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Efficient hedging in an illiquid market

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Abstract

Vattenfall hedge its future electricity production in order to decrease fluctuations in the result. Hedging can in a simplified way be described as selling the future electricity deliveries in long-term contracts so that the future price of the delivery becomes fixed. The contracts used are electricity forwards traded at the Nordic electricity market Nord Pool. An imbalance between buyers and sellers can lead to a situation where the forward price not equals the expected spot price. The difference between the forward price and the expected spot price is referred to as the market risk premium. This is the extra premium that market participants are willing to pay to offset risk. Vattenfall's production portfolio is one of the largest in the Nordic region and the lack of liquidity at Nord Pool's long-term contracts is therefore a limiting factor in effective risk management. The theory is that partly due to the lower liquidity in the longer contracts, Vattenfall pays an unfavorable risk premium in its long term hedges (i.e. selling the electricity to a discount).

In this master thesis the risk premia in the Nord Pool electricity market is measured. It is also investigated if the risk premia changes with different time left to delivery. The results show that the risk premia is positive for contracts entered close to delivery, i.e. the forward price exceeds the expected spot price. When time to delivery increases the risk premia decreases and turns negative around one and a half year prior to delivery.

The second part of this master thesis consists of an introduction and evaluation of a hedge strategy which is commonly referred to as rolling the hedge. This strategy is supposed to remove the negative effects of the long term negative risk premium. The concept is to use two or more short-term contracts instead of a long-term contract. In this way the negative risk premium is avoided. This can be done because the price movements of the short-term contracts are correlated with the long-term contracts so that the result is protected in the same way as with a long-term contract. However less than perfect which means that the volatility (i.e. the risk) will increase.

To investigate whether this strategy, in an efficient way, can be applied to increase the expected return without a significant increase in risk, the outcome of the strategy in terms of risk and return from several different starting points are calculated with actual historical price data.

It is showed, although the significance of the result should be interpreted with caution, that the expected return of the combined spot delivery and hedge program can be increased without any major increase in the volatility of the returns.

Sammanfattning

Vattenfall prissäkrar sin framtida elproduktion för att minska fluktuationer i resultatet. De kontrakt som används är finansiella el-terminer på den nordiska elbörsen Nord Pool. Tidshorisonten på kontrakten är innevarande år plus fem år där kontrakten närmast i tid har betydligt högre likviditet än de med leverans längre fram i tiden.

Priset på terminsmarknaden är som varje annan öppen marknad drivet av utbud och efterfrågan. På grund av detta kan en obalans mellan säljare och köpare leda till att terminspriset på el inte är det samma som det förväntade spotpriset. Skillnaden mellan terminspriserna och det förväntade framtida spotpriset kallas för marknadens riskpremie. Detta är den extra premie som en köpare eller säljare av terminskontrakt är villig att betala för att bli av med risk. Om likviditeten på marknaden är låg är chansen större att agerandet hos en stor aktör kan påverka priset. Vattenfalls produktionsportfölj är en av de största i Norden. Det här göra att likviditeten på Nord Pool är en begränsande faktor för en effektiv riskhantering. Teorin är att Vattenfall, delvis på grund av låg likviditet betalar en ofördelaktig riskpremie i sina långsiktiga terminskontrakt vilket i praktiken innebär att man säljer sin el till rabatterat pris.

I detta examensarbete har riskpremien på den nordiska elmarknaden Nord Pool uppmätts. Det har också undersökts hur denna variera med olika tid till leverans. På grund av att marknadens förväntade spotpris inte är någonting som går att mäta har skillnaden mellan terminspriserna och det faktiska utfallet på spotmarknaden använts som en approximation. Detta kan anses korrekt om det inte existerar några systematiska fel i prognoserna på framtida spotpris. Resultaten visar att terminspriset är högre än det förväntade spotpriset när tiden kvar till leverans är kort men att det omvända förhållandet råder när tiden kvar till leverans är lång. Detta kan uttryckas som att riskpremien är positiv nära leverans och negativ med långt tid till leverans. Riskpremien byter tecken runt ett och ett halvt år innan leverans.

Den andra delen av detta examensarbete utgörs av en introduktion och ett mindre evalueringsexempel av en hedge-strategi som skulle kunna användas för att överkomma den negativa resultateffekt som en negativ riskpremie medför. Konceptet kan sammanfattas som att man istället för att använda ett långsiktigt terminskontrat används istället flera kortsiktiga. Detta kallas allmänt för en rulland hedge. Att den approximationen blir möjlig beror på att prisrörelserna i de kortsiktiga och långsiktiga kontrakten har hög korrelation vilket innebär att resultatet skyddas på ett liknande sätt. Denna korrelation är dock inte helt perfekt vilket innebär att volatiliteten, d.v.s. risken i portföljen, ökar.

För att undersöka om denna strategi på ett effektivt sätt kan användas för att öka den förväntade avkastningen utan en signifikant ökning av risken, har utfallet från ett flertal simuleringar av olika varianter på denna strategi uppmätts med hjälp av historiska data.

Resultatet visar, även om signifikansen av resultatet bör tolkas med försiktighet, att den förväntade avkastningen från prissäkringen kan förbättras utan någon större ökning av risken.

Contents

1 Introduction

1.1 Purpose and problem formulation

Vattenfall hedge its future electricity production in order to decrease fluctuations in the result. The contracts used are financially settled electricity forwards traded at the Nordic electricity market Nord Pool. The time horizons vary but can be as far as 5 years previous to delivery, where the contracts closer to delivery have significantly higher liquidity than those with longer time to delivery. Since Vattenfall's production portfolio is one of the largest in the Nordic region the lack of liquidity at Nord Pool is a limiting factor for effective risk management. The theory is that partly due to the lower liquidity in the more long-term contracts, Vattenfall pays unfavorable risk premia in its long-term hedges.

The purpose of this thesis is two-fold. The first objective is to investigate if there exists risk premia in the forward market at Nord Pool, see if it changes over time and see if there is any significant difference between the risk premium in the Stockholm price area and the system price area. The second objective is to present an alternative way to hedge, called stacked hedge or rolling hedge, which is a way to manage the negative effect of unfavorable risk premium in the market.

There exist numerous papers where the risk premia is measured both at Nord Pool and other international markets. However due to limitations in available data long-term risk premia have never been measured at Nord Pool before. The access to Vattenfalls forward curve will give the opportunity to do this because it extends the notation of prices for contracts beyond the time where it is available for trading at the Nord Pool market.

1.2 Previous studies

Since the deregulation of power markets around the world started in the early 1990´s the amount of research on risk premium and the pricing of electricity derivatives have grown rapidly.

In the most frequently quoted paper in the field, Bessembinder and Lemon (2002) works out a theoretical model which implicates that the risk premium decreases by the expected variance of wholesale spot price and increases by the expected skewness of the spot price. The distribution of the spot power prices becomes positively skewed when expected demand is high relative to capacity or demand is more variable. A low demand and demand risk will lead to a negative risk premium. An increase in demand and demand risk will increase the risk premium which can then even become positive. These theoretical results are also confirmed in many empirical tests, e.g. by Longstaff and Wang (2003), whom examined day-ahead forward market on the US East Coast PJM market and also by Furió and Menue (2008) in their investigation of long-term risk premium in the Spanish electricity market.

Benth et al. (2007) develops a theoretical model where the sign and magnitude of the risk premium is determined by the difference in the willingness to hedge positions and diversify risk between buyers and sellers. This difference is denoted market power and the relative market power of producers and consumers will shift the equilibrium between supply and demand and hence the price of the forward contract. They argue that producers will generally be exposed to market uncertainty for a longer period of time and therefore are more willing to enter contracts with longer time-to-maturity than the consumers, who have a shorter time horizon. This leads to a positive risk premium for contracts with shorter time-to-maturity and a negative risk premium for longer time-to-maturity. They also test their theoretical result empirically on the German electricity market where they find support for their model.

Pietz (2009) obtains similar results in a study of the German electricity market. As Benth et al.(2007) it is suggested that the consumers are mainly interested in hedging their short-term price exposure and therefore use short-term futures, whereas producers mainly use long-term futures. The economic rational behind this behavior may be the long-term character of investments in the energy industry.

This difference in behavior by producers and the consumers is translated into a positive risk premium in the short term and a negative risk premium in the long-term. In the German one-month delivery futures market evidence is found of a positive risk premium in short-term futures, which then decreases with increased time-to-maturity. There is also evidence of seasonality with a positive risk premium for delivery month in the winter and zero or even negative for delivery month in the summer.

There are also several studies made at Nord Pool. Kristiansen (2006) examine the efficiency of the Nordic market by comparing monthly and yearly forwards and finds evidence of lack in efficiency. This could be interpreted as if a significant difference between the forward price and the corresponding realized spot price is not due to risk premium but rather due to lack of pricing efficiency.

Marckhoff and Wimschulte (2009) look at risk premium in CfD:s at the Nord Pool market. They find that CfD:s on average contains a significant risk premium. The risk premium seems to differ in both magnitude and sign between different areas. They find a significant long-term risk premium and a positive short-term risk premium. The result also supports the Bessembinder and Lemon model with a positive relation between risk premium and variance of the spot price and a negative relation between risk premium and skewness of the spot price distribution.

Torró (2007) investigated weekly futures at Nord Pool from January 1998 to December 2005 and found significantly positive risk premium. Botterud et al. (2002) found a positive risk premium in futures with up to one year to delivery at Nord Pool.

In the field of stacked hedge, we will follow Wahrenburg (2000), which studies the well-known example of Metallgesellschaft. This work clarifies that to effectively handle risk it is important to consider the time perspective. The optimal way to hedge when risk is measured over short-term may deviate significantly from the optimal hedge when risk is measured over long-term. Metallgesellschaft lost a considerable amount of money as an oil retailer partly due to their hedge program, and it has been debated weather their hedge program was to be regarded as risk reducing or even risk increasing. Wharenburg shows through historical simulation that Metallgesellschaft's strategy of hedging in fact were effective in reducing long-term risk but that the equity base was far to low to cover the short-term risks.

The paper also analytically develops a way to minimize the risk of a three period rolled hedge.

Allen and Padovani (2002) extend the concept of rolling hedge by using options. They use a hedge technique that they call quasi static hedge which means that they adjust their hedge but try to minimize the number of adjustments.

2 Theory

2.1 Derivatives

Derivatives are financial instruments such as options, forwards and futures, which popularity have increased enormously during the last two decades. The price of a derivative is derived from an underlying asset, such as stocks, currencies and commodities. In most developed markets the turnover at the derivatives market is many times higher than the turnover at the actual market of the underlying asset. At Nord Pool the turnover in the financial market during 2009 was 333 TWh whereas on the spot market the turnover for the same period was only 96 TWh (http://www.nordpool.com/asa/).

Forward and futures contract are a type of derivatives that are very similar. In both cases the participants agrees to buy or sell a certain amount of an asset at a certain time at a predetermined price. The agreed price is called the forward or futures price. Note that no money is transferred until delivery. This can be contrasted by a spot contract which is an agreement to buy or sell an asset today. One of the parties of a forward or futures contract assumes a *long* position and agrees to buy the underlying asset on a certain specified future date for a certain specified price. The other party assumes a *short* position and agrees to sell the asset on the same date for the same price.

The contract time can be divided into a trading period, which is the time the contract can be traded at the market, and a delivery period which is the period during which the asset is delivered[1]. The time remaining of the contract until delivery is referred to as *time-to-maturity*.

The main difference between futures and forwards is that futures contract has a marking-to-market procedure where the profit or loss of the contract is realized day by day during the whole period between agreement and settlement, whereas in forward contracts the whole profit or loss is realized at delivery. It is also more common for futures to be traded on exchanges while forwards normally is traded over-the-counter. Forwards and futures can be treated as equal for pricing purposes under the assumption of deterministic interest rates but not if the interest rates are stochastic (Hull, 2006).

Three main categories of derivative users can be identified: Hedgers, speculators and arbitrageurs. Speculators use them to bet on future movement in a market variable. Arbitrageurs try to find inefficiency in the market to make risk free profits. Hedgers use them to reduce the risk they face from potential unfavorable movements in the market. For example, the later case can be illustrated by an oil-retailer company who knows that it needs to buy oil in six month. The company can then *hedge* the risk of unfavorable price movements by taking a long position at the same amount in the six-month forward market and thereby secure a price and hence reduce the risk of unfavorable price movements.

2.2 Risk premium definition

To understand the concept of risk premium we first have to look at how to price forward and futures contract. A common way of pricing financial asset- and commodity derivatives is the no-arbitrage or cost-of-carry model. If the forward price does not equal the cost of buying the asset today and hold it until maturity, an arbitrage opportunity will arise. Arbitrage means a certain profit without any risk of loss. If the forward price exceeds the cost-of-carry, an agent on the market can take a short position in the forward, buy the asset and then sell it at maturity with a cer-

[1] Most contracts never lead to delivery. The reason is that most traders choose to close out their position prior to the delivery period specified in the contract. Closing out a position means entering into the opposite type of trade from the original one (Hull, 2006).

tain profit (Hull, 2006)[2]. E.g. if the forward price of oil with one month to delivery dosen't exceed the cost of buying oil today and store it one month. Hence, today's spot price and the forward price are closely linked to each other. It is important to understand that this model relies on the ability to buy the underlying asset and then store it to maturity of the contract. The forward price $F(t,T)$ at time t and delivery in T in such a case can be described by the equation

$$F(t,T) = \left(S(T) + C(t,T) - Y(t,T)\right)e^{r(T-t)}$$

(Burger, Graeber & Schindlmayer, 2007)

Where $S(T)$ is the spot price, $C(t,T)$ is the cost of storing the commodity from t to T and $Y(t,T)$ is the sum of the additional benefits owners of the commodity obtains from time t to time T .

However since electricity can not be stored without facing unrealistically high costs, this model can not be applied to electricity derivatives. To buy or sell electricity today can not be regarded as the same product as electricity tomorrow or in one month. One can argue that electricity can be stored as water in dams. However, this is just a possibility for some producers. There are also a few technologies that in theory could be used to store electric energy acquired at the market in order to use it later. That is e.g. batteries and pumps. However, the amount of energy lost in this process and the cost of this utilities by far exceeds the levels at which one could make any commercial use of it. Hence there is today no realistic way of buying electricity in the market and then store it with intention to sell with a profit in the future.

A second approach in the pricing of derivatives is that of risk premium, where the forward price $F(t,T)$ is split between the expected spot price $E[S(T)]$ and a risk premium $\pi(t)$, so that the forward price can then be expressed as:

$$F(t,T) = E\left[S(T)|\Omega(t)\right] + \pi(t),$$

[2] In an efficient market such arbitrage opportunities will not occur frequently and if they do, speculators or arbitrageurs will take advantage of the situation. The demand for short position in forwards will rise. By the law of supply and demand the price on forwards will fall and the market will be arbitrage free again (Hull 2006 p.14).

where $E[S(T)|\Omega(t)]$ is the expected spot price conditional on the available information $\Omega(t)$ at time t. Here π represents a premium that market participants are willing to accept to eliminate the risk of unfavorable price movements. The sign of the risk premium depends on the market power, risk aversion and the planning horizon of the market participants. The willingness from different groups of participants to take positions on the market is in the literature referred to as hedging pressure (Benth et al, 2008), since the objective for entering the forward and futures market mainly is to hedge against unfavorable price movements.

A systematic difference between the spot price and the forward price does not lead to arbitrage opportunities but it can lead to a profit on average (Burger, Graeber & Schindlmayer, 2007).

2.3 Risk premia in electricity markets

In one of the first papers published in the filed of derivatives pricing, Keynes, (1930) argues that the forward price should always be below the expected spot price and hence a strictly negative risk premium. This is because the hedgers are mostly producers in a short position and their counterpart consists of speculators in the long position. The hedger is then willing to sell the asset at a discount to avoid a certain risk. On the contrary the speculators need a certain compensation to bear this risk.

This is not mainly the case on the electricity market, although it can be some times. The financial electricity markets are made up of many different types of participants e.g. retailers, producers, end customers and speculators. As explained by Bessembinder and Lemon (2000), and Benth, Cartea and Kiesel (2007) the hedging pressure from buyers and sellers shift with increasing time-to-maturity and the volatility and skewness of the price of the underlying asset. The following part is a combination of the theoretical results from this two papers and the empirical confirmation of them.

The construction of energy producing utilities is mainly a project with a very long-term economic horizon. To offset the risk of future fluctuations in revenue the producers wants to sell their electricity in long-term contracts. This induced hedging pressure from the producers will lead to downward pressure on the forward price and a negative risk premium for contracts with longer time-to-delivery.

Most of the consumers are generally more worried about price spikes. This means that an increased positive skewness of the spot price distribution leads to an increased hedging pressure from consumers. Hedging against price spikes is mainly of short-term nature. Hence, the influence of price spikes increase with shorter time-to-maturity and therefore also the hedging pressure from consumers. The demand for long position in forward contracts increase, which then leads to that the risk premium sign shift from negative to positive when time-to-maturity decrease.

Price spikes are most common in conditions of extreme temperature. This means that risk premia also can show a great deal of seasonality. Due to a large amount of electricity dependant heating and the absence of need for cooling in the summer, these extreme temperatures only affect the Scandinavian power system in cold weather and are hence only observed in the winter. In other parts of the world where air condition is common, price spikes also frequently occurs in the summer when the weather is extremely hot.

2.4 Liquidity and risk premium

To sum up what has previously been said, the price of forward contracts depends on supply and demand just like in any other open market. The balance of supply and demand shift due to different risk preferences of different actors and this is what creates the risk premia. The link between risk premia and market liquidity is then not very complicated to understand.

The liquidity of the market is a measure of the turnover. If the liquidity is low and a big player enters the market it is more probable that it is going to shift the balance and push the price in either direction. As mentioned the liquidity in the Nordic financial electricity market decreases with increased time-to-maturity which also means increased sensitivity in the market. An effect of this is that the sub areas in the Nord Pool market e. g. Stockholm price area is more sensitive than the system area since it is a smaller market.

The picture below is an example of a particular situation where the market price and risk premium is altered due to changed conditions but with constant expectations on future spot price which leads to risk premium in the market.

Supply and demand curve of a forward contract

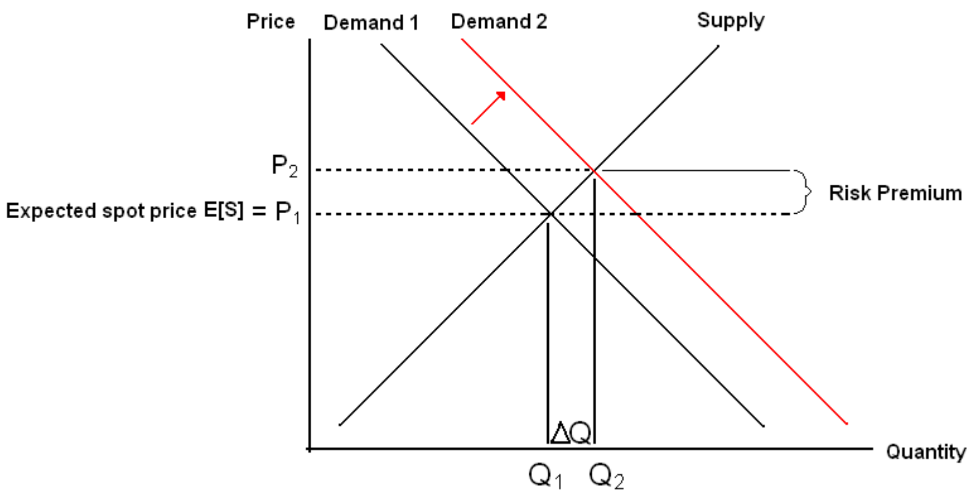

Figure 1. In P_1 supply and demand of the forward contract is in balance, buyers and sellers have the same risk preferences and price equals the aggregated expected spot price of the market. Demand for hedging increase, e.g. due to skewness in the spot price but the future expected spot price is the same. A new equilibrium occurs at P2. The difference in the forward price and the expected spot price consists of a Risk Premium - a price that the holders of long position have to pay to receive risk reduction. It is very probable that the bigger the increased demand ΔQ is compared to the quantity Q1 the more the risk premium will increase.

3 The Electricity market

3.1 Electricity trading and Deregulation

Electricity markets around the world start to get more and more deregulated. Among them, the Scandinavian market Nord Pool is one of the oldest and most developed.

Nord Pool is the common market for Sweden, Norway, Finland and Denmark. Nord Pool provides a spot market for physical trading, a financial market for trading with derivatives and a clearing function, which means that Nord Pool agrees to take the counterparty risk in the deals made by its participants.

Nord Pool first opened under the name Statnett Market AS when the Norwegian market was deregulated in 1993. In the turn of 1995 and 1996 the Swedish market also became deregulated with the purpose of increasing competition and cost reduction in the market. In January 1996 the existing Norwegian electricity exchange became available for both Norwegian and Swedish participant under the same conditions. The Swedish system operator Svenska Kraftnät bought half the shares of Statnett Market AS from the Norwegian system operator Statnett. At the same time Statnett Market AS changed name to Nord Pool. In 1998 Finland joined, and during 1999-2000 Denmark also became a member. The Nordic region was now to be regarded as a common open market for electricity trading.

3.2 Spot and Physical trading Nord Pool

Every day before 12:00 am, all the market participants give their buy and sell bids to Nord Pool where they have to decide how much electricity they are willing to buy or sell at a certain price for every hour the next day. The buy and sell bids are then aggregated to form a supply and demand curve. The intersection between those gives the spot price for every hour the next day. At 14:00 Nord Pool informs about the following days prices. This procedure is illustrated in figure 2.

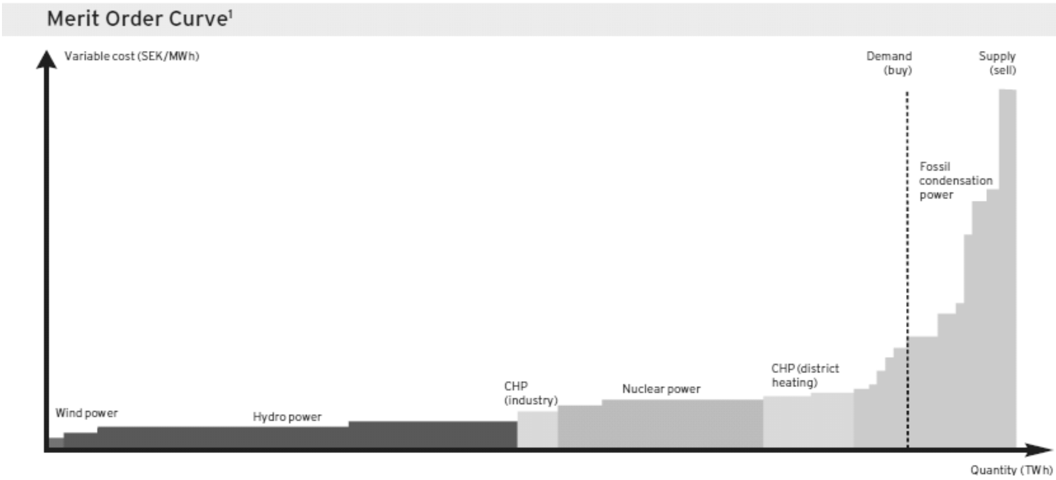

Figure 2. The Pricing in Nordic electricity market. Almost horizontal Demand curve gives opening for potential price spikes. http://www.vattenfall.com/en/file/europes-energy-markets_8459821.pdf

Due to the long time span (up to 36 hours) between spot market price fixing and delivery, the forecasted demand or supply of a participant may turn out to be wrong. Therefore Nord Pool also operates a market for adjustment which opens right after Nord Pool announces the next days system prices. This market is called Elbas and the exchange; EL-EX is only open to participants in Sweden and Finland.

Because the input effect must match the output effect at every point in time the Nordic transmission system operators(TSOs) also operates a market for regulating power where the participants can be asked to adjust their power output up and down in real time.

3.3 Price Areas

Due to restraints in the transmission system there are limits in how much power that can be transmitted from one area to another. These transmission restraints are typically referred to as bottlenecks. If electricity flows between areas, resulting from the Nord Pool auction, are within the capacity limits set by the system operators, all area prices are equal to the system price for the specific hour through the entire Nordic market. However, if the electricity flows reaches the available transmission capacities (i.e., congestion occurs) the market is split up and separate area prices are calculated. For this purpose, the market areas on each side of the congestions are combined and new equilibrium prices are calculated for every area, each in the same manner as before. The main price areas that exist are Sweden, Norway, Finland, West- and East Denmark. It is also possible to divide the market to even smaller sub areas. At the time of writing this paper, Sweden is in progress of being split up to four different areas.

3.4 Financial trading at Nord Pool

Besides the spot market Nord Pool also offers a market for standardized financial contracts, which range as long as up to five years into the future. The financial market is used both as a tool for risk management for retailers, producers and consumers as well as for speculation. Nord Pool offers four main types of financial contracts; options, futures, forwards and CfD:s.

Forward and futures contract at Nord Pool are settled financially which means that no actual delivery of the underlying asset takes place. Instead the difference between the agreed price and the spot price is paid out. In other markets, such as the German EEX, the contracts can also be settled physically which means that the long position holder actually receives the purchased amount of electricity.

Because of some special features of electricity, forward contracts with electricity as the underlying asset works different than contract on other assets (e.g. a stock or a barrel of oil). The special features of Nord Pool forwards and CfD contracts will be explained in more detail[3].

Futures are available for delivery periods of days and weeks. The currently traded forward contracts have delivery periods of months, quarters and years. The minimum volume of a contract is 1 MW. A buyer of this volume will receive 1

[3] In fact, financial electricity forward contracts resemble more of an other contract called a swap than a normal forward contract.

MWh every hour through out the entire delivery period. In 2006 Nord Pool switched from the previous season contract, which split the year in to three seasons, to quarter contract in order to adjust to international standards. Year-contracts are first listed five years prior to delivery, quarter-contracts are available for the current year and for every quarter the subsequent year, month-contracts are listed six months before delivery. This rolling cycle is showed in Figure 3.

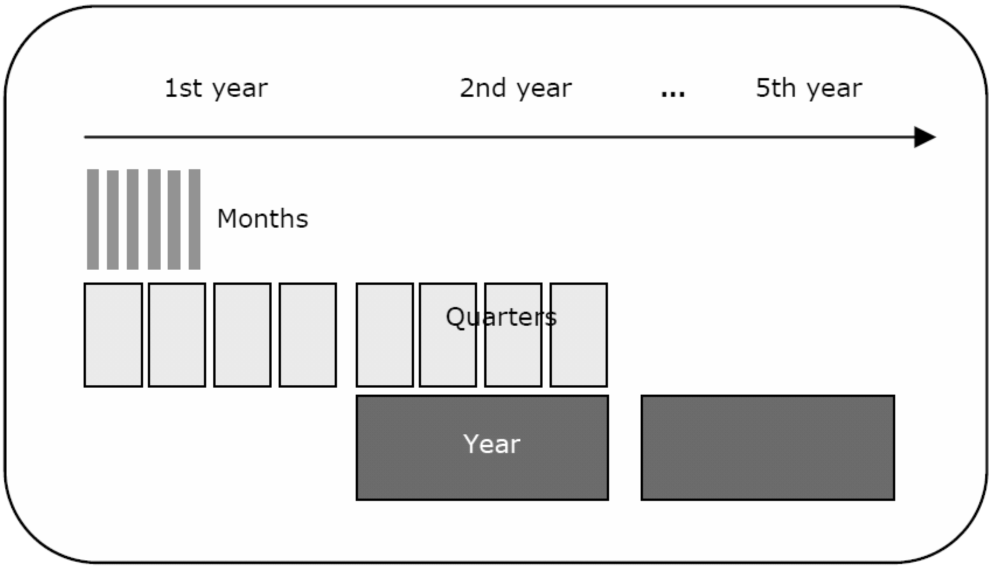

Figure 3. Illustration of the four year rolling cycle of Nord Pool forward contracts. (http://www.fer.hr/_download/repository/Nord%20Pool%20Financial%20Market.pdf)

CfD:s are a special type of forward contract where the holder of the long position receives the difference between the system spot price and the above mentioned special area price (Area Price – System Price). Because the ordinary forward and futures contracts are settled against the system price, this could be useful for a participant who is exposed to a special area price to further reduce the risk. CfD:s were introduced in November 2004. Together with a forward contract they can be used to form an artificial area forward. Nord Pool chose to use CfD:s instead of area forwards to ensure high liquidity in the system forward market. (J Marrckhoff, J Wimschulte, 2009). In order to make it easy to combine CfD:s with area forwards they are available for the same length of delivery periods. However CfD:s are not listed as early as system forwards. CfD:s are available for the nearest 2 months, 3 quarters and 3 years, for the corresponding products. CfD:s exists for the areas: Aarhus, Copenhagen, Oslo, Helsinki, and Stockholm. Although the names of the CfDs point out special locations they can be used in the entire price area that the specific place are located in. E.g the electricity price in Stockholm is the same as in the rest of Sweden since it is one entire price area, so the Stockholm CfD is applicable in the whole of Sweden.

3.5 Settlement of Nord Pool forwards

The Specific features of a Nord Pool electricity forward is presented below. Although this procedure may seem complicated it is designed to be an exact replication of an electricity transfer between two parts who agrees to buy or sell a fixed amount of electricity in the future to a fixed price. This is of course only true if they have the intention to buy or sell the same amount at the spot market as stipulated in the forward contract at time of maturity of the contract.

The special features of Nord Pool forwards are illustrated in figure 4.

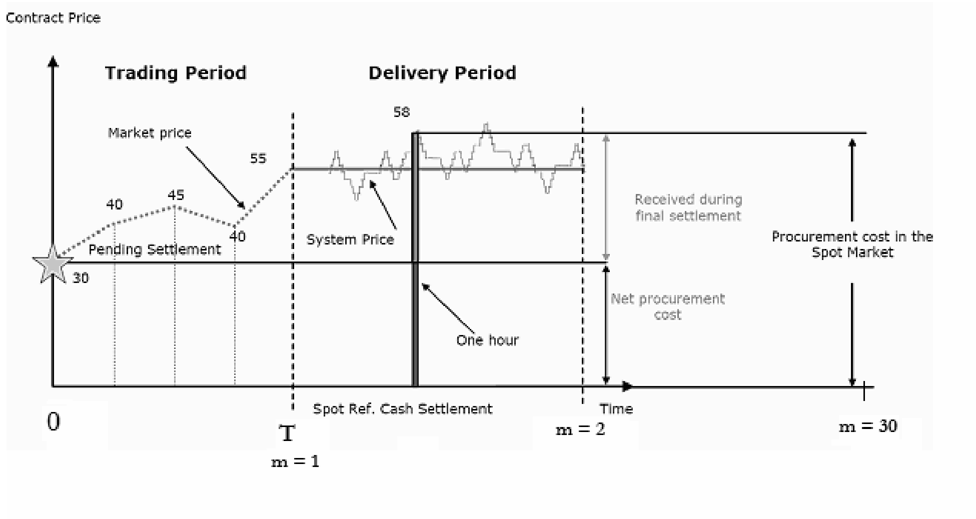

Figure 4. Forward contract settlement. Source: Nord Pool 2007-04-02

The contract time can be divided in to two periods. The first one is the trading period where the contract is still being traded at the market. The second one is the delivery period where financial settlement between the holder of the long- and the short position takes place. In figure 4 the forward contract is entered at a price of 30€/MW at time 0. During the trading period no cash settlement is done. When the contract reachs maturity at time T it has a value of 55€/MW. Now the delivery period starts and the holder of the long position receives $S_m^n - F_{t,T}$ every day during the delivery period from the holder of the short position, were S_m^n is the spot price and $F_{t,T}$ is the predetermined forward price at t with delivery in T, m denotes the specific day and n denotes the specific hour. The fact that the cash settlement is done step wise during the whole delivery period is due to the fact that the system spot price is only known until the next 24 hours.

Note that the transferred amount could also be a negative value which means that the holder of the short position receives money from the holder of the long position. In this case though, the spot price is steady above the contract price throughout the entire delivery period which means that the cash flow is strictly one way. In the specific hour that is illustrated above, the holder of the long position will receive 58 – 30 €/MW = 28 €/MW. In this way the buyer is compensated for the extra 28 €/MW that it needs to pay for the electricity on the spot market. More generally the pay-of from the forward contract can be expressed as

$$X_T = \sum_{m=1}^{30}\sum_{n=1}^{24}\left(S_m^n - F_{t,T}\right)$$

where X_T is the sum of all cash flows during the delivery period, S_m^n is the spot price hour m at day n and $F_{t,T}$ is the agreed forward price at time t with delivery during T.

3.6 Contract for difference (CfD)

The procedure of settlement of CfD:s is very similar to that of a forward contract, only that the price of a CfD is settled against the difference between the spot price of the specific area and the system.

The pay off from the CfD can be expressed as

$$X_T = \sum_{m=1}^{30}\sum_{n=1}^{24}\left(CfD_{t,T} - \left(S_{m,a}^n - S_{m,sys}^n\right)\right)$$

$CfD_{t,T}$ is the agreed price of the contract for difference at time t with delivery during T, $S_{m,a}^n$ and $S_{m,sys}^n$ is the spot price in the specific area respectively system spot price in hour n day m.

Together with a system forward an artificial area forward can be replicated. The implied area forward price can be calculated as

$$F(t,T)_a = CfD(t,T) + F(t,T)_{sys}$$

As long as CfD:s are traded, the market price of the specific area forward can be calculated. However, CfD:s have a shorter trading period than their corresponding system forwards. CfD:s with a delivery period of one month is listed just two month before delivery. CfD:s with delivery period of a year and a quarter have longer trading periods and can be used as an approximation of the month CfD:s with longer time-to-maturity, by splitting them up in smaller pieces, with some loss in accuracy as result.

4 Data and Method

4.1 Data

To be able to carry out a study with high enough statistical relevance the obtained data set has to be larger than would be possible for year and quarterly delivery contracts. The amount of available year contracts is at present limited to 13 and quarterly contracts were introduced as late as 2004 which gives 32 contracts. Therefore contracts with a month length will be used. To calculate the Stockholm area price, CfD:s will be used together with a system forward. The CfD is however already aggregated to the system price in the data set, so the calculation is only implicit.

The data used is obtained from two main sources. Firstly historical Nord Pool prices stored by Vattenfall will be used. This data set stretches back to January 2004 which will give a sample of 72 data points. It would be possible to obtain a larger data set by using data of monthly forwards taken from Nord Pools own server. However, prior to 2004 most of the financial products were designed in a different way, e.g. all contracts were traded in NOK. The trading period of this contracts are restricted to one year, which is long enough time for estimation of short term risk premium but not enough to estimate the long term risk premium.

To estimate the risk premium for contracts with longer time-to-maturity data is obtained from the forward curve used by Vattenfall Energy Trading. This is a combination of market data for available products, OTC-contracts and an estimation of market prices for products not yet listed. E.g. a monthly forward with delivery in two years can be estimated by the tradable quarterly forward by slitting it up in three pieces.

From the Vattenfall forward curve, prices of contracts with delivery until now can be obtained from August 2005. This gives a sample of around 55 data points which decreases with longer time to delivery. E.g. to estimate risk premium for contracts with two years to maturity one has to start with contracts traded from August 2007, which reduce the data set to 26 observations. This, of course effect the statistical significance with a decreasing effect for longer time-to-maturity.

4.2 Statistical method

Risk premium was earlier defined as

$$\pi = F(t,T) - E[S(T)|\Omega(t)]$$

Where $E[S(T)|\Omega(t)]$ was the expected spot price at maturity. Unless one has access to the aggregated anticipation of the future spot price from the whole market, the expected spot price can not be measured. There are two main ways to get around this. The first one is to develop an own spot price model to calculate the future spot price. The accuracy of this approach is of course very dependant on the assumptions made, and the accuracy of the model. To estimate the risk premium this way is known as the ex-ante approach

The other way, which will be used in this thesis, is called the ex-post approach. In this case realized spot price at time T, $S(T)$ is used as an estimation of $E[S(T)|\Omega(t)]$ and hence the risk premium is estimated as

$$\pi(t,T) = F(t,T) - S(T)$$

The drawback of this approach is that the difference not only depends on the risk premium but also on the precision in the prediction of the spot price made by the market participants. However, with a large enough data set and no systematic error in the predictions, the prediction errors should on average be zero and leave us only with the risk premium.

To empirically test if the risk premium is significantly separated from zero, the following hypothesis is formed.

$$\alpha = \sum_{i=1}^{n} \left(F(t,T)_i - S(T)_i + \varepsilon_t \right) \Big/ n$$
$$H_0 : \alpha = 0$$
$$H_1 : \alpha \neq 0$$

Where ε_t is the random error term and α is the risk premium. $\sum_{i=1}^{n} \left(F(t,T)_i - S(T)_i + \varepsilon_t \right) \Big/ n$ is the sample mean of the realized risk premium of the forward price day t with maturity in T. This will be done a number of times for different time-to-maturity to form a confidence interval and p-values for the mean.

Because forward contracts with delivery period of one month are used, the spot price $S(T)$ will be calculated as the average of the hourly price during the delivery period.

To estimate the risk premium in the Stockholm area in SEK an artificial area forward is created from the combination of a system forward and a CfD in the following way.

$$F_{Sto} = F_{sys} + CfD_{sto}$$

Where F_{Sto} is the price of the artificial area forward for the Stockholm price area, F_{sys} is the price of the system forward and CfD_{sto} is the price of the contract for difference for the Stockholm area. This is as mentioned above already done in the data set which is used. The hypothesis is formed in a similar way as above.

$$\alpha = \sum_{i=1}^{n} \left(F_{sto}(t,T)_i - S_{sto}(T)_i + \varepsilon_t \right) \Big/ n$$
$$H_0 : \alpha = 0$$
$$H_1 : \alpha \neq 0$$

Because the CfD are already aggregated in a Stockholm area forward the risk premium in the Stockholm area CfD will be calculated as the difference between the Stockholm area risk premium and the system area risk premium. To justify this, note that the price of the CfD is

$$CfD(t,T) = F_{sto}(t,T) - F_{sys}(t,T) \qquad (1)$$

where $CfD(t,T)$ is the forward price of the CfD at time t with delivery in T. The realized value of the CfD at delivery is

$$CfD(T) = S_{sto}(T) - S_{sys}(T). \qquad (2)$$

The final outcome is therefore $CfD(t,T)$ - $CfD(T)$, which gives the risk premium of the CfD as

$$\pi_{CfD} = CfD(t,T)) - E[CfD(T)] \; . \qquad (3)$$

By substituting equation (1) + (2) to HL of (3)

$$\pi_{CfD} = F_{sto} - F_{sys} - E\left[S(t,T)_{sto} - S(t,T)_{sys}\right] = F_{sto} - E\left[S(t,T)_{sto}\right] - \left(F_{sys} - E\left[S(t,T)_{sys}\right]\right) = \pi_{sto} - \pi_{sys}$$

$$\pi_{CfD} = \pi_{sto} - \pi \qquad (4)$$

Eq. (4) gives the risk premium in the CfD which is then calculated in a similar way as before.

$$\alpha = \sum_{i=1}^{n} \left(\pi(t)_{sto,i} - \pi(t)_{sys,i} + \varepsilon_t\right) \Big/ n$$
$$H_0 : \alpha = 0$$
$$H_1 : \alpha \neq 0$$

Similar to the system forward and the Stockholm area forward the means for different time-to-maturity and a confidence interval for the mean will be calculated.

4.3 Results from measuring risk premia

This is the result from the measurements of the risk premia carried out as described above. Time-to-maturity is measured as trading days left until the last day of trading.

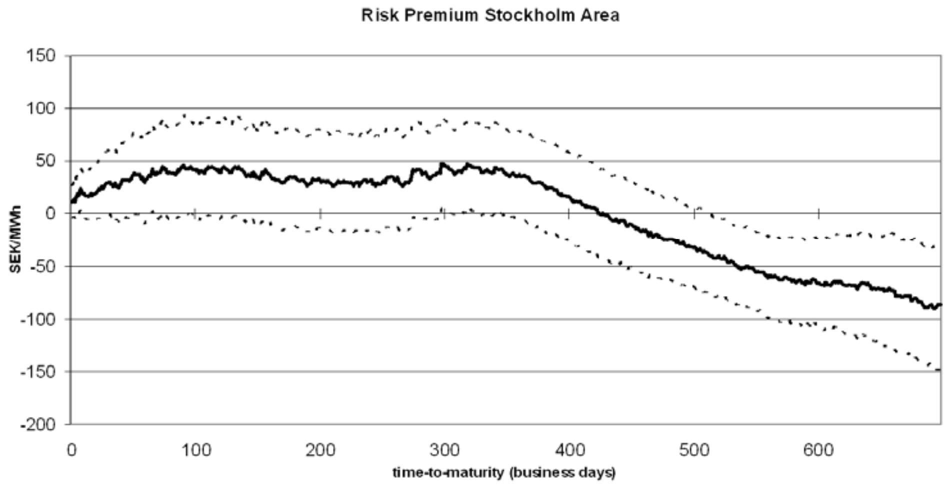

Figure 5. Risk Premium in the Stockholm area in SEK, with a 95-percent confidence interval of the mean. The forward prices used in the calculations are obtained from Vattenfall Energy Trading forward curve. Time-to-maturity is measured as days that the contract can be traded left until delivery.

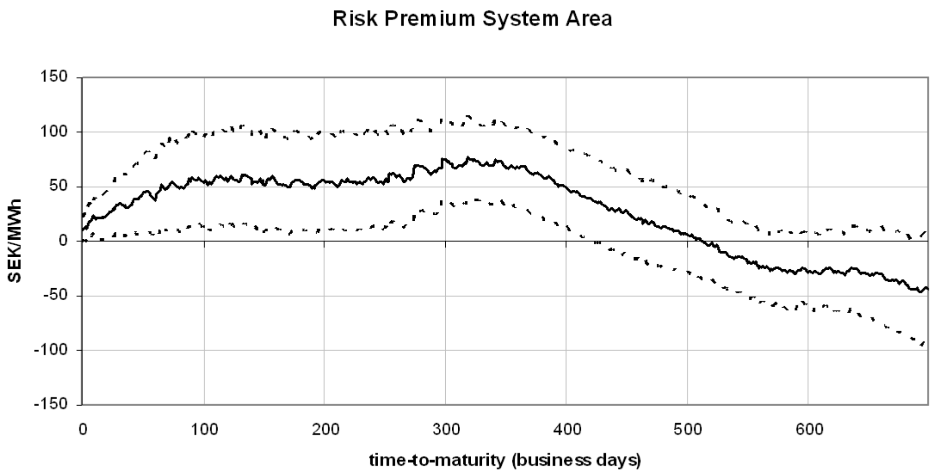

Figure 6. Risk Premium in the System area in SEK, with a 95-percent confidence interval of the mean. The forward prices used in the calculations are obtained from Vattenfall Energy Trading forward curve. Time-to-maturity is measured as days that the contract can be traded left until delivery.

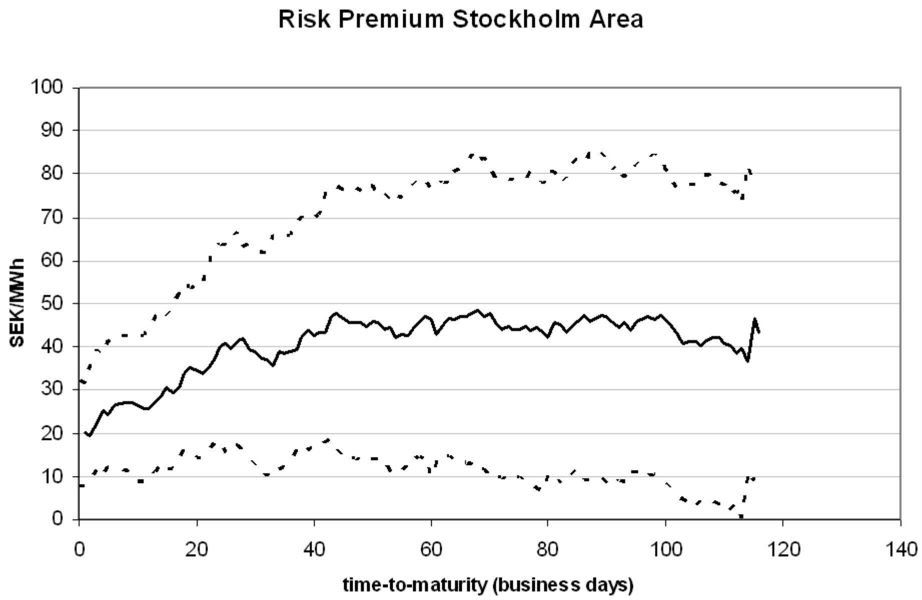

Figure 7. Risk Premium in the Stockholm area in SEK, with a 95-percent confidence interval of the mean with the difference that the forward prices are closing prices from Nord Pool which in this case gives a larger data set. Time-to-maturity is the number of days that the contract can be traded left until delivery.

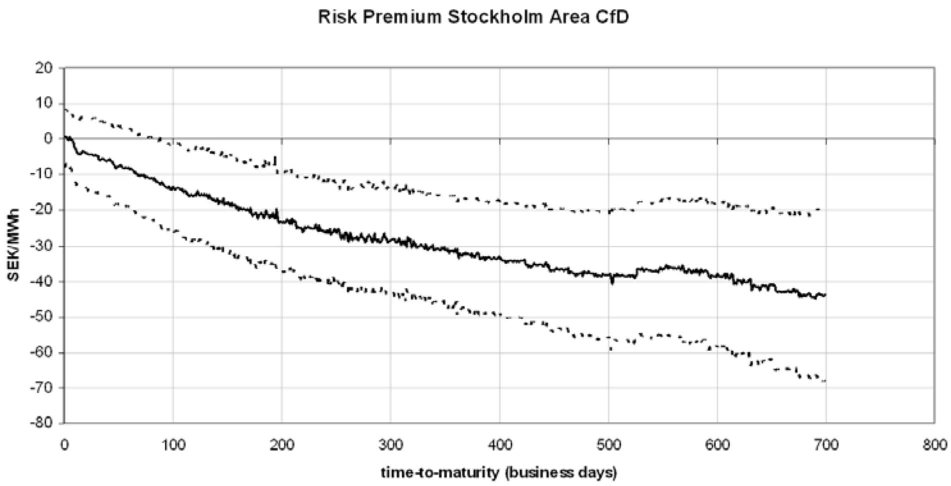

Figure 8. The risk premium in the CfD of the Stockholm area. Which is calculated as the difference between the risk premium of the system area and the risk premium of the Stockholm area, with forward prices from Vattenfall forward curve.

4.4 Comments on the results of measuring risk premia

Although the significance level of the results shifts, the results clearly indicates that the risk premium in both System and Stockholm area is positive close to delivery and negative when time-to-maturity increases. We can also se a significant negative time dependant risk premium in the Stockholm area CfD, i.e. a higher risk premium in the System area than in the Stockholm area. This means that by hedging production long time prior to delivery the expected return is lower compared to the case where the hedge is made closer to delivery. This effect is stronger in the Stockholm area than in the system. The short-term positive risk premia in the Stockholm and System area was highly expected and consistent with empirical results of previous studies. Although the data set is limited, especially in measuring the long-term risk premia the significance of the empirical results of the tests together with theoretical results from other studies make such strong case that the hypothesis of positive risk premium close to delivery and negative long-term risk premium can be regarded as true in terms of basis for decision making in the next part of this thesis.

The result from the market data analysis is consistent with that from the forward curve but with a higher significance due to a larger data set. This increase the reliability of the analysis made with data from the forward curve.

The results implicates that the expected return is higher when hedging closer to delivery than if hedging is made long time prior to delivery. However the risk is of course higher. This is due to the fact that today's spot price is positively correlated with future spot prices with a decreasing effect over time, i.e. when hedging close to delivery it might be too late to hedge against a low spot price from a global risk reduction point of view. Although this effect is less in the electricity market than in many of the other commodity markets, because electricity markets shows a great deal of volatility. This means that to smooth out the result fluctuations between years it is important to consider the time left to maturity. The decision of what to do will be the classical trade-off between risk and return.

5 Rolling the hedge, a way to handle insufficient liquidity and risk premia

The results from the previous section lead us into the question of what could be done to use the information of the difference in risk premia and if any such action is worth the possible extra risk.

A sometimes used strategy to coop with risks that can not be hedged with the preferable contract either by lack of liquidity or because time-to-maturity is to long for any contracts to be traded at the market, is the strategy of a rolling hedge where a more nearby and liquid contract is used, and then rolled over to the next-to-nearest contract as time passes. This could be a way to avoid the unfavorable risk premium in the long term contracts. The concept is explained below.

Suppose that in January an electricity company would like to hedge its continuous delivery of 1 unit every month during 4 years time from now, and that there are no such long-term contracts available in the market or that the market is not liquid enough. The company can then enter a short position in 48 (12 *4) March contracts and then in February, offset the March contracts and short 47 April contracts. In March the company offsets the April contracts and then shorts 46 June contracts, etc, until the end of the agreed delivery. This is called a stacked hedge.

In the case of a continuously delivering electricity company we will also have a continuous renewing of contracts so that the reduced position resulting from the latest delivery is replaced with a hedge of a new delivery in the front.

The idea behind this strategy is that the short term forward contract is positively correlated with the long term forward so that the result is protected in the same way as it should have been if the actual long term forward were used. This correlation is of course not always completely perfect and will lead to an extra basis risk in the portfolio[4].

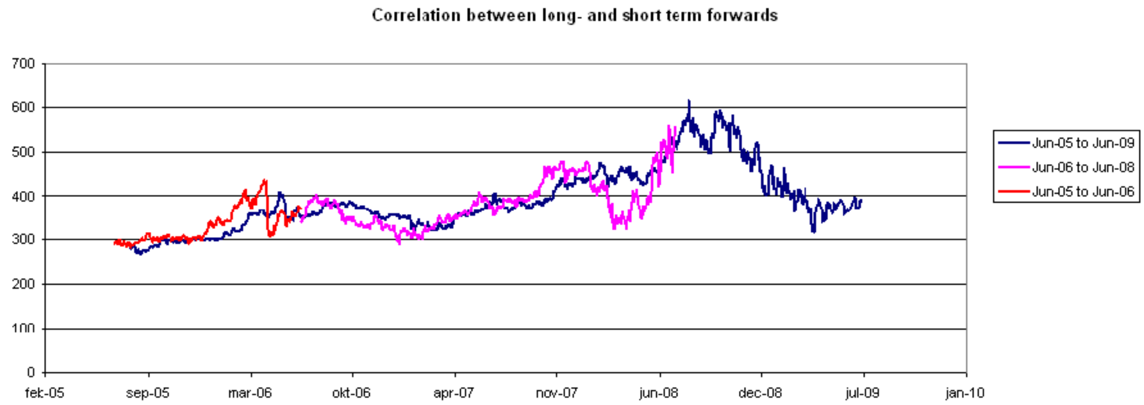

Figure 9. Illustration of price movements of a long-term forward contract and two short-term contracts. As can be seen in the figure the price movements is highly correlated although the delivery is separated with one year or more.

Also, every time the hedge is rolled over the value of the hedge is realized which means that the cash flow from the forwards will be partly separated in time from the cash flow of the physical delivery. The cash flow from the realized value of the contract is supposed to be compensated by changed present value of the future spot delivery in both possible directions. However this is probably the most problematic aspect of this strategy since the risk of short term cash flow fluctuations probably needs to be compensated with increased equity capital. As mentioned above we have the most famous example of Metallgesellschaft who went bankrupt after being unable to handle the short term cash flow fluctuations from there hedging program. (Mark Wahrenburg, 2000).

The question then is how to use this technique to offset the risk that Vattenfall faces in its long term hedges of about three to four years and in the same time avoid paying to high risk premium. In what frequency should the hedge be rolled and in what time compared to delivery should we choose the stacked hedge

[4] Basis risk is the risk that the spot price is not the same as the forward price at delivery, this can be true if the asset hedged is not exactly the same as the asset of the forward contract. This can be due to difference in time of delivery of the asset and the contract, or difference in the hedged asset and delivered asset.

The present value V_t at delivery from a one month delivery commitment and the combined hedge program can be calculated as follows. Let the average spot price during month T be $S(T)$, the Forward price at t with delivery in T be $F(t,T)$, the continuous compounded interest rate be r and the hedge ratio[5] used in time t be N_t. Then

$$V_t = N_0(F_{0,1} - S_1)e^{r \cdot t} + N_1(F_{1,2} - S_2)e^{(t-1)r} + \ldots + N_{t-2}(F_{t-2,t-1} - S_{t-1})e^{(t-1)r} + N_{t-1}(F_{t-1} - S_t) \quad (5)$$

5.1 Rolling Strategy and importance of time horizon in the view of risk

From Figure 5 which shows the Stockholm area risk premium one can clearly see that the risk premium really starts to decline when time-to-maturity reaches over 340 business days.

Suppose one wants to hedge a delivery three years from today. By using a three-year contract one can see by looking at the graphs that the risk premium at that time on average is -80 SEK/MWh[6]. By using a one-year contract and then at the end of the first year roll over to a two-year contract the risk premium would on average be 40 SEK/MWh – 30 SEK/MWh = 10 SEK/MWh. The price paid is of course an increased risk due to the fact that the correlation between $F_{0,2}$ and $F_{0,3}$ is probably less than perfect, i.e. the contract used is not perfectly correlated with the contract that has the same time-to-maturity as the delivery one wants to hedge.

It would be desirable to evaluate this strategy by measuring the tradeoff between risk and return for different hedge ratios and frequencies in the rolled hedge. This would preferably be done by creating an efficiency frontier[7] to see how much extra risk is given a certain extra return.

The performance of the strategy in terms of risk and return can be evaluated in more than one way. It is important to clarify what time horizon one wants to mini-

[5] Hedge ratio is the ratio between the delivery that is hedged and the amount of contracts used to hedge, e.g. if a delivery of 10MW is hedged with 8 MW forward contract the hedge ratio is 0.8).

[6] (one year = 250 business days)

[7] An efficiency frontier is created by plotting every possible asset combination in the risk-return space so that it forms a continuous line, the upper part of this line is the efficiency frontier

mize the risk when the hedge ratio is chosen. E.g. if the risk is supposed be minimized over the whole program i.e. the global risk or next period of time, i.e. the local risk, the strategy is probably going to look different. To estimate the minimum variance hedge ratio for one period the normal way is typically to use a regression between the long term forward and the short term forward which gives the optimal hedge ratio. The risk minimum variance hedge can in many cases be calculated analytically, see Wahrenburg(2000). However we don't just want to minimize the risk but also try to find a way to minimize the negative effect of risk premia at a certain risk which means that the risk has to be compared to the return.

A robust way to evaluate the strategy of rolling the hedge would be to use the method of Wahrenburg(2000), and use historical data to estimate the performance of the strategy by calculating the cash flow from a hedging program of oil for different hedge ratios. This could be applied in a similar way to equation 6 to estimated return and the variance in cash flow from a hedge program in electricity forwards. The advantage of this approach is that it not only shows the minimum risk but also shows the expected return. A higher expected return is a prerequisite for the rolling hedge strategy to be used. Another advantage is that it also covers the precontractual risk. From a global perspective just signing the contract and lock in a future cash flow doesn't remove all risk from the point of view that the forward price can be in a global minimum. It is desirable to minimize the frequency of the times the hedge is rolled over. This is both due to uncertainty of future transaction costs and future change in market prices. (Allen & Padovani 2002). Therefore the maximum times that the hedge is rolled is set to three.

For Vattenfall the following four strategies would be of interest.

$$V_3 = S_3 + N_0\left(F_{0,3} - S_3\right) \tag{6}$$

$$V_3 = S_3 + N_0\left(F_{0,2} - S_2\right)e^r + N_1(F_{2,3} - S_3) \tag{7}$$

$$V_3 = S_3 + N_0\left(F_{0,1} - S_1\right)e^{2r} + N_1(F_{1,3} - S_3) \tag{8}$$

$$V_3 = S_3 + N_0\left(F_{0,1} - S_1\right)e^{2r} + N_1(F_{1,2} - S_2)e^r + N_2\left(F_{2,3} - S_3\right) \tag{9}$$

This is the case of hedging one month of delivery three periods prior to delivery with a one month forward contract. Even tough a total period of three years or more would be preferable in the evaluation to really capture the long term effects, the period is set to 2 and a half years (30 months), which means that the index figure 1 represents 10 months and hence, 2 and 3 represents 20 and 30 months. This is done due to the limitations in available data. The evaluation is made for a continuous delivery of one MW every month for a period between January 2008 and February 2010, which gives a total number of 26 evaluations[8].

In the first case the delivery is hedged directly with a three-year to maturity forward. In the second case the position is first hedged with a two-year to maturity forward and then rolled over to a one year to maturity forward. For the third strategy the delivery is first hedged with a one-year to maturity forward and then rolled over to a two-year to maturity forward. In the final fourth strategy the delivery is hedged with a one-year to maturity forward and then rolled over to a new one- year two maturity forward and then rolled over again to a one-year to maturity forward.

These strategies will also be compared with the strategy of hedging everything 30 month prior to delivery, hedging everything 15 month prior to delivery and the strategy of not hedging at all.

This will also be evaluated for a number of different hedge ratios to show how it can affect the different strategies in terms of risk and return. Hedge ratios can be set in a number of different ways. Especially in those cases where the hedge is rolled two times or more where it is possible to combine different hedge ratios. To keep down the amount of possible cases the hedge ratio N_t is calculated as N/(years to maturity), which increase the hedge ratio for the contracts used closer to maturity. This follows no scientific model used for hedging purpose but is used both because it resembles the way that the hedging is done in real, where the hedge is increased over time and it also turns out to outperform a static hedge ratio.

It is also important to emphasize that it is beyond the scoop of this thesis to try to fully optimize the way to use a rolling hedge but mearly to introduce a concept and show that it can be well performing. This is firstly due to the fact that the available data set is still small so that all results of the estimation of historical data should be interpreted with caution. Secondly, there are so many more aspects to consider, if a

[8] In a real case the actual price of the delivery would be the power times hours of the month times the price, In this case it is simplified to just one MWh for every delivery. This of course effect the weight between month with different length but this should not affect the result in any significant extent. It also makes it easier to interpret the results since returns are often measured as average price per MWh.

real optimization of the risk and return of a hedging program is to be carried out that it is no meaning to try to find the absolute best way in this thesis.

If the strategies turn out to be effective they should produce a low volatility of the final payoff and compensation for the extra risk taken i.e. a higher return. One drawback is that the volatility is calculated as the deviation between months. Typically the difference in the result is measured over years or quarters.

The spot prices used for the simulation are the spot prices at Nord Pool for the Stockholm area in SEK stored by Vattenfall. The Forward Prices used are obtained from the Vattenfall forward-curve. Interest rates are obtained from the Swedish central bank, zero-coupon rates are used and when the time-to-maturity differs between the zero-coupon and the cash flow from the hedging program the used interest rates are interpolated.

5.2 Results from evaluation of the stack and roll strategy

Figure 9 shows the results of different rolling hedge strategies along with their efficiency frontiers created by variations in hedge ratio. As can be seen, they all converge in the point of "No hedge", which is also a way to see whether the efficiency frontier contains higher or lower hedge ratio than that of the variance minimizing ratio. The variance is here measured as the difference in return between different months. The drawback of this approach is that the return is subjected to a significant difference between different times of the year, e.g. the return in a winter month has a higher expected return than a month in the summer. Therefore some volatility is automatically expected in the result.

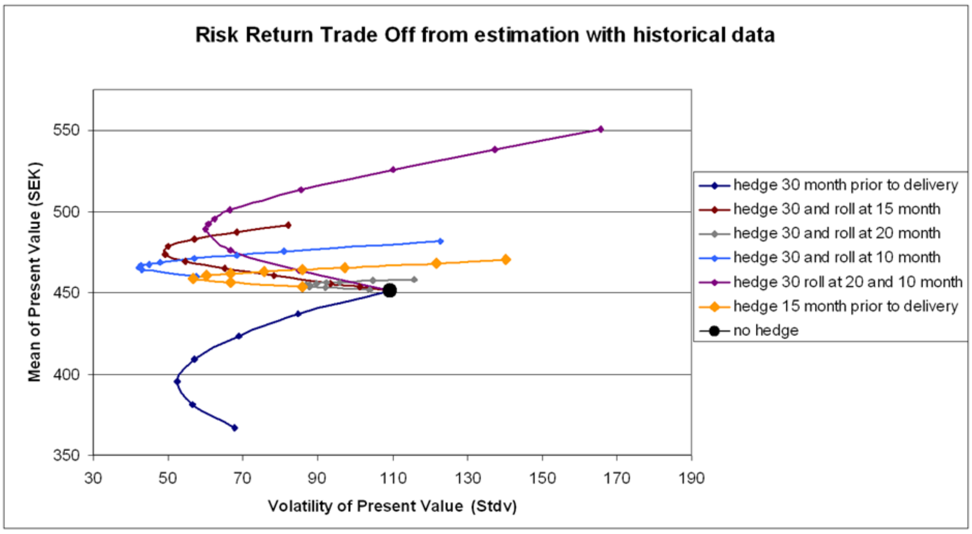

Figure 10. Performance of the different hedge strategies in terms of risk and return

Almost all the strategies perform better or nearly as good as the strategy of hedging the entire delivery 30 month prior to delivery in terms of volatility in the result, and they all outperform the strategy of no hedge. All the strategies except that of hedging all 30 month prior to delivery have a higher expected return than the no hedge strategy. This is in line with the result from measuring the risk premium and it could also be an effect of higher present values in earlier cash flows.

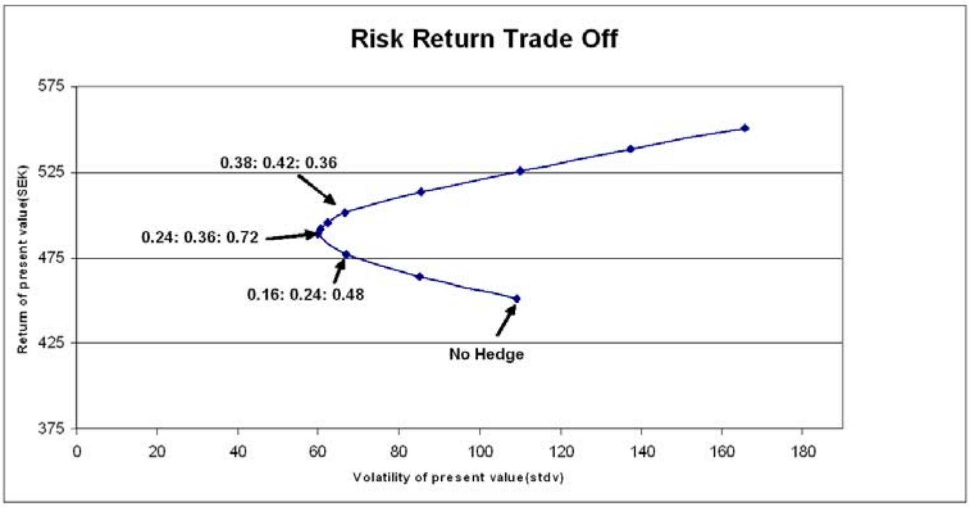

Figure 11. The best performing strategy in terms of return are lifted out which is the strategy of rolling the hedge at 30, 20, and 10 month prior to delivery. Interesting hedge ratios at the frontier are plotted. It should be stressed that the fact that the strategy is best performing in terms of return doesn't necessarily means that it is the best performing strategy which is dependant of the risk aversion

Figure 12 shows the local cash flow risk which is an attempt to capture the extra basis risk caused by the rolling hedge strategy. The basis risk is as explained above the extra risk that is induced by not hedging the exact product that is bought or sold. In this case we have a time difference. The Basis risk is here measured as the difference in cash flow from the price received when entering the first forward contract of the rolling cycle. As can be seen in figure 12 the cash flow risk is in this theoretical example zero when using a standard 1:1 hedge without volume risk, i.e. a perfect hedge. It should also be noted that it here is negative to have a high value on the vertical axis since it indicates high volatility.

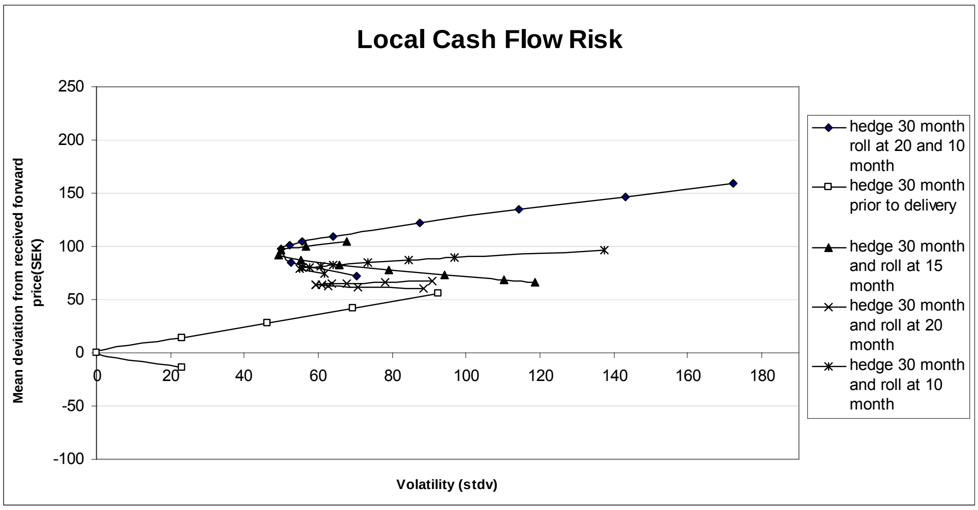

Figure 12. Basis risk measured as deviation from perfect hedge together with one standard deviation.

6 Conclusion

When it comes to the risk premium the statistical tests are consistent with the prevailing theories in the field. The risk premium is positive close to maturity which is consistent with other empirical as well as theoretical results. It is negative with longer time-to-maturity which confirms previous theoretical results. It would of course be desirable to have a longer time-series of data since the period used can be divided into two separate periods. First it is the time from the 2005 where we had an upward market which can be one explanation of the long time negative risk premium and secondly we had the time after the financial crisis with start 2008 where we had a very downward sloping market. A longer time-series would probably be able to span over more business cycles and hence give a more reliable result especially when it comes to long time risk premia.

The risk premium in the Stockholm area is on average lower than in the system area, which is the same as a negative risk premium in the CfD. This is the case from the last day of trading with an increasing effect when time-to-maturity increase.

If the theory of liquidity dependant risk premia holds the risk premium in the Stockholm area CfD should be above the system area risk premium when the risk premium is high and below when the risk premium is lower, i.e. stronger effect on both the up and the down side. This is however not the case. The risk premium is steady below zero. There are of course other possible causes for this result. But why that is the case is hard to say. The confidence interval exceeds zero close to maturity which makes it possible for the risk premium to have a positive value close to maturity.

The risk premia is in this thesis measured without consideration of possible seasonality. Since price-pikes are seasonal phenomena it is highly likely that the risk premia also shows seasonality. This is both a theoretical result and proven empirically in the German market by Pietz (2009). When hedging contracts with shorter delivery periods than a year this is of course an issue for efficient risk management.

The fact that the risk premium is higher in the system area for almost all time-to-maturity indicates that there are profits to be made by the usage of a proxy hedge of system forwards instead of the Stockholm area forward which also should be interesting to analyze in terms of risk and return.

A rolling hedge seems in the simulations made in this thesis to be an efficient way to increase the expected returns without significantly increasing the risk. This is however only with respect to the global risk and not on the local. As with the risk premia the result should be interpreted with caution since the data set is limited. Further testing should be carried out and since the amount of available data increases rapidly in proportion the potential for better results also increases.

If choosing to implement a rolling hedge it is recommended that the hedger takes in consideration not only the possible effect on the result but also the cash flow risk.

The rolling hedge strategy can be designed in a numerous different ways. It would not be difficult to optimize the hedge ratios of a certain delivery under certain constraints if only the constraint would be known. The constraints should be composed to suit the special conditions of the specific portfolio. Such constraints could e.g. be dependant on volume and cash flow risks. Therefore an optimization of such a hedge should if implemented be done with respect to the specific case and not arbitrary as in this thesis.

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7 Appendix

Table 1. This table presents the mean realized risk premium for a number of different times-to-maturity for the Stockholm area along with the p-value. Calculations are based on the forward curve. P-value is measured as the one sided probability that the real mean value is above zero for positive numbers and below zero for negative numbers.

time-to-maturity	mean	p-value
1	11.06	0.066217
10	11.58	0.025814
50	24.77	0.028046
100	30.77	0.031092
150	24.36	0.058547
200	22.34	0.084946
250	17.38	0.073147
300	35.18	0.024391
350	29.34	0.042936
400	9.93	0.301315
450	-19.94	0.201918
500	-43.72	0.033897
550	-67.86	0.002007
600	-80.12	0.002648
650	-85.98	0.003097
700	-104.20	0.002113

Table 2. This table presents the mean realized risk premium for a number of different times-to-maturity for the System area along with the p-value. Calculations are based on the forward curve. P-value is measured as the one sided probability that the real mean value is above zero for positive numbers and below zero for negative numbers.

time-to-maturity	mean	p-value
1	10.24	0.027806
10	21.53	0.006016
50	43.28	0.007585
100	55.27	0.005138
150	52.29	0.009252
200	56.22	0.006975
250	55.15	0.007896
300	75.18	0.000178
350	68.60	0.000297
400	49.78	0.004231
450	28.13	0.070407
500	5.88	0.363516
550	-19.59	0.121502
600	-28.54	0.051282
650	-30.38	0.067635
700	-42.92	0.045823

Table 3. This table presents the mean realized risk premium for a number of different times-to-maturity for the System area along with the p-value. Calculations are based on the forward curve. P-value is measured as the one sided probability that the real mean value is above zero for positive numbers and below zero for negative numbers.

time-to-maturity	mean	p-value
1	20.27	0.000934
5	24.26	0.000284
15	30.44	0.000782
20	34.73	0.000521
25	40.99	0.000923
30	39.04	0.002049
40	42.78	0.000906
50	46.12	0.002726
60	46.46	0.006154
70	47.79	0.006833
80	42.22	0.006004
90	47.07	0.008866
100	46.42	0.008386
110	40.76	0.019750
120	11.14	0.263671

Table 4. This table presents the mean realized risk premium for a number of different times-to-maturity for the CfD along with the p-value. The p--value is measured as the one sided probability that the real mean value is above zero.

time-to-maturity	mean	p-value
1	0.82	0.415447
10	-2.45	0.282982
50	-7.52	0.084010
100	-13.27	0.016412
150	-18.22	0.003812
200	-23.21	0.000946
250	-26.14	0.000275
300	-28.56	0.000199
350	-31.13	0.000106
400	-33.08	0.000085
450	-36.99	0.000053
500	-38.15	0.000068
550	-36.45	0.000362
600	-37.85	0.000371
650	-40.90	0.000285
700	-44.00	0.000605

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