) are significant at 1 %, 5% and 10 % critical level. The R-squared value indicate that the variation in the independent variables used to estimate Model 1, explains approximately 60 % of the variation in the balancing price of regulation.

The two-tail p-values confirm the hypothesis that each coefficient is significantly different from 0, at 1 %, 5 % and 10 % critical levels. The estimated coefficient spot price DK-West is significant and with a positive sign. This indicates that the balancing market follows the signals of the spot market. The price of balancing regulation is positively related to the spot price, if the spot price increases the balancing price increase. This is a clear indication that the balancing price of regulation is not independent from the spot price of DK-West. In the table this variable is called Area price West Denmark.

The estimated dummy variable for up-regulation, which in Model 1 is given by the coefficient β_0, has a negative sign. Therefore the price of balancing regulation and the estimated dummy variable move in the opposite direction. The results are opposite for the down-regulation dummy variable, given by the coefficient γ_0, which in Model 1, which has a positive sign. This could possibly imply stabilizing effects of the up and down regulation. When there is up regulation power supply increases in the market, and when supply increases the demand is closer to being satisfied, and price will eventually decrease. The same interpretation applies for down-regulation, because when down-regulation occurs, power supply is either withdrawn from the system or at least there is no increase in supply in the system, which will eventually lead to a price increase. The interpreted chain of events is not reflected as a result in one single hour of delivery, but for the interval from 12 to 36 hours of actual delivery of power.

The estimated dummy variable for up-regulation multiplied with the area price DK-West has a positive sign. The price of balancing regulation and this estimated variable are positively correlated, which means that, during up-regulation an increase the area price DK- West will imply an increase in price of balancing regulation. They are both positive and move in the same direction when a unit change occurs. A possible explanation can be that the area price is positively correlated with the price of balancing regulation, therefore the spot price multiplied with the dummy variable has a positive net impact. When the down regulation dummy is equal to 1, the dummy variable is multiplied with the spot price, and this relation has a positive sign. If regulation does not occur at all, zero multiplied with the spot price, will have no effect. The estimated dummy variable for down-regulation multiplied with the area price of DK-West is negatively correlated to the price of balancing regulation. The estimated coefficient is significant, but the price of balancing regulation and the coefficient move in the opposite direction. When there is a unit decrease in the estimated coefficient, there will be an increase in the price of balancing regulation.

The coefficient β_2, which represents the dummy variable for up-regulation multiplied with the volume of up regulation, is significant with a positive sign. This is in agreement with the economic theory, which means that there is an increased cost. When the regulating power volume increases, the price of balancing regulation increases, and this represents the increased cost reflected in the increased price of balancing regulation. When regulation volumes increase, the price for balancing regulation increases. The dummy variable picks up the frequency of up regulation, and the volume times the frequency affects the price for regulation. The result is almost the same for the estimated coefficient γ_2, which represents the same relation in the case of down regulation. The volume of down regulation times the frequency of down regulation also share a positive and significant relationship with the balancing price. The use of regulation services is regarded as an additional cost, so the question is if it is more beneficial to use this market to minimize this cost. In the next section the difference in average price of up-regulation and down-regulation is graphed in order to compare the skewness and over all difference in average prices.

6.1.1 The average price of up-regulation and down-regulation

The variable price of down-regulation has a left skewed distribution, which means that the values are mostly on the right side of the mean. The opposite is valid for the price of up-regulation, where the distribution is right skewed. There are asymmetries in the distribution of both variables. Figure 3 below shows average price difference of up and down regulation. The graph representing hourly averages of up and down regulation prices is the result of eq. (9) given in Model 1. The top graph shows the hourly average, while the graph below represents the difference in hourly averages for both prices. Mean value of the up regulation price is higher than the price for down regulation.

Figure 3: Daily up and down regulation.

6.2 Results Model 2

Results from Model 2 are here represented in a similar order as was done in the analysis of chapter five.

6.2.1 Total regulation

First, the dependable variable total regulation was generated and its distribution is shown in the graph below. Total regulation is on the X-axis and the timeframe of 17544 hours is given on the Y-axis. This graph represents the volume of total regulation and not price. To distinguish between up and down-regulation, a positive sign is given to the amount of up regulation, and a negative sign is given to the down-regulation amount in the data set. The bell shaped curve indicates a normal distribution, but most of the observations are around a value of zero. The minimum value of total regulation is -704.7 and the maximum value is 714.9. The median value is zero and the mean value is 1,51 and there is a right skewed distribution with a value of 61.58, (see Table 1). Based on the descriptive statistics most of the values are to the right of the mean. This would imply that up-regulation dominates the distribution, because up-regulation regard for all the positive values. However, by looking at the graph, the most frequent value is just below zero. This value is negative and all negative values imply that there is down-regulation. This implies a contradiction in the results. A possible explanation can be that down-regulation happens frequently but in smaller quantities, and the volume of up-regulation is higher each time. That in turn causes the mean value of total regulation to become positive.

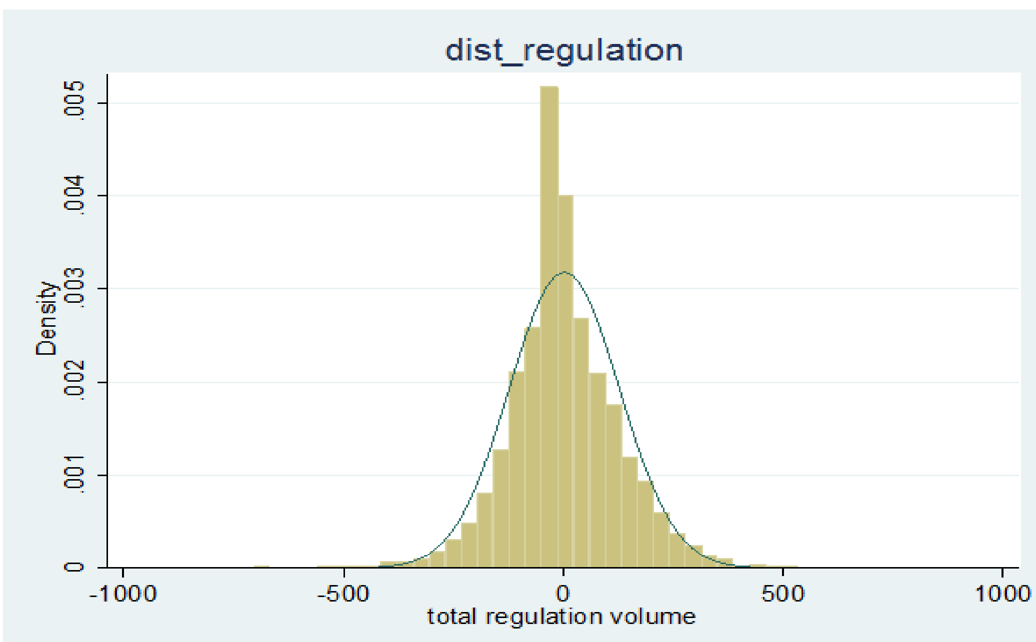

Figure 4: Distribution of the variable total regulation.

6.2.2 Estimated parameters Model 2

The table below provides the results of all the estimated parameters in Model 2. The comparison of the OLS, OLS estimation with a proxy variable, and the 2SLS is done based on the results in the table below.

Table 3: Estimated parameters OLS, OLS_Proxy, 2SLS

	OLS	**OLS (Proxy)**	**IV-2SLS**
Dependent Variable: Volume of total regulation power (N = 17544)			
	b/se	b/se	b/se
Total power production	0.0001	0.0004	0.0096***
	(0.0013)	(0.0012)	(0.0013)
Wind power production	-0.028***	-0.127***	-0.004**
	(0.002)	(0.003)	(0.002)
Net power exports	-0.020***	-0.013***	0.002
	(0.002)	(0.002)	(0.002)
Wind Prognosis		0.108***	
		(0.003)	
Constant	30.105***	21.426***	-9.401***
	(3.142)	(3.065)	(3.409)
F statistics	146.28	373.92	
	(0.000)	(0.000)	
Adjusted R squared	0.024	0.078	

***, ** and * implies significant at 1%, 5% and 10% critical levels respectively

6.2.3 OLS estimation with wind power production

OLS estimation showed that the coefficient of total production is not significant. Wind power production is negatively correlated with total regulation. Both wind power production and net exports have negative signs, which means that when net exports and wind power production decrease by one unit, the total regulation increases by one unit. The adjusted R-squared value is low, approximately 2 %, therefore based on this value no significant conclusions can be made.

The Ramsey-reset test rejected the hypothesis of no omitted variables with a p-value of 0.00. The model is concluded as misspecified. Heteroscedasticity is detected by the White's test, a possible way to correct for heteroscedasticity was to use robust standard errors, but even if they had been used, model misspecification would remain. Heteroscedasticity was confirmed with a chi-square value of 327.22 and a p-value of 0.00. Breusch-Pegan test rejected the hypothesis of constant variance in the error term based on a chi-square value of 144.18 and p-value of 0.00. The Linktest applied on the OLS concluded with sign of missing variables in the model, because the squared component is significant with a p-value of 0.00, see appendix 2 for details of specification tests.

OLS estimation seems to produce biased results, and there is a strong suspicion of endogeneity, due to unforeseen systematic behavior. An indication of this is given by the results of Model 1. A possible explanation is that there could be a missing variable that enhances the ability to predict wind power production. This ability may be linked to strategic behaviour or possibly a measurement error in wind production. OLS estimation with a proxy variable, and then the 2SLS approach is used to check for better results.

6.2.4 Wind prognosis as a proxy variable

Planned wind power production is not observable at the time when the bid is placed. Using OLS estimation, wind power prognosis is assumed to be a good proxy for the actual wind power production, because the partial regression coefficient is 0.9621. There is therefore a strong but not perfect correlation between them, see appendix 3 for details.

When the proxy variable was included in the OLS, the R-squared value increased to become 8 %. This value is still regarded as low. The Ramsey-Reset test still classifies the model as misspecified, with significant p-value of 0.00. Heteroscedasticity was confirmed by the White's test and there was not any improvement in results from the Linktest, as the predicted component squared is still significant.

The Breushc-Pegan test showed improvement in the variance of the error term. The chi-square value of the test is 0.89, followed by a p-value of 0.3465. This is the only evidence of the slight improvement from the OLS estimation without a proxy variable. There are still signs of misspecification possibly due to measurement errors in the independent variables. The likelihood ratio test concludes that OLS and OLS with proxy gave different results.

There is a slight change in the estimated coefficients, but introducing a proxy does not improve the overall result since the model is still misspecified and there are signs of missing variables. Even if the estimates improve slightly in magnitude, the model remains misspecified and therefore there is not a substantial change in the results.

Using wind prognosis, as proxy variable does not solve model misspecification, therefore there is still suspicion of endogeneity. A possible explanation is that the missing variable is related to the planned wind power production and its effect on total regulation. The next method applied to the problem is the 2SLS.

6.2.5 The instrumental variable approach

The criteria for using an instrumental variable is met, the F-value of 56560.86 shows that the instrument can be regarded as a strong instrument. The correlation between wind power production and wind power prognosis is 0.9621, which means the variables are strongly correlated, see appendix 3. The positive relationship between wind power production and wind power prognosis is the first stage of the 2SLS, see appendix 2 for details.

The results in the 2SLS indicate that there is a negative relationship between total regulation and the instrumental variable. One may interpret this as planned wind power production given by the wind power prognosis and total regulation is negatively related. The coefficient of net exports is not significant. Total power production has a positive sign and is significant. The unit change in total production will lead to a unit change in total regulation, both in the same direction. Wind prognosis and total regulation move in opposite directions, if wind prognosis shows an increase, the volume of total regulation will decrease. These values have a lagged relationship, and the aim is to find an instrument for planned wind power production, which in this case is the wind power prognosis. To compare the OLS and 2SLS, the Wu-Hausman test is applied, which confirmed endogeneity, see appendix 2.

The Wu-Hausman test rejected that wind power production is an exogenous variable. The OLS, OLS with a proxy or the 2SLS are all estimated with a problem of measurement. The IV-regression does not correct for the mistakes in the OLS and OLS with a proxy variable.

6.2.6 Measurement error

Comparing the OLS results with the IV regression in the Wu- Hausman concludes that the null hypothesis is rejected and wind power production is endogenous. The instrumental variable approach does not correct for the endogeneity problem. The same result is obtained by comparing the OLS results with the OLS estimation with the proxy variable. All of the tests in Model 2 confirm the same thing; there is a measurement error in the model. There is endogeneity in the model. Using the wind prognosis as a proxy variable does not solve the model misspecification problem. The cause of endogeneity can also be a missing variable. This indicates unforeseen systematic behaviour, because wind power production should be an exogenous predictor of total regulation.

6.3 Discussion of results

The main findings in Model 1 imply that the spot market signals the regulation market, because there is a significant relationship between the spot price and the regulation price. The average regulation price is reflected in the constant term, which is the regulation price that is independent of any other factor. If the estimated coefficient values are substituted into equation 8 of Model 1, the results are as following:

$$P_{Rt} = 0{,}98 + 0{,}93P_D + (-15{,}3)D_{up} + 0{,}47\left(P_D * D_{up}\right) + 0{,}15\left(V_{up} * D_{up}\right) + 26{,}84D_{do} + (-0{,}85)(P_D * D_{do}) + 0{,}048(V_{do} * D_{do}) + \varepsilon$$

Hence, the effect of up- regulation and price when all other factors held constant is given as:

$$P_{Rt} = 0{,}98 + 0{,}93P_D + (-15{,}3)D_{up} + 0{,}47\left(P_D * D_{up}\right)$$

$$P_{Rt} = 0{,}98 - 15{,}3 + (0{,}93 + 0{,}47)P_D$$

$$P_{Rt} = -14{,}32 + 1{,}4P_D$$

And the effect of down- regulation and price when all other factors held constant is:

$$P_{Rt} = 0{,}98 + 0{,}93P_D + 26{,}84D_{do} + (-0{,}85)(P_D * D_{do})$$

$$P_{Rt} = 0{,}98 + 26{,}84 + (0{,}93 - 0{,}85)P_D$$

$$P_{Rt} = 27{,}82 + 0{,}08\,P_D$$

$$1{,}4P_D - 0{,}08\,P_D = 1{,}32$$

Findings indicate that price of using up-regulation services is higher than the price of using down-regulation services. A higher price of up-regulation means a higher cost for producers frequently use up-regulation services. The effects of up and down -regulation are not the same. The possibilities of joint optimisation as discussed in chapter two and three are present. If the price and effects of up and down regulation were the same, such possibilities would be limited. Assume that wind power producers have a marginal cost of production close to zero and when the market price is positive, they bid the entire amount above or equal to their marginal cost. Then supply is bid based on the planned wind power production, which is most likely based on the wind prognosis. The deviation between planned and actual production can have very different consequences in the regulation market. In periods with excessive amounts of wind, the use of the regulation market will be cheaper compared to periods with little wind. This is a very clear incentive to systematically bid less supply than the wind power prognosis on the spot market. In this manner they will need to buy down-regulation services. These results are in line with Skytte's findings (Skytte 1999). With this analysis it can only be stated that there is an incentive present to systematically bid on the spot market because of the asymmetric price relation. The daily difference in average prices of up and down-regulation are asymmetrically distributed and therefore the price difference is of significance. The deviation between predicted and actual production of wind power could work as an incentive to strategically place the supply bid on the spot market, and optimize the use of regulation services. There might be a strategic incentive to systematically bid less power supply at the spot market to obtain a reduced regulation price.

The total regulation variable has a positive mean value, and a median valued zero. However the most frequent value was below zero according to the graph. This strengthens the argument that a frequent use of down-regulation occurs. The amount must have been small every time that it did not affect the mean value to become negative, and possibly every time they up-regulate the volume has higher compared to when they down-regulate. Contradiction between the graph and the statistics indicate that there is systematic and frequent use of down-regulation services. To state if they strategically bid less as systematic action is difficult to state without the additional information of the actual supply bid into Nord Pool. The results indicate that the incentive of strategic behaviour on the spot market is present, and therefore W_t^S is not equal to zero in equation (2) and planned wind power production is determined by wind power production supply bids and the strategic element related to wind power.

Ideally, planned wind power production and actual wind power production would be the same, and there would not be any systematic use of the regulation market. Thus wind power prognosis would have been 100 % accurate and no deviations would have taken place. In reality this is very challenging to obtain.

When Model 2 was estimated the assumption was that actual wind power production is an exogenous independent variable in predicting total regulation. As seen from specification tests results, wind power production variable included in the OLS produced biased results due to possible missing variables or measurement error problem. Then planned wind power production, wind power prognosis is used as a proxy variable alongside actual wind power production when the OLS was estimated again. Now results were noticeably different compared to the OLS without a proxy but the specification tests did not improve substantially. The results from instrument variable 2SLS estimation indicate wind power production to be endogenous in predicting total regulation. There is a very strong indication of measurement error in the model. Significant measurement error could be indirect evidence on systematic action of strategic behaviour. The findings imply that the incentive to act strategically is present, and in addition to that finding there is an unforeseen measurement error in the model.

On the basis of the results from Model 2, one may significant systematic unforeseen behaviour. The regulation market and the spot market are supposed to be treated as two separate markets. Systematic use of the regulation market may encourage gaming strategies, and collusion among the wind power producers.

However, there are several limitations in the provided analysis. No cross validation has been done and hence these findings are only valid for these 24 months. The models are not validated outside the sample. The analysis for the long -run may produce completely different results. Another limitation is that this analysis is based on indirect evidence. If there was data available on the actual bidding amount submitted to Nord Pool, this analysis may possibly show different results. An analysis done directly using actual bidding data may lead to different results, as there would be direct evidence for the findings. The chain of events in the energy market are very strongly linked to each other, meaning that there may be factors present which have not been considered in the analyssi, such as consumer aspect, seasonal variation in demand, and the retailers role all together. This research focused only on the production side of the market, which may not be a complete picture. One important thing in this respect is that the regulation market is not only used by wind power producers, while the in the analysis there is an assumption that conventional power producers can control their production. In reality, wind power producers in often struggle with anticipating their actual production amount.

In the event that Denmark decides to pursue its plans of increasing its wind power production, several aspects of this analysis may be relevant. The cost structure of wind power producers must be taken into consideration when more actors will enter the market. The interests of Nord Pool, the regulation market and the wind power producers must be taken into consideration when dealing with increased wind power in the system. In addition large investments are required to expand the wind power sector. The investment plans bring forward higher uncertainty and in addition to that if the strategic use of the regulation market adds up as a factor of economic inefficiency the plans must be evaluated very carefully.

To sum up, the findings in Model 1 rejected the first hypothesis, because there is a difference in price for up-and down regulation, and the use of the regulation market is asymmetric. The findings in Model 2 rejected the second hypothesis, and wind power production is an endogenous variable when predicting the total regulation amount. The deviation between planned and actual production of wind power can be used as an incentive to place the supply bids strategically on the spot market, to obtain a better price in the regulation market. This behaviour distinguishes from mark-up and capital-withdrawal strategies as discussed in chapter 2.3.1. The effect using the regulation market strategically may not have a direct effect on the demand and thus may not affect consumers at all. Whether this type of incentive leads to economic inefficiency or not, cannot be stated without collecting substantial evidence and data for the long run.

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7 Conclusions

The objective of this study was to test for systematic relationship between up and down-regulation and price for regulating power. Results imply that the deviation between predicted production and actual production of wind power could work as an incentive to strategically submit supply bid at the spot market, and optimize the use of regulation services because of the higher cost of up-regulation compared to down-regulation. This incentive can lead the producers to place a bid lower than the actual production, to avoid the use of up-regulation services. In addition the results also implied that there was a frequent use of down-regulation services even if the mean value of the observations was positive, and related to up-regulation. Since the spot price effect the total regulation price, the cost of regulation can be anticipated before the actual delivery of power. The second analysis concluded that wind power production was endogenous in predicting total regulation and the instrument of wind prognosis did not correct for endogeneity. Actual wind power production should be equal to planned wind power production and therefore be exogenous in predicting total regulation. An unobservable strategic element may have been added to the supply bid and comes up in the model as a systematic measurement error.

For further research it is recommended to analyse whether strategic bidding behaviour will lead to externalities associated with wind power production in the future. If it turns out that strategic use of the regulation market is revealed in the long run, then some improved bidding structure should be suggested for producers of wind power that will decrease the opportunities to use the regulation market strategically.

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Appendix 1

Dickey fuller test for unit root

Variable	Test Statistics	P-Value	Lags
Area price Denmark West	-22.877***	0.000	24
Up regulation price	-33.833***	0.000	7
Volume traded up regulation	-31.081***	0.000	5
Down regulation price	-32.623***	0.000	10
Volume traded on down regulation	-38.495***		5
ADF Critical Values:	**1%**	**5%**	**10%**
ADF test statistics	**-3.430**	**-2.860**	**-2.570**

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Appendix 2

	OLS	OLS with proxy	IV 2SLS
	F-statistic /P-value	F-statistic /P-value	
Ramsey-Reset test	24.84***	9.52***	
	(0.000)	(0.000)	
	Chi-square/p-value	Chi-square/p-value	
White´s test	327.22***	511.56***	
	(0.000)	(0.000)	
Breusch-Pagan	144.18***	0.89	
	(0.000)	(0.347)	
Link test	T-statistic /P-value	T-statistic /P-value	
Predicted hat	20.52***	37.24***	
	(0.000)	(0.000)	
Predicted hat squared	-7.39***	-4.16***	
	(0.000)	(0.000)	
Likelihood ratio test comparing OLS and OLS with proxy			
	LR Chi-square/p-value		
	1002.19***		
	(0.000)		
Conclusion	There is a significant difference		
Test for endogneity			
Durbin	Chi-square (1)/p-value		974.098***
			(0.000)
Wu-Hausman	F-statistic(1,17539)/P-value		1031.07
			(0.000)
Conclusion	Wind production is endogenous		

Test for suitability of wind prognosis, net exports and total production as good instruments for wind production

```
estat first
```

First-stage regression summary statistics

Variable	R-sq.	Adjusted R-sq.	Partial R-sq.	F(2,17540)	Prob > F
windprod	0.9308	0.9307	0.8557	51996	0.0000

Minimum eigenvalue statistic = 51996

Critical Values	# of endogenous regressors:	1
Ho: Instruments are weak	# of excluded instruments:	2

	5%	10%	20%	30%
2SLS relative bias	(not available)			
	10%	15%	20%	25%
2SLS Size of nominal 5% Wald test	19.93	11.59	8.75	7.25
LIML Size of nominal 5% Wald test	8.68	5.33	4.42	3.92

Appendix 3

Wind power as strong and relevant instrument

```
70. test windprog // Strong intrument

 ( 1)  windprog = 0

       F(  1, 17540) =56560.86
            Prob > F =    0.0000

71. ttest windprog =1

One-sample t test
```

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf.	Interval]
windprog	17544	919.0875	5.58407	739.6311	908.1422	930.0328

```
    mean = mean(windprog)                                 t = 164.4119
Ho: mean = 1                             degrees of freedom =    17543

    Ha: mean < 1                 Ha: mean != 1                 Ha: mean > 1
 Pr(T < t) = 1.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 0.0000

72. corr windprod windprog // relevant instruments
(obs=17544)
```

	windprod	windprog
windprod	1.0000	
windprog	0.9621	1.0000

```
73. //strongly correlated, not perfectly correlated, windprod vs windprog
```

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