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Risk Premia in Electricity Wholesale Spot Markets – Empirical Evidence from Germany

Matthäus Pietz*

This paper contributes to the ongoing discussion on price formation in electricity markets. For this, we conduct an analysis of the German electricity wholesale spot market which is located at the European Energy Exchange (EEX). Our dataset covers three spot market segments, namely the intraday market, the block contract market and the day-ahead market. Data ranges from August 2002 to May 2009. As results we find significant positive risk premia, both in the block contract market and in the day-ahead market. The risk premia in day-ahead market contracts vary in magnitude and in sign throughout the day. Furthermore, we detect a term structure of risk premia during the sub-period in which all three market segments were simultaneously existent. When testing for seasonality in the risk premia, we find evidence for higher risk premia in the summer months. The hypothesis of a relation between the risk premia and the spot price variance and skewness has to be rejected.

Keywords: Electricity, Intraday Market, Day-Ahead Market, Risk Premia, Risk Premium

JEL classification: G13, L94, Q40

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1. Introduction

Electricity as an exchange traded commodity emerged around fifteen years ago. Its non-storable nature together with its other special characteristics made the trading in this commodity from the beginning a challenging task.[1] Thus electricity trading established itself fast as an independent profession. The academic profession has also quickly recognized the exchange traded commodity electricity as an interesting research topic, with research mainly focusing on questions related to market efficiency, price forecasting and the mechanisms behind price formation, both in spot and futures markets. These questions are of particular interest since electricity exchanges are designed as wholesale markets, resulting in a relatively low number of market participants. Therefore, a still ongoing discussion on whether price formation is efficient in these markets and whether price manipulation is possible, e.g. by imposing market power, emerged immediately. The concentration of the generation capacities in the hands of only a few companies is further fuelling this discussion.[2]

Our paper aims to contribute to this discussion through an analysis of the price formation in the German electricity wholesale spot market. Trading in the German spot market in its current form started in 2002. At the beginning there were two market segments, a day-ahead and a block contract market. Later an intraday market was established and the block contract market was closed. Specific blocks of (successional) hours are traded in the block contract market whereas single hour contracts are traded in the day-ahead and intraday market.[3] All contracts in the spot market imply physical settlement. Contracts traded in different market segments in part have identical delivery periods. Trading in the block contract market and in the day-ahead market takes place from one to three days before delivery. In the intraday market trading takes place up to 75 minutes before delivery. The former two market segments therefore virtually represent futures markets with a time-to-delivery of one to three days. During the period in which the block contract market has been existent it was possible to replicate a long position in a specific block contract by taking a

[1] See Bierbrauer et al. (2007) for stylized facts on electricity markets.

[2] In Germany two companies control around 50% and four companies almost 85% of the generation capacity. For further details see Weigt and von Hirschhausen (2008).

[3] Electricity contracts, both spot and future, are due to the non-storability always characterised by a delivery period.

long position in the corresponding hour contracts in the day-ahead market. Since the introduction of the intraday market, electricity for delivery in a specific hour can be bought in both the day-ahead and intraday market. For a short time period, September 2006 to August 2008, contracts with the same delivery period were traded in all three market segments.

In an efficient commodity market with risk-neutral market participants, identical contracts – except the time-to-delivery – should, at least on average, have the same price (Borenstein et al. 2008). Based on this assumption we would expect the same price for contracts with identical delivery periods in all market segments of the spot market. However, empirical research shows that this is not the case in electricity markets, neither in spot markets (Longstaff and Wang 2004) nor in futures markets (Shawky et al. 2003). Prices differ and empirical results suggest that in electricity spot markets prices are higher in market segments where trading takes place earlier. These price differences seem to be persistent. This is not necessarily a sign for an inefficient market. Assuming a market in equilibrium and using the hedging pressure approach, the risk-aversion of market participants who are willing to pay a risk premium for the possibility to hedge their price risk may be used as an explanation for the observed price differences. The frequent price peaks in electricity spot markets which can have ruinous consequences for unhedged market participants outline the importance of hedging in electricity markets and thus support this explanation. Therefore, according to the hedging pressure approach, we interpret the price difference between two market segments as a risk premium paid for the transfer of price risk.

Our analysis of the German spot market yields the following results: we find evidence for the existence of significant risk premia. These risk premia are positive, i.e. according to the theoretical considerations above identical contracts are priced higher in market segments where trading takes place earlier. The positive risk premia are observed in both the block contract market and the day-ahead market. Thus both block contracts and day-ahead market contracts are upward-biased estimators of the expected spot prices during the delivery period. When analysing the day-ahead market, we also find that the risk premia are extreme volatile and change in sign throughout the day. Testing for seasonality in the risk premia we detect evidence of higher (positive) risk premia in summer months. Furthermore, we find evidence of a term structure of risk premia when analysing the period in which all three market segments have been simultaneously existent. Risk premia seem to be higher in contracts with a longer time-to-delivery. The analysis of potential drivers yields no significant results for the relation between the risk premia and the variance and skewness of the realised spot prices.

The research of this paper is related to the work of Ronn and Wimschulte (2009) and of Viehmann (2009). Ronn and Wimschulte (2009) conduct a first empirical analysis of the block contract market; Viehmann (2009) conducts a first empirical analysis of the day-ahead market. We confirm the results obtained for the block contract market and find similar results for the day-ahead market. However, we estimate the risk premia in the day-ahead market differently than Viehmann (2009). By extending the sample period as well as including the intraday market in our analysis we are also able to answer further reaching questions regarding the German spot market. We contribute with our research at least two-fold to the existing literature. First, to our best knowledge, we are the first to conduct an in-depth analysis of the German intraday market. By analysing a sample period covering almost 33 months we believe that first empirical conclusions can be drawn. Second, the sample period in which all three market segments of the German spot market were simultaneously existent, gives us a unique opportunity to investigate the existence of a term structure of risk premia on a very short time scale.

This paper is structured as follows: In the second chapter we describe the setup of the German electricity spot market and characterise the individual market segments. In the third chapter we discuss the theoretical background on price formation in electricity forward markets and the risk premia approach. In addition, we review the existing empirical literature. The fourth chapter contains the results of our empirical analysis. Starting with a description of our data we then report the estimated risk premia. Thereafter we investigate the existence of a term structure of risk premia and analyse potential drivers. In the fifth and last chapter we conclude our results and discuss promising venues for future research.

2. The German Electricity Spot Market

In this chapter we provide background information on the European Energy Exchange (EEX) and discuss each of the three market segments of the spot market.

European Energy Exchange

The EEX is located in Leipzig, Germany, and was founded in 1999. The EEX exists in its current form since 2002, after the former European Energy Exchange, then located in Frankfurt, merged with the Leipzig Power Exchange. The tradable commodities on the EEX are coal, electricity, emission rights, and gas. Clearing of OTC trades is also offered. The trading of electricity takes place in a spot and in a derivatives market. The derivatives market consists of a futures and options market, the spot market of an intraday and a day-ahead market. The day-ahead market has been active since the founding of the EEX. The intraday market was introduced in September 2006 (EEX 2006). In addition, contracts for three specific blocks of hours have been traded in a block contract market until August 2008.[4]

The EEX is the largest energy exchange in continental Europe and – after the Scandinavian Nord Pool – the second largest in Europe. There are currently around 235 participants from over 20 countries trading in the spot and futures market of the EEX. The traded volume in the spot market in 2008 was around 150 TWh. When compared with a yearly (gross) electricity consumption of around 610 TWh in Germany almost 25% of the German electricity is traded in the spot market of the EEX. Similar to other electricity exchanges most of the traded volume in the spot market – over 95% – is observed in the day-ahead market. The intraday market seems to be mainly used as a balance market for short-term adjustments (Weber 2009).

Day-Ahead Market

The day-ahead market is used for trading of contracts with a delivery period of one hour. These hour contracts[5] ensure the delivery of electricity over a specified delivery hour. The price finding mechanism in the day-ahead market is a uniform auction, a common and accepted mechanism in European electricity day-ahead markets (Ockenfels et al. 2008). All buy and sale orders are thereby collected in a closed order book. For a specific hour contract orders can be entered, changed, deleted or retrieved up to 14 days before delivery; the auction takes place on the last exchange day before the delivery day.[6] In every auction 24 independent prices are established for each single hour of the delivery day. Until September 2008 auctions were only taking place from Monday to Friday and not on public holidays, i.e. on Fridays and before public holidays more than one auction took place. Starting with September 9, 2008 the EEX introduced seven-day-trading in the day-ahead market (EEX 2008b).

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[4] In 2008 the EEX and the French energy exchange Powernext declared an intense cooperation. The result of this cooperation is a common electricity spot market, located in Paris, and a common electricity futures market, located in Leipzig.

[5] For further details regarding the contract specifications see EEX (2008c) and EEX (2009).

[6] For further details regarding the trading process see EEX (2008a).

The EEX calculates a daily and a monthly index for the day-ahead market, the Physical Electricity Index (Phelix). The daily index is calculated as a simple arithmetic average of the hourly prices for the base (0 am to 24 am) and peak hours (8 am to 8 pm). The monthly index is calculated as an arithmetic average of the daily index values. The monthly Phelix Peak is only calculated based on prices between Mondays and Fridays.

Intraday Market

In the intraday market hour contracts with similar specifications to the day-ahead market are traded. The main differences compared to the day-ahead market are the trading period and the price formation mechanism. The intraday market operates as a continuous market and trading takes place around the clock, seven days a week. Trading in a specific hour contract starts at 3 pm of the previous day and lasts up to 75 minutes before beginning of the delivery hour. The trading periods of the hour contracts of a certain day are therefore different as they all have different ending points.

Trading at negative prices occasionally occurs in the intraday market.[7] The possibility of negative prices emerges due to the fact that production of electricity cannot be stopped in the short-term and/or implies very high costs.

Block Contract Market

Trading took place in the block contract market until August 2008. Block contracts ensured the delivery of power over several delivery hours. Traded block contracts were a base load, a peak load and a weekend base load contract.[8] The base load block contract ensured delivery of electricity throughout the day while the peak load block contract ensured delivery in the peak hours (8 am to 8 pm) only. The base load block contract was available for all days,

[7] Negative prices in the intraday market were introduced in December 2007. During the analysed sample period we observe 35 hours with a negative price in the intraday market. All negative price observations occur on non-working days, mainly in the morning hours. The permitted price range for intraday market contracts is from minus to plus 9999 Euro/MWh. It is also allowed to bid negative prices in the day-ahead market (price range: -3000 Euro/MWh to +3000 Euro/MWh; introduction of negative prices in 2008). During the analysed sample period we observe 32 hours with a negative price in the day-ahead market, 15 on working days and 17 on non-working days. All observed negative prices occur also in the morning hours, with the 15 negative price observations on working days concentrated on three days.

[8] The weekend base load block contract was introduced at a later date compared to the two other block contracts, starting trading on November 1, 2002. However, replicating the weekend base load block contract had already been possible by taking long positions in base load contracts with delivery on a Saturday and a Sunday.

the peak load block contract only between Mondays and Fridays. The weekend base load block contract ensured delivery in all hours of the weekend. Trading in the block contract market included an auction mechanism as well as a continuous trading period. Trading took place between 8 am and 12 am and was divided in the opening auction, the continuous trading period, and a closing auction.[9]

Today, the same blocks of (delivery) hours as in the block contract market can be traded by bidding for the specific hours in the day-ahead market. The orders for these synthetic blocks can be made in the form of a block bid, a special bid form that ensures that either all or none of the specific hour contracts are traded. However, the block bids do not have a pricing of their own as block contracts in the block contract market had (EEX 2008a).

3. Risk Premia in Electricity Markets

In the following chapter we give an overview on the theoretical background on price formation in electricity forward markets and review the related empirical literature.

Theoretical Background

In general the day-ahead electricity market is seen as the spot market. Accounting for the traded volume and the number of market participants in this market segment this point-of-view seems to be justified, in particular when compared with the intraday market. In the case of the EEX the fact that the day-ahead market is serving as an underlying for the futures market also confirms this view. However, from a theoretical perspective it is rather the intraday market which fits more to the characteristics of a spot market. The day-ahead market and also the block contract market are rather futures markets with a time-to-delivery of one to three days. This leads to the question on the theory behind price formation in electricity forward markets.

Most forward markets can be linked to the related spot market using the cost-of-carry approach as a non-arbitrage relation. The critical assumption underlying this relation is the storability of the particular commodity or asset. Since this assumption is not valid in the case

[9] According to Ronn and Wimschulte (2009) almost all trading in the block contract market took place in the continuous trading period.

of electricity – which is at least in economic terms non-storable – this approach is not applicable and thus another mechanism is required.[10] Assuming a market in equilibrium the hedging pressure approach seems to be suitable. This approach postulates that forward prices are formed as the sum of the expected spot price of the underlying at maturity of the future and a risk premium. The risk premium[11] is paid by risk-averse market participants for the elimination of price risk. Depending on the average risk aversion in the market the risk premium can be both negative and positive.

When estimating the risk premium in this paper we will use an approach yielding the ex post or realized risk premium

$$RP_T = F(t,T) - S(T)\,. \tag{1}$$

The risk premium RP_T in this approach is defined as the difference of the futures price $F(t, T)$ at time t and the realised spot price $S(T)$ at maturity T.[12]

Another possibility to estimate the risk premium is the use of the ex ante approach by replacing the realised spot price through the expected spot price at maturity $E_t[S(T)]$. The result is the ex ante or expected risk premium

$$RP_{t,T} = F(t,T) - E_t[S(T)]\,. \tag{2}$$

The interpretation of the estimated ex ante risk premium, $RP_{t,T}$, is problematic due to the fact that a specific spot price model has to be used to estimate the expected spot price at maturity with the available information set in t.[13]

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[10] Routledge et al. (2001) develop a model that extends the theory of storage to goods which are not directly storable.

[11] Risk premia in commodity futures can also be linked to systematic risk. However, empirical literature mostly denies systematic risk in commodity futures, see e.g. Jagannathan (1985).

[12] The realised spot price is calculated as the arithmetic average of the *n* hourly prices, S_i, in the delivery period *T*

$$S(T) = \frac{1}{n}\sum_{i=1}^{n} S_i\,.$$

[13] The ex post and ex ante risk premium can be linked by the assumption of rational expectations, resulting in

$$F(t,T) - S(T) = RP_{t,T} + \varepsilon_t\,.$$

Empirical Literature

Empirical research on risk premia in electricity markets – apart from the distinction between ex ante and ex post risk premia – can be divided in two broad groups which are characterised by the maturity of the analysed contracts. In the following we will discuss empirical results dealing with risk premia in electricity spot markets. The other group deals with risk premia in futures markets, mainly analysing week and month futures. Botterud et al. (2002), Shawky et al. (2003), Wilkens and Wimschulte (2007), Lucia and Torro (2008), Torro (2008), Kolos and Ronn (2008), Furio and Meneu (2009), Marckhoff and Wimschulte (2009), Pietz (2009) and Capitan Herraiz and Rodriguez Monroy (2009) contribute, among others, to this research. The main findings are evidence for positive risk premia at the short-end and mixed evidence for seasonality in risk premia and a term structure of risk premia.

The most-cited empirical paper regarding risk premia in electricity spot markets is probably Longstaff and Wang (2004). The authors analyse in their paper the Pennsylvania, New Jersey and Maryland (PJM) market over the period June 2000 to November 2002. After finding significant risk premia which systematically vary throughout the day they link these risk premia to different risk factors. Boogert and Dupont (2005) analyse the relation between the intraday and day-ahead market in the Netherlands. Using a dataset covering the period January 2001 to December 2003 they find that the risk premia are slightly positive but not statistically significant. Testing the profitability of trading strategies based on these risk premia the authors report weak evidence. Karakatsani and Bunn (2005) use in their study a dataset from the British market from June 2001 to June 2003 and show the existence of significant risk premia which change sign, depending on whether peak or off-peak hours are investigated. Analysing the period January 2001 to August 2005 and using OTC prices, Diko et al. (2006) find statistically significant positive risk premia during peak hours in three European electricity markets. Hadsell and Shawky (2007) examine the New York independent system over the period 2001 to 2005. Finding significant risk premia they show that the magnitudes vary on a daily, weekly and monthly basis. Ronn and Wimschulte (2009) conduct a first analysis of the German spot market. Using data from 2002 to 2007 they find positive risk premia in the block contract market. Daskalakis and Markellos (2009) obtain

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Under this assumption the ex post risk premium equals the ex ante risk premium plus a random (forecast) error. See Redl et al. (2009) regarding the possibility of systematic forecast errors.

first results for the German intraday market. When analysing the period September 2006 to October 2007 – approximately the first year of operation of the intraday market – the authors detect negative daily risk premia. Viehmann (2009) estimates the risk premia in the day-ahead market of the EEX, using price data from the Austrian electricity exchange as substitute for over-the-counter prices. The author finds – covering the sample period October 2005 to September 2008 – hourly risk premia that are significantly different from zero.

4. Empirical Results

In the first section of this chapter we describe our data and report descriptive statistics. The second section contains results on the risk premia. The existence of a term structure of risk premia is investigated in the third section. The fourth and last section deals with potential drivers of risk premia.

4.1 Data and Descriptive Statistics

In the following we describe our data and report individual descriptive statistics for the three market segments discussed above.

Day-Ahead Market

The day-ahead market dataset consists of hourly prices and the corresponding traded volume, covering the period between August 1, 2002 and May 15, 2009.[14] Prices for the day-ahead market and all other market segments are quoted in Euro/MWh. In order to simplify the terminology we will report prices in Euro only. All our data, including the data for the day-ahead market, has been directly obtained from the EEX.

Prior to computing descriptive statistics for the day-ahead market data, we recall that one of the prevalent characteristics of electricity prices is their seasonality, observed at least on three time scales: on a daily, weekly and monthly scale. At the beginning of our analysis we are primarily interested in the weekly seasonality and hence calculate the average daily price, the Phelix Base, on all weekdays. As a result, we get a maximum price on Tuesdays

[14] Our dataset starts on August 1, 2002 due to the fact that the EEX changed the trading system on this day. Trading in the day-ahead market was already taking place before. The same applies to the block contract market.

(49.09 Euro), almost identical prices on Wednesdays and Thursdays and slightly lower prices on Mondays and Fridays. In contrast, the average prices on Saturdays and Sundays, 34.42 Euro and 26.63 Euro, respectively, are significantly lower. Going a step further we use the official trading calendar of the EEX and calculate the average prices on working and non-working days. Non-working days are weekend days and public holidays. The results show that prices on public holidays during the week are also significantly lower than on normal working days. We hence decide to distinguish in the following – not only for the day-ahead market but also for the two other market segments – between working and non-working days. The descriptive statistics for the reordered dataset are reported in table 1.

- Include table 1 about here -

The term Hour 1 corresponds to the hour contract with delivery between 0 – 1 am. The following hours are set accordingly. When examining the hourly prices in table 1 we detect the expected seasonality on a daily basis. On average, the hourly prices on working days are three times higher around midday than in the early morning hours. A similar pattern is observed for the volatility. When surveying the maximum prices and the third and fourth moment of the distributions, hours with frequent price observations in the magnitude of ten times as high as the average price are observed.[15] These maximum prices are the well-known and dreaded price spikes or jumps (Seifert and Uhrig-Homburg 2007), one of the unique characteristics of electricity prices which is due to its non-storability.[16] The price jumps combined with the high skewness of the price distributions during high demand hours underlines the importance of hedging in electricity markets.[17]

When comparing working to non-working days it stands out that not a single price spike is observed on a non-working day. The volatility and the skewness of the distributions on non-working days are also significantly lower than on working days. We display the daily price during our sample period in figure 1 in order to illustrate the discussed characteristics.

[15] Our dataset even includes four observations of prices above 1000 Euro: Two in delivery hour 12 (11 am – 12am) on the 07/25/06 and 07/27/06; two in delivery hour 19 (18 pm – 19 pm) on the 01/07/03 and 11/07/06. The last observation will be of importance at a later point.

[16] See Viehmann (2009) for a discussion of the factors causing these maximum prices in the German market.

[17] See Deng and Oren (2006) for an overview on hedging in electricity markets.

- Include figure 1 about here -

In addition to the frequent price spikes, an analysis of figure 1 discloses an apparently increasing volatility during the sample period. To analyse this further, we order the price data by years, both for the base and peak hours. The descriptive statistics for these data can be found in table 2.

- Include table 2 about here -

The daily average price in table 2 seems to incorporate a positive drift. Except for the years 2007 and 2009 – where only data up to the middle of May is available – we observe a steady increase in the average prices. A particularly strong increase occurred in 2005 when the European Union emission trading system was introduced. The adoption of the emissions right price as a cost factor in electricity generation also represents a potential source for the increasing volatility (Zachmann and von Hirschhausen 2008). On average, prices in peak hours are around 20% higher than in base hours. The volatility in the peak hours is also significantly higher.

Block Contract Market

Data from the block contract market is available between August 1, 2002 and August 31, 2008. The last day of the dataset is at the same time the closing day of this market segment. The dataset includes price series of the three block contracts discussed above (base load, peak load, and weekend base load) and the traded volume. Each price time series consists of volume-weighted average prices.

Table 3 reports the descriptive statistics for the block contract prices. In addition day-ahead market prices are also included.

- Include table 3 about here -

The reported data for the day-ahead market are the corresponding synthetic block contracts. When comparing the block contracts with the synthetic block contracts we observe that the descriptive statistics are very similar except for a higher skewness and kurtosis of the day-ahead market data. This is probably due to the frequent price spikes in this market.

When examining the number of price observations in the block contract and day-ahead market it stands out that on around 30% of days no trading took place in the block contract market. On non-working days this number is even higher and in particular the peak contract with delivery on non-working days was almost never traded. We therefore exclude this contract from the further analysis and note that the high number and the uneven distribution of the non-trading days have to be considered when interpreting the following results. Another systematic pattern in the data, also already observed by Ronn and Wimschulte (2009), is a higher number of days without trading in contracts with delivery on Mondays.

Intraday Market

Data from the intraday market is available for the period September 25, 2006 to May 15, 2009. The dataset includes hourly prices and the corresponding traded volume. Two price series are available, the average and the last price. The average price is the average of all trades which took place in a specific hour contract. The last price is the one at which the last trade took place. No information on the number and timing of single trades is available. When testing for systematic differences between the last and the average price no obvious results are found. The mean of the average price is slightly higher than the one of the last price and its volatility is slightly lower than the one of the last price.

When considering which price series to use, we believe that the last price is the one that should be used for the following analysis. This is due to the theoretical framework behind the use of the risk premia approach. We interpret market segments of the spot market with earlier trading as being futures markets. A day-ahead market contract is in general interpreted as a future with a time-to-delivery of one day. The time difference between trading in these two market segments is therefore the main characteristic of interest. The last price is the price observation which maximizes the temporal difference between trading in the day-ahead and in the intraday market and is hence the price which should be used. However, considering the thin trading in the intraday market and the presumably uneven distribution of trades during the permitted trading phase for a specific contract, in the following we will also discuss results obtained by using the average price.

Descriptive statistics for hourly (last) prices on working and non-working days on the intraday market are reported in table 4.

- Include table 4 about here -

The intraday market price data are similar to the day-ahead market price data. Perhaps the most striking differences are the significantly lower maximum prices in the intraday market and the smaller skewness and kurtosis of the price distributions.

As previously mentioned the observed liquidity in the intraday market is low – compared to the day-ahead market – but seems to steadily increase. However, the question remains whether the high number of hours without trades – in particular in the first months of operations – is leading to biased estimates. In addition, the missing information regarding the specific point-in-time at which the last trade takes place is problematic. We refer to Viehmann (2009) for a deeper discussion on the occurring problems and point out that further research on the liquidity of the intraday market is necessary.

4.2 Risk Premia

The estimated risk premia are reported separately for the block contract market and the day-ahead market.

Risk Premia in the Block Contract Market

The estimated risk premia in block contracts are summarized in table 5. Results are reported for working and non-working days. The table contains results for the base load and peak load contracts on working days and for the base load and weekend load contracts on non-working days. Data from the day-ahead market are used to estimate the risk premia. We apply the Newey-West estimator to receive autocorrelation and heteroscedasticity robust results.

- Include table 5 about here -

Table 5 reveals the existence of significant risk premia, in both base load and peak load contracts, with statistically significant results on working days. A high risk premium, significant at the 1% level, is observed in base load and peak load contracts, in particular on Mondays. In addition, significant risk premia in the base load contracts are observed on Wednesdays and Fridays as they also are in the peak load contract on Fridays. Overall, the risk premia in both contracts are significant at the 5% level and have a magnitude of 0.79 Euro in the base load contracts and of 1.55 Euro in the peak load contracts. Compared with the average prices (see table 3) of the base load and peak load contract the results imply that on average 1.66% and 2.54%, respectively, of the block contract price is paid for the hedging of price risk. For the block contract with delivery on Mondays this number even goes up to around 5%.

The obtained results seem to confirm the theory. Market participants are apparently willing to pay a risk premium to secure future prices and the earlier the hedging is possible the more market participants are willing to pay. From this perspective, especially the risk premium in block contracts with delivery on Mondays should be relatively high since these contracts have a time-to-delivery of three days, forcing market participants to forecast the spot price three days in advance. The high observed risk premia in this contract match therefore the theoretical framework. The fact that the block contracts with delivery on Mondays were considerably less often traded than the other contracts can also be regarded as support for the high risk of these contracts.

Our results confirm the results of Ronn and Wimschulte (2009). Although pursing a different goal, the authors analyse the sample period August 1, 2002 to September 30, 2007 and estimate the risk premia in the block contracts. Using an extended sample period our results are consistent with the results reported in table 2 of their working paper.

Risk Premia in the Day-Ahead Market

Risk premia in day-ahead market contracts are estimated as the price difference between the day-ahead market and intraday market contracts with the same delivery hour. We use the last price of the intraday market and separately estimate the risk premia in contracts with delivery on working and non-working days. Table 6 contains the results of the estimation. We report the average risk premium, the median value as a robustness check and the standard deviation.[18] The Newey-West estimator is used to get autocorrelation and heteroskedasticity consistent results.

- Include table 6 about here -

The average risk premium on working days is 0.80 Euro and statistically significant at the 1% level. For non-working days the analysis yields an average risk premium of 1.40 Euro, also significant at the 1% level. In both cases the median is slightly lower than the average but

[18] The median value is perhaps a better measure when analysing ex post risk premia (estimated with a small dataset) as the average value is sensitive to price peaks in one of the markets.

still in the same range. Using the average price we get significant risk premia on working days and non-working days with a magnitude of 0.32 Euro and of 0.59 Euro, respectively. It stands out that the risk premia seem to be higher on non-working days than on working days.[19]

The hourly risk premia are very volatile and frequently change in sign. This corresponds to results from other markets, as for example to the results reported by Longstaff and Wang (2004) for the PJM market. We find significant risk premia in 16 of the 24 hours in day-ahead market contracts with delivery on working days. The risk premia are positive and highly significant especially around midday, e.g. for hour 12 on working days the risk premium has a magnitude of 3.61 Euro. That represents a relative risk premium of around 5%. On the other side, for hour 9 we find a risk premium of – 4.19 Euro. In the night hours the risk premia are mainly negative and also significant. On non-working days 15 of 24 hourly risk premia are statistically significant. Comparing the median values and standard deviation of the separate hour contracts only the volatility of hour 19 on working days stands out. Yet this can be explained with one extreme price observation in the day-ahead market.[20] Using the average prices of the intraday market to estimate the risk premia in the single hour contracts we find no systematic differences in the results.

To illustrate the high volatility of the risk premia the evolution of the risk premia in four selected hour contracts is plotted in figure 2.

- Include figure 2 about here -

The selected hours shown in figure 2 are equally spread over the day – with a constant five hour gap in-between – so that the risk premia in hour contracts with fundamental different demand profiles are shown. The vertical axes of the four graphs in figure 2 are set between minus and plus 50 Euro to amplify the different volatility. The last price in the corresponding intraday market contract is used to compute the data. As it can be seen, the

[19] A possible explanation of this observation is that electricity buyers primarily use the day-ahead market and, in particular, seem to avoid the intraday market – due to a lack of liquidity – on non-working days. See also Weber (2009) for a discussion of possible reasons for the low liquidity in the German intraday market.

[20] The extreme observation in hour 19 occurs on 11/07/06 with a price of 2436.63 Euro. The exclusion of this price observation from the dataset results in a volatility for hour 19 which is comparable to the volatility of the other hours.

graphs for hour 12 and hour 18 show a significantly higher volatility compared to the two other hours. It also seems that a form of volatility clustering can be observed in the risk premia. Further research on the evolution of the risk premia is necessary[21], given an extended dataset is available.[22] In particular the evolution of the magnitude of the risk premia is of interest (Saravia 2003).

Another interesting question regarding risk premia in electricity markets is the existence of seasonality. Hadsell and Shawky (2007) report for the American market high risk premia in winter and summer months, according to the yearly demand pattern. Lucia and Torro (2008) report seasonality in risk premia in week futures traded at the Nord Pool. For the analysis of our data regarding the existence of seasonality in the risk premia we have the choice to either analyse all hour contracts separately or to use the daily average or some blocks of hours. The estimation of the daily risk premia – calculated as the daily price in the day-ahead market minus the daily price in the intraday market – and the estimation of the average monthly risk premia based on the daily results seem to be the most straightforward approach. However, this procedure is not practicable due to the significant number of hours

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[21] When testing for the evolution of the risk premia throughout the analysed sample period we find no obvious trend. From beginning on the risk premia seems to be positive and extremely volatile. The negative daily risk premia obtained by Daskalakis and Markellos (2009) for the first year of the intraday market's existence is probably due to calculation of daily prices on the intraday market as arithmetic averages of the hourly prices and the high number of non-trading hours in this period.

[22] Similar to Boogert and Dupont (2005) we examine the practical relevance of the hourly risk premia by testing two simple (spread) trading strategies. A spread strategy in electricity markets consists of a long position in one market segment and a short position in the other one. We therefore examine the two hours with the largest positive and negative risk premia over the whole sample period (on working days), hour 9 and hour 12. For the hour with a positive risk premium the strategy to be tested is a short position in the day-ahead and a long position in the intraday market. For the hour with a negative risk premium the opposite strategy applies. The profit for the first strategy (per MWh) is the day-ahead price minus the intraday price, for the second strategy the intraday minus the day-ahead price. We start our test in August 2008, because from this month on there is no occurrence of non-trading days in the hours of interest. Without further investigating the traded volume (and by ignoring transaction costs) we assume that it is possible to trade an additional volume of 10% at the quoted price in the intraday market. As results we get a three-digit average profit for hour 9 and a three-digit average loss for hour 12 as well as a high volatility. Based on these results we wonder if professional market participants with no interest in the physical delivery of electricity (speculators, arbitrageurs, etc.) are seriously interested in investing time and money in trading strategies with such profit-loss potentials. Discussing this point with representatives of a leading investment bank in Western Europe we received the argument that based on the low liquidity in the intraday market and on the high volatility of the risk premia the potential profits of an arbitrage strategy based on the risk premia are by far not sufficient to justify an engagement..

without trading in the intraday market.[23] We therefore decide to evaluate the existence of seasonality by applying the following procedure: first, we estimate the risk premia in all hour contracts. Second, we reorder the estimated risk premia by months. Third, we calculate the average risk premia for three blocks of hours: base (0 – 24 am), peak (8 am – 8 pm) and off-peak (0 am – 8 am and 8 pm – 0 am), based on the above obtained results which show that these blocks of hours exhibit similar characteristics. Table 7 summarizes the result.

- Include table 7 about here -

Significant positive risk premia are found for the summer months, i.e. June, July and August. Significant negative risk premia are found for January. The results for the other months are not significant and mixed. Carefully interpreting these results we think that based on the analysed sample period and data the existence of positive risk premia in summer months can be detected. However, Viehmann (2009) analyses four selected hours and finds – using data from the day-ahead market and estimated prices for over-the-counter trades taking place two hours before the day-ahead market auction – significantly higher risk premia in winter months.

4.3 Term structure of Risk Premia

The time period between September 25, 2006 and August 30, 2008 offers the unique opportunity to analyse the German electricity spot market in respect to the existence of a term structure of risk premia. That is due to the fact that during this time period the three market segments were simultaneously in existence. Thus it was possible to buy and sell electricity for the same delivery period in three different market segments with the only difference being the trading point-in-time or rather the time-to-delivery of the specific contract. However, it was not possible to trade single hour contracts but the tradable delivery periods were determined by the block contract market. The tradable delivery periods were hence the whole day (base load contract), the peak hours (peak load contract), and the off-peak hours (through a synthetic contract: a long position in the base load contract and a short position in the peak load contract).

[23] Off-peak hours have the highest number of days without trading. Thus one may assume that the daily average price is upward biased.

The question if market participants are willing to pay different risk premia depending on the time-to-delivery is of high importance, for both theoretical and empirical purposes. The results above indicate that similar to other markets the German spot market is characterised by positive risk premia. However, based on the above results no conclusion concerning a term structure of risk premia can be drawn. Empirical results on the existence of a term structure of risk premia in futures markets are mixed. Shawky et al. (2003) find that the risk premia in futures with delivery at the California-Oregon Border, traded at the New York Mercantile Exchange, is an increasing function of time-to-delivery. Weron (2008) and Marckhoff and Wimschulte (2009) on the other side offer empirical evidence for a decreasing risk premia with increasing time-to-delivery. Pietz (2009) reports increasing risk premia at the short-end and decreasing risk premia thereafter for the German futures market. From a theoretical point-of-view the framework developed by Benth et al. (2008) is able to explain a term structure of risk premia with changing risk preferences and hedging demand across different maturities. All empirical results obtained to date deal with maturities in the range of weeks or months. As far as we know we are the first to have the possibility to research the term structure of risk premia on such a short time scale. The already obtained results lead us to expect finding higher risk premia in the block contract market.

When analysing the available data the low liquidity in the block contract and in the intraday market has to be considered. In particular at the beginning of the above defined sample period, when trading in the intraday market had just been introduced and at the end, when trading in the block contract market was coming to an end. For this reason we reorder our dataset. For the analysis of a specific contract only days with trading in all hours of interest in all three market segments can be included in the final dataset. Originally, the sample period extends over 706 trading days, 486 of them being working days.

We begin to reorder the data with the working days. The reduction of the dataset to days when trading in all hours of interest in the intraday market took place, results in 174 working days with trading in all hours and 350 working days with trading in the peak hours. In a second step we sort out all days without trading in the corresponding block contract. We get 147 working days for the base hours and 285 working days for the peak hours at which at least one trade in all three market segments and hours of interest took place. For the off-peak hour contracts trading in all off-peak hours in the intraday market and in both the peak and block contract in the block contracts market is necessary. The reordering shows that this has been the case on 132 working days. Conducting the same reordering procedure for the non-working days results in an extremely small dataset. We therefore decide to forgo the non-working days. Thus the following analysis only deals with working days.

After the reordering of the data we estimate the risk premia at two points-of-time, one being the trading in the block contract market and the other one in the day-ahead market. This results in two risk premia in contracts with identical delivery periods and different time-to-deliveries. The results therefore allow us to evaluate whether a term structure of risk premia on such a short time scale is apparent. The results for the two markets and three contracts are shown in table 8.

- Include table 8 about here -

Due to the skewness of the distributions of the risk premia table 8 contains the average and the median risk premia. We again employ the last price from the intraday market. The risk premia in the block and in the day-ahead market contracts are estimated as the price difference between the particular market and the intraday market. That is a significant difference compared to the section above, where the risk premia in the block contracts were estimated as the price difference between the block contract and day-ahead market. The results for the base and off-peak hours are insignificant although in the off-peak contracts the risk premia seem to be higher in the day-ahead than in the block contracts. The risk premia is higher in the block contracts for the base hours than in the day-ahead contracts. For the peak contracts – as mentioned the most liquid ones – we get statistically significant results. The risk premium in the peak load contract is on average 3.04 Euro and significant at the 1% level. For the day-ahead peak hours we get a risk premium of 1.76 Euro, significant at the 5% level. Market participants were therefore apparently willing to pay a higher risk premium for the possibility of an earlier hedge during the period when all three market segments of the spot market were active. This is consistent with the results of Pietz (2009) who finds increasing risk premia with increasing time-to-delivery at the short-end in the German futures market.

4.4 Drivers of Risk Premia

When investigating potential drivers of the risk premia the equilibrium model of Bessembinder and Lemmon (2002) provides a relation between the anticipated distribution of the expected spot price and the ex ante risk premium. With the methodology proposed by Longstaff and Wang (2004) this theoretical model can be transformed in an empirically testable equation. Thereby the ex post risk premia $RP_{T,i}$ are regressed on the variance $VAR_i[S(T)]$ and skewness $SKEW_i[S(T)]$ of the corresponding spot prices. The skewness in this case is non-standardized.

$$RP_{T,i} = a + b \cdot VAR_i[S(T)] + c \cdot SKEW_i[(S(T)] \tag{3}$$

Bessembinder and Lemmon (2002) show that the relation between the risk premia and the variance – under certain conditions – is negative and between the risk premia and the skewness positive.

We regress the 24 hourly ex post risk premia in day-ahead market contracts on the variance and skewness of the corresponding price distributions, for both working and non-working days, and find no significant relation. We therefore forgo reporting the results. Our findings are contrary to Longstaff and Wang (2004) who find a significant relation for the PJM day-ahead market. Furio and Meneu (2009) analyse the Spanish futures market and also find supporting evidence. On the other side, Lucia and Torro (2008) report mixed results. To our knowledge Ronn and Wimschulte (2009) are the only ones testing the relation for the German spot market. They use the risk premia in futures traded at the Austrian exchange with delivery in Germany and the prices in the day-ahead market of the EEX. The results for working days are all insignificant.

Further potential drivers of the risk premia are discussed at this point from a qualitative perspective whereas an empirical verification is left open for future research. Lucia and Torro (2008) find a significant relation between risk premia and low water reservoir levels for futures traded at the Nord Pool. However, these results could be specific to the Scandinavian area where water power plays a dominant role in the electricity production (Torro 2008). Furio and Meneu (2009) link the risk premia in futures with delivery in Spain to an unexpected variation in demand and hydro-energy capacity. Longstaff and Wang (2004) find a positive relation between the risk premia and the conditional volatilities of unexpected changes in demand, spot prices and total revenue. Natural gas storage (Douglas and Popova 2008) and emission allowance prices (Daskalakis and Markellos 2009) are identified in the literature as further potential drivers of the risk premia.

5. Conclusion

The aim of this paper is an empirical analysis of the price formation mechanism in the German electricity wholesale spot market. We therefore conduct an in-depth analysis of all three market segments which are or were in existence during our sample period which extends between August 2002 and May 2009. These three market segments are the day-ahead market, the block contract market and the intraday market. Trading in the day-ahead market in its current form started in August 2002, trading in the intraday market started in September 2006. The block contracts market ceased its activity in August 2008.

Our results are: we find positive risk premia in the block contract and in the day-ahead market. Risk premia in block contracts are in particular significant and high for contracts with delivery on Mondays. Risk premia in day-ahead market contracts are extremely volatile and change in sign throughout the day. Furthermore, we detect a term structure of risk premia during the sample period when all three market segments were active. Risk premia seem to be higher in contracts with a longer time-to-delivery. In addition, we find evidence of seasonality in the risk premia with higher risk premia in the summer months. When testing for a relation between the variance and skewness of the underlying spot price and the risk premia we find no significant results.

Further research on this topic seems to be promising and necessary. First, an identification of potential drivers of the risk premia in the German market would extend our understanding on the mechanism behind price formation in the spot market. Second – as soon as a larger dataset is available – the time-variation of the risk premia should be analysed. The question whether a convergence of the day-ahead and the intraday prices will take place or whether the risk premia will persist is of particular interest. Both research venues are related to the question whether the observed positive risk premia are an adequate compensation for the associated risk or rather an indication of market inefficiency. The liquidity of the intraday market has to be also further investigated in order to test the robustness of our results.

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Figure 1
Time Series of Daily Prices on the Day-Ahead Market

Time series of daily prices on the day-ahead market. Sample period: August 1, 2002 to May 15, 2009. Both working and non-working days are included. The daily price is calculated as an arithmetic average of the 24 hourly prices. The EEX publishes the daily price as the PHELIX (Physical Electricity Index) Base.

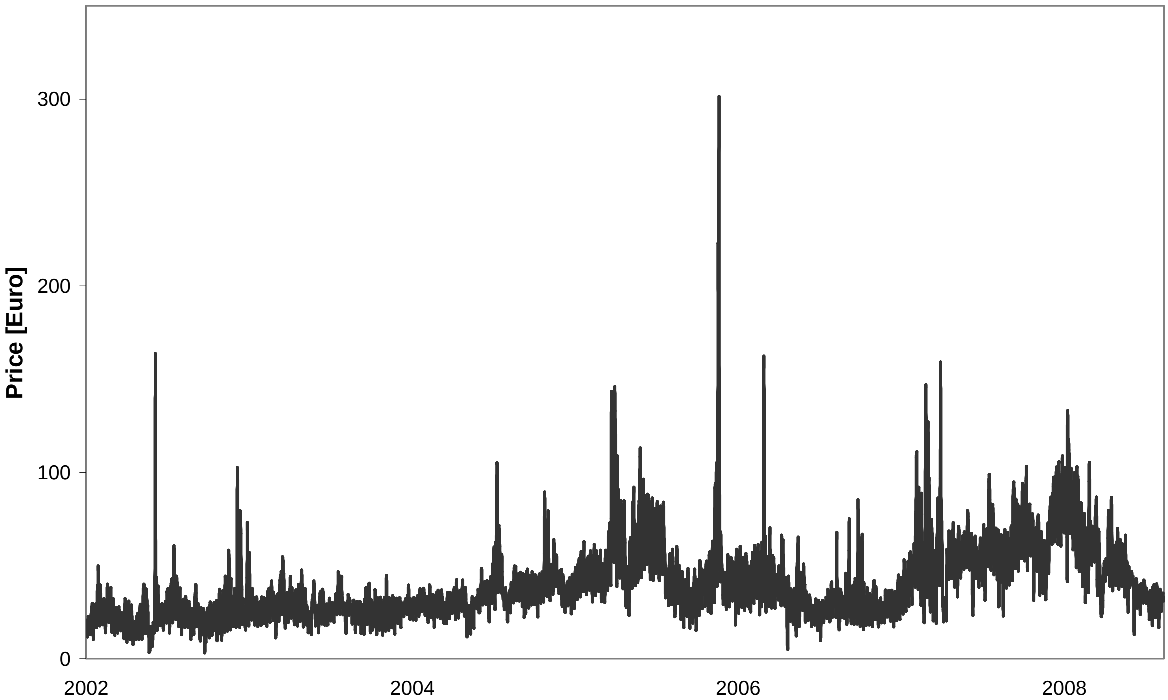

Figure 2

Time Series of Risk Premia in Day-Ahead Market Contracts for Selected Hours

Time series of risk premia in day-ahead market contracts for selected hours. Sample period: September 25, 2006 to May 15, 2009. The risk premia in hour 6 (5-6 am), hour 12 (11-12 am), hour 18 (5-6 pm), and hour 24 (11-12 pm) are displayed. The vertical axis is set between -50 and +50 Euro.

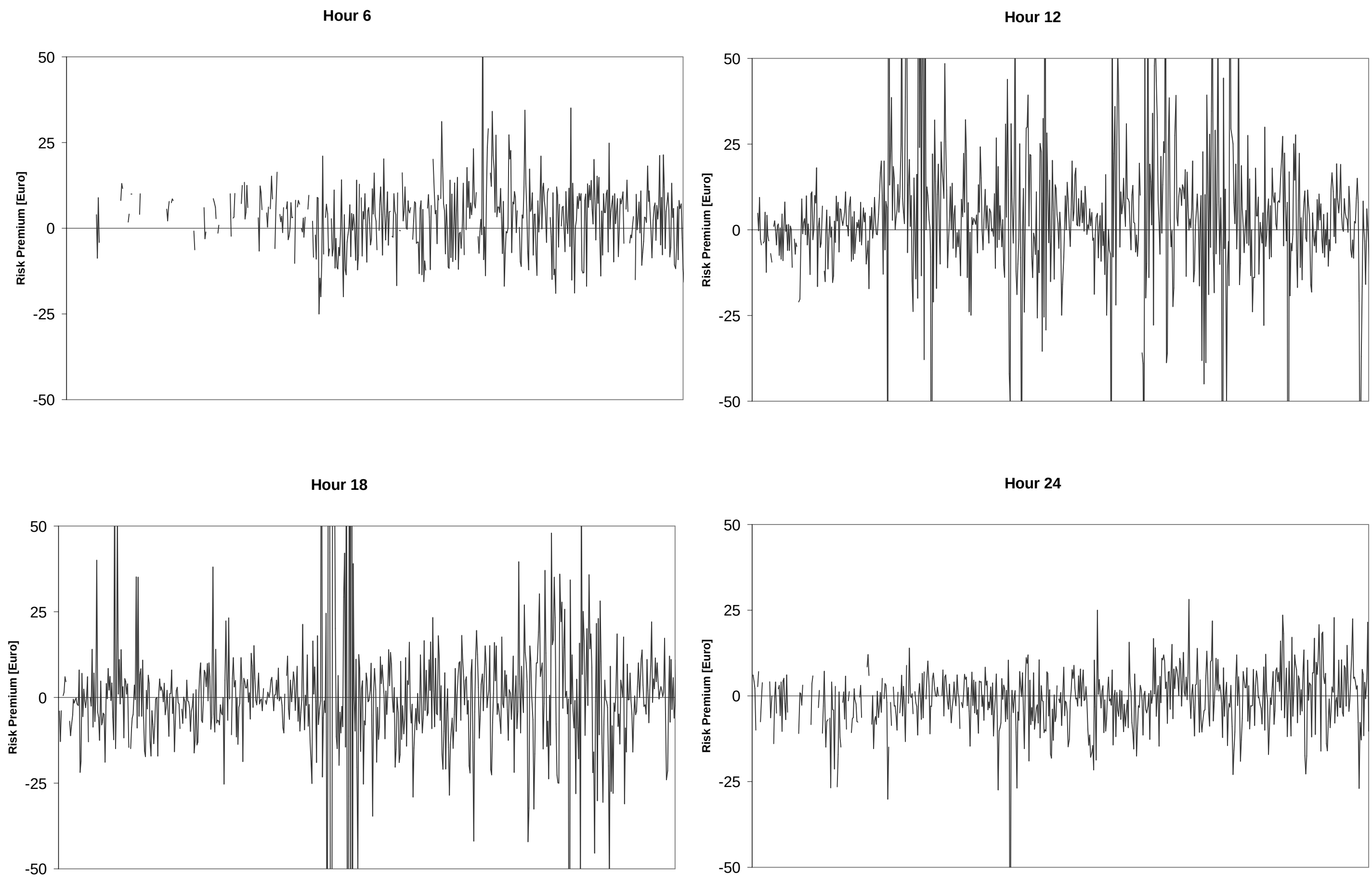

Table 1

Descriptive Statistics for Hourly Day-Ahead Market Prices

Descriptive statistics for hourly day-ahead markt prices, both for working and non-working days. The covered sample period is August 1, 2002 to May 15, 2009. Overall 41400 price observations on working days and 18480 on non-working days are included. Hour 1 stands for the hour contract with delivery between 0 am and 1 am. The following hours are set accordingly.

	Working Days							**Non-Working Days**						
Hour	Mean	Std.Dev.	Minimum	Median	Maximum	Skewness	Kurtosis	Mean	Std.Dev.	Minimum	Median	Maximum	Skewness	Kurtosis
1	*30,89*	*13,42*	*-16,67*	*27,72*	*75,01*	*0,82*	*0,42*	*30,22*	*14,00*	*1,64*	*27,22*	*76,02*	*0,90*	*0,43*
2	*27,01*	*13,47*	*-151,67*	*24,94*	*69,63*	*-0,79*	*17,98*	*25,28*	*13,58*	*0,00*	*23,12*	*71,07*	*0,83*	*0,56*
3	*24,43*	*12,40*	*-101,52*	*22,79*	*64,09*	*-0,05*	*6,18*	*22,53*	*13,33*	*-0,07*	*20,98*	*67,93*	*0,72*	*0,35*
4	*22,40*	*11,89*	*-101,52*	*21,22*	*60,20*	*-0,20*	*7,40*	*20,57*	*12,43*	*0,00*	*18,44*	*69,52*	*0,81*	*0,45*
5	*23,33*	*12,00*	*-101,50*	*22,08*	*61,93*	*-0,70*	*12,87*	*19,57*	*12,10*	*0,00*	*17,86*	*69,92*	*0,89*	*0,75*
6	*29,62*	*12,19*	*-9,98*	*27,06*	*70,51*	*0,80*	*0,51*	*19,66*	*12,34*	*-0,02*	*18,11*	*69,90*	*0,87*	*0,74*
7	*38,09*	*15,70*	*1,09*	*34,04*	*104,93*	*0,96*	*0,75*	*15,88*	*13,69*	*-109,97*	*14,08*	*75,25*	*-0,30*	*10,66*
8	*54,34*	*25,86*	*3,03*	*45,94*	*301,01*	*2,21*	*12,09*	*20,81*	*14,30*	*-50,60*	*19,37*	*80,68*	*0,80*	*1,80*
9	*58,55*	*30,02*	*8,02*	*50,04*	*437,26*	*3,14*	*23,02*	*26,93*	*15,24*	*0,00*	*24,57*	*91,05*	*0,95*	*1,18*
10	*61,15*	*32,79*	*13,39*	*52,00*	*499,68*	*3,44*	*26,69*	*33,14*	*16,65*	*0,00*	*30,03*	*96,04*	*1,01*	*1,09*
11	*63,93*	*40,60*	*13,61*	*54,43*	*998,24*	*8,88*	*173,18*	*36,75*	*17,27*	*0,00*	*33,24*	*99,75*	*1,05*	*1,06*
12	*72,89*	*70,17*	*15,54*	*61,16*	*2000,07*	*16,67*	*408,11*	*40,29*	*17,36*	*1,92*	*36,16*	*105,02*	*1,02*	*0,85*
13	*62,05*	*34,78*	*14,28*	*53,84*	*699,81*	*5,97*	*83,61*	*38,06*	*16,79*	*1,88*	*34,43*	*99,82*	*0,99*	*0,78*
14	*60,08*	*33,32*	*14,63*	*51,62*	*699,88*	*6,08*	*91,79*	*33,48*	*15,07*	*1,03*	*30,11*	*91,44*	*0,92*	*0,68*
15	*56,99*	*33,17*	*13,04*	*48,38*	*800,09*	*7,87*	*151,15*	*29,97*	*14,00*	*0,07*	*27,29*	*87,16*	*0,88*	*0,71*
16	*53,28*	*29,49*	*11,76*	*45,12*	*693,23*	*7,22*	*133,40*	*27,97*	*13,46*	*0,00*	*25,54*	*82,93*	*0,87*	*0,74*
17	*51,59*	*26,24*	*15,23*	*43,54*	*300,01*	*2,60*	*13,70*	*28,61*	*13,81*	*0,00*	*25,60*	*80,08*	*0,92*	*0,79*
18	*56,98*	*43,78*	*15,17*	*45,81*	*821,90*	*7,36*	*92,38*	*34,18*	*16,83*	*0,00*	*30,01*	*109,95*	*1,03*	*0,96*
19	*61,61*	*82,73*	*13,92*	*47,24*	*2436,63*	*19,48*	*496,01*	*38,93*	*18,75*	*0,26*	*33,82*	*119,98*	*0,96*	*0,50*
20	*53,81*	*28,66*	*14,54*	*43,99*	*300,01*	*2,39*	*11,47*	*39,34*	*18,47*	*1,01*	*34,56*	*111,02*	*0,96*	*0,62*
21	*50,14*	*21,80*	*15,81*	*42,96*	*194,62*	*1,17*	*1,69*	*36,74*	*15,74*	*2,27*	*33,51*	*105,31*	*1,03*	*1,19*
22	*43,68*	*17,28*	*12,48*	*38,93*	*118,93*	*0,97*	*0,55*	*34,19*	*14,10*	*2,23*	*31,00*	*89,96*	*0,95*	*0,86*
23	*40,93*	*15,89*	*13,93*	*36,33*	*94,82*	*0,90*	*0,09*	*35,92*	*14,78*	*4,53*	*32,52*	*87,26*	*0,94*	*0,52*
24	*33,93*	*13,21*	*9,15*	*30,40*	*80,98*	*0,93*	*0,37*	*29,39*	*12,71*	*1,61*	*26,13*	*75,09*	*0,96*	*0,77*
Overall	*47,15*	*36,15*	*-151,67*	*39,92*	*2436,63*	*17,87*	*876,42*	*29,93*	*16,57*	*-109,97*	*27,07*	*119,98*	*0,88*	*1,42*

Table 2
Descriptive Statistics for Daily Day-Ahead Market Prices By Year

Descriptive statistics for daily day-ahead market prices by year, both for the base and peak hours. Sample period: August 1, 2002 to May 15, 2009. The daily price is calculated as an arithmetic average of the 24 hourly prices. The EEX publishes the daily price as the PHELIX (Physical Electricity Index) Base.

	Base							**Peak**						
Year	Mean	Std.Dev.	Minimum	Median	Maximum	Skewness	Kurtosis	Mean	Std.Dev.	Minimum	Median	Maximum	Skewness	Kurtosis
2002	*22,98*	*8,22*	*3,47*	*22,89*	*49,77*	*0,19*	*0,09*	*29,36*	*11,33*	*4,14*	*28,88*	*75,40*	*0,47*	*1,05*
2003	*29,49*	*13,07*	*3,12*	*29,05*	*163,46*	*3,78*	*32,58*	*37,00*	*21,44*	*0,80*	*35,24*	*277,64*	*5,21*	*48,71*
2004	*28,52*	*6,53*	*12,06*	*29,38*	*46,61*	*-0,37*	*0,03*	*33,99*	*8,56*	*11,79*	*35,12*	*60,17*	*-0,13*	*0,00*
2005	*45,98*	*18,42*	*13,56*	*42,37*	*145,97*	*2,47*	*9,15*	*56,00*	*28,55*	*16,03*	*49,62*	*226,33*	*2,97*	*12,12*
2006	*50,79*	*24,50*	*13,98*	*46,86*	*301,54*	*4,42*	*36,69*	*63,81*	*40,98*	*17,42*	*57,74*	*543,72*	*6,45*	*63,49*
2007	*37,99*	*19,90*	*5,80*	*32,71*	*158,97*	*2,38*	*7,98*	*48,75*	*30,76*	*6,76*	*41,00*	*248,38*	*2,77*	*11,11*
2008	*65,76*	*18,12*	*21,03*	*65,71*	*131,40*	*0,26*	*0,21*	*79,43*	*24,24*	*21,54*	*76,86*	*177,49*	*0,56*	*0,47*
2009	*42,35*	*13,22*	*13,00*	*39,46*	*86,36*	*0,80*	*0,84*	*49,76*	*16,81*	*19,75*	*44,98*	*114,63*	*1,11*	*1,54*

Table 3
Descriptive Statistics for Block Contract Market Prices

Descriptive statistics for block contract market prices. The second table contains the descriptive statistics for the corresponding (synthetic) block contract prices in the day-ahead market. Sample period: August 1, 2002 to August 31, 2008. The weekend base contract series starts in November 2002. The peak contract series on non-working days consists of 14 observations.

Block Contracts

	Working Days							**Non-Working Days**						
	Mean	Std.Dev.	Minimum	Median	Maximum	Skewness	Kurtosis	Mean	Std.Dev.	Minimum	Median	Maximum	Skewness	Kurtosis
Base	*47,70*	*22,56*	*12,00*	*40,31*	*179,33*	*1,61*	*4,25*	*28,26*	*14,32*	*5,25*	*24,23*	*66,50*	*0,89*	*-0,05*
Peak	*61,04*	*31,75*	*16,67*	*51,07*	*288,42*	*2,33*	*9,11*	*23,43*	*11,23*	*8,00*	*25,27*	*42,21*	*0,01*	*-0,93*
Weekend Base	-	-	-	-	-	-	-	*30,56*	*13,23*	*10,68*	*24,75*	*66,88*	*0,69*	*-0,76*

Day-Ahead Market Contracts

	Working Days							**Non-Working Days**						
	Mean	Std.Dev.	Minimum	Median	Maximum	Skewness	Kurtosis	Mean	Std.Dev.	Minimum	Median	Maximum	Skewness	Kurtosis
Base	*45,29*	*21,22*	*12,40*	*38,98*	*301,54*	*2,83*	*19,63*	*28,43*	*12,56*	*3,12*	*25,54*	*80,42*	*0,94*	*0,71*
Peak	*57,28*	*32,00*	*15,86*	*48,41*	*543,72*	*4,71*	*47,92*	*32,29*	*14,25*	*0,80*	*28,97*	*86,69*	*0,96*	*0,72*
Weekend Base	-	-	-	-	-	-	-	*29,56*	*11,63*	*9,24*	*26,04*	*70,95*	*0,87*	*0,14*

Table 4
Descriptive Statistics for Hourly Intraday Market Prices

Descriptive statistics for hourly intraday market prices, both for working and non-working days. The price of the last trade in the intraday market is used. Sample period: September 25, 2006 to May 15, 2009. Overall 14700 price observations on working days and 5998 on non-working days are included.

	Working Days							Non-Working Days						
Hour	Mean	Std.Dev.	Minimum	Median	Maximum	Skewness	Kurtosis	Mean	Std.Dev.	Minimum	Median	Maximum	Skewness	Kurtosis
1	*37,75*	*16,74*	*-19,00*	*37,00*	*84,00*	*0,11*	*-0,45*	*34,80*	*15,72*	*-7,00*	*33,00*	*79,50*	*0,25*	*-0,33*
2	*33,53*	*16,50*	*-20,00*	*33,00*	*75,00*	*0,07*	*-0,37*	*29,86*	*15,85*	*-2,50*	*30,00*	*93,00*	*0,42*	*0,26*
3	*30,09*	*16,15*	*-44,00*	*30,00*	*79,00*	*0,11*	*0,56*	*27,63*	*16,17*	*-50,00*	*25,75*	*69,00*	*-0,22*	*1,69*
4	*27,37*	*14,99*	*-10,00*	*25,00*	*70,00*	*0,36*	*-0,31*	*25,19*	*16,11*	*-50,00*	*24,00*	*68,00*	*0,03*	*1,53*
5	*28,25*	*15,35*	*-28,00*	*27,00*	*76,00*	*0,28*	*-0,04*	*24,21*	*15,26*	*-30,00*	*23,25*	*69,00*	*0,21*	*0,03*
6	*35,19*	*16,70*	*-30,00*	*35,00*	*84,00*	*0,04*	*0,23*	*23,48*	*15,72*	*-15,00*	*20,25*	*66,00*	*0,43*	*-0,34*
7	*51,46*	*19,97*	*4,00*	*50,00*	*111,00*	*0,15*	*-0,42*	*22,49*	*17,29*	*-35,00*	*20,00*	*80,00*	*0,56*	*0,61*
8	*69,93*	*28,63*	*12,00*	*69,00*	*330,00*	*1,83*	*13,05*	*28,08*	*18,25*	*-15,00*	*25,00*	*77,00*	*0,32*	*-0,47*
9	*76,89*	*33,98*	*16,00*	*72,00*	*400,00*	*2,10*	*14,22*	*33,38*	*19,48*	*-40,00*	*32,00*	*95,00*	*0,17*	*0,42*
10	*75,23*	*33,20*	*21,00*	*71,00*	*250,00*	*1,30*	*3,02*	*42,26*	*20,21*	*1,00*	*40,00*	*105,00*	*0,44*	*-0,18*
11	*74,69*	*34,17*	*21,00*	*70,00*	*300,00*	*1,54*	*4,88*	*45,08*	*18,66*	*10,00*	*42,00*	*102,00*	*0,61*	*-0,08*
12	*78,94*	*38,08*	*22,50*	*72,00*	*300,00*	*1,72*	*4,78*	*46,99*	*19,14*	*1,00*	*44,00*	*103,00*	*0,56*	*-0,13*
13	*70,54*	*29,67*	*22,00*	*67,00*	*220,00*	*1,13*	*2,12*	*44,15*	*18,60*	*1,00*	*40,00*	*101,00*	*0,65*	*-0,12*
14	*67,60*	*28,81*	*15,00*	*65,00*	*210,00*	*1,11*	*2,12*	*39,62*	*16,82*	*1,00*	*37,00*	*85,50*	*0,47*	*-0,36*
15	*64,89*	*28,61*	*15,50*	*62,00*	*250,00*	*1,20*	*3,22*	*35,20*	*15,83*	*0,50*	*33,00*	*87,50*	*0,41*	*-0,35*
16	*61,51*	*26,87*	*10,00*	*59,00*	*210,00*	*1,06*	*2,23*	*34,08*	*16,44*	*-8,00*	*31,50*	*95,00*	*0,49*	*0,21*
17	*62,01*	*29,28*	*7,00*	*59,75*	*300,00*	*1,68*	*7,83*	*34,40*	*16,97*	*0,01*	*32,00*	*90,00*	*0,48*	*-0,33*
18	*70,09*	*47,62*	*17,15*	*64,00*	*500,00*	*4,44*	*30,22*	*42,39*	*20,08*	*-2,00*	*40,00*	*105,00*	*0,40*	*-0,36*
19	*73,47*	*45,50*	*5,00*	*69,50*	*500,00*	*3,88*	*27,50*	*48,71*	*22,33*	*6,00*	*48,50*	*142,00*	*0,63*	*0,60*
20	*66,96*	*30,70*	*17,00*	*65,00*	*270,00*	*1,40*	*4,72*	*49,18*	*22,39*	*1,00*	*48,00*	*125,00*	*0,70*	*0,41*
21	*58,47*	*24,32*	*1,00*	*58,00*	*190,00*	*0,90*	*1,70*	*44,67*	*18,74*	*10,00*	*43,23*	*113,00*	*0,64*	*0,24*
22	*52,27*	*19,59*	*17,00*	*52,00*	*129,00*	*0,53*	*-0,01*	*41,88*	*16,87*	*-5,00*	*40,90*	*80,50*	*0,16*	*-0,69*
23	*50,18*	*19,80*	*16,00*	*48,50*	*199,00*	*0,93*	*4,00*	*42,87*	*18,74*	*5,00*	*40,00*	*96,00*	*0,42*	*-0,66*
24	*41,76*	*16,83*	*5,00*	*40,00*	*149,00*	*0,70*	*1,82*	*35,83*	*15,86*	*1,00*	*34,00*	*76,00*	*0,40*	*-0,67*
Overall	*58,12*	*32,85*	*-44,00*	*53,00*	*500,00*	*2,29*	*16,50*	*37,20*	*19,75*	*-50,00*	*35,00*	*142,00*	*0,50*	*0,45*

Table 5

Risk Premia in Block Contracts

Risk premia in block contracts. The first table contains results for working days, the second for non-working days. ***, ** and * indicate significance at the 1, 5 and 10 % level; the Newey-West estimator is used to obtain robust standard errors.

Working Days

	Mean	Std.Dev.	Minimum	Median	Maximum	Skewness	Kurtosis
Base	*0,79***	*11,34*	*-131,54*	*0,64*	*128,94*	*-1,82*	*64,17*
Monday	*2,11****	*6,19*	*-34,26*	*1,41*	*36,01*	*0,28*	*12,84*
Tuesday	*0,03*	*16,69*	*-126,46*	*0,81*	*128,94*	*-1,27*	*41,19*
Wednesday	*1,12**	*9,57*	*-60,76*	*0,69*	*65,09*	*1,64*	*26,05*
Thursday	*-0,17*	*11,52*	*-131,54*	*0,27*	*43,39*	*-6,66*	*80,04*
Friday	*1,21**	*8,96*	*-33,11*	*0,40*	*69,01*	*3,93*	*30,12*
Peak	*1,55***	*20,37*	*-255,30*	*1,51*	*190,45*	*-3,74*	*68,54*
Monday	*3,41****	*11,60*	*-56,69*	*2,00*	*69,24*	*0,87*	*12,32*
Tuesday	*-0,16*	*30,14*	*-230,31*	*2,24*	*190,45*	*-3,44*	*37,42*
Wednesday	*1,53*	*15,53*	*-115,71*	*0,99*	*134,28*	*0,96*	*37,83*
Thursday	*0,44*	*21,66*	*-255,30*	*0,29*	*75,63*	*-7,00*	*86,74*
Friday	*3,15****	*15,29*	*-52,40*	*1,62*	*126,72*	*4,80*	*39,40*

Non-Working Days

	Mean	Std.Dev.	Minimum	Median	Maximum	Skewness	Kurtosis
Base	*0,08*	*3,43*	*-12,80*	*-0,21*	*12,94*	*0,27*	*1,70*
Saturday	*-0,22*	*3,79*	*-12,80*	*-0,45*	*10,12*	*-0,09*	*0,81*
Sunday	*-0,07*	*2,26*	*-5,56*	*-0,25*	*8,18*	*0,51*	*1,33*
Weekend	*0,12*	*3,11*	*-7,06*	*-0,09*	*10,62*	*0,61*	*1,01*

Table 6
Risk Premia in Day-Ahead Market Contracts

Risk premia in day-ahead market contracts. ***, ** and * indicate significance at the 1, 5 and 10 % level; the Newey-West estimator is used to obtain robust standard errors.

	Working Days			Non-Working Days		
Hour	Mean	Median	Std.Dev.	Mean	Median	Std.Dev.
1	*1,83****	*2,80*	*8,93*	*4,96****	*4,34*	*9,82*
2	*0,6*	*1,33*	*11,08*	*3,04****	*4,08*	*10,81*
3	*0,91***	*2,12*	*9,68*	*2,26****	*2,50*	*10,50*
4	*0,63*	*1,53*	*10,06*	*1,1*	*1,09*	*10,69*
5	*1,32***	*2,04*	*10,65*	*1*	*1,56*	*10,60*
6	*3,05****	*4,08*	*9,62*	*1,41***	*1,03*	*10,73*
7	*-1,26***	*-0,76*	*11,84*	*-2,73****	*-1,75*	*11,85*
8	*1,7***	*1,98*	*15,78*	*-1,54**	*-0,31*	*11,83*
9	*-4,19****	*-2,98*	*16,55*	*1,99****	*2,04*	*10,91*
10	*-1,55***	*-0,88*	*14,63*	*0,72*	*1,05*	*10,48*
11	*1,02*	*1,24*	*19,59*	*1,52***	*0,94*	*9,62*
12	*3,61****	*2,17*	*25,93*	*3,21****	*2,94*	*10,00*
13	*2,37****	*1,99*	*16,45*	*3,1****	*2,06*	*10,26*
14	*2,47****	*2,04*	*16,21*	*2,17****	*1,91*	*10,15*
15	*1,96****	*1,93*	*15,18*	*1,74****	*1,23*	*9,29*
16	*1,1***	*1,06*	*13,78*	*-0,1*	*0,59*	*10,09*
17	*-0,27*	*0,39*	*16,17*	*0,57*	*1,14*	*9,37*
18	*0,22*	*-0,48*	*28,51*	*0,88*	*0,73*	*11,56*
19	*3,27*	*-0,54*	*97,64*	*1,08*	*1,04*	*11,85*
20	*-0,38*	*-0,38*	*18,41*	*1*	*0,66*	*12,39*
21	*2,58****	*2,05*	*12,80*	*1,71***	*0,88*	*11,41*
22	*-0,03*	*0,09*	*10,19*	*1,39**	*1,87*	*11,34*
23	*-1,13***	*-0,26*	*10,75*	*2,05***	*1,83*	*11,56*
24	*-1,14***	*-0,71*	*9,37*	*1,11*	*1,01*	*10,25*
Overall	*0,8****	*0,76*	*26,02*	*1,4****	*1,37*	*10,82*

Table 7
Risk Premia in Day-Ahead Market Contracts By Delivery Month

Risk premia in day-ahead market contracts by delivery month. The estimated risk premia are shown for three blocks of hours on working days.
***, ** and * indicate significance at the 1, 5 and 10 % level; the Newey-West estimator is used to obtain robust standard errors.

	Base			Peak			Off-Peak		
	Mean	Median	Std.Dev.	Mean	Median	Std.Dev.	Mean	Median	Std.Dev.
January	*-1,98***	*-0,09*	*16,22*	*-2,9***	*-0,68*	*19,20*	*-0,88*	*0,42*	*11,66*
February	*0,67*	*1,17*	*10,21*	*0,36*	*0,96*	*10,78*	*1,05**	*1,72*	*9,45*
March	*-0,1*	*-0,19*	*9,16*	*-0,53*	*-0,11*	*9,69*	*0,41*	*-0,35*	*8,47*
April	*0,58*	*0,93*	*14,06*	*0,54*	*1,05*	*16,81*	*0,62*	*0,78*	*9,85*
May	*0,55*	*0,90*	*13,45*	*1,17*	*0,42*	*14,40*	*-0,15*	*1,04*	*12,26*
June	*3,31****	*2,03*	*17,51*	*4,57****	*2,63*	*21,53*	*1,77***	*1,10*	*10,55*
July	*1,38*	*2,95*	*15,90*	*-0,23*	*2,54*	*19,78*	*3,25****	*3,58*	*9,28*
August	*1,6****	*1,65*	*9,28*	*0,51*	*0,78*	*9,58*	*2,88****	*2,99*	*8,76*
September	*0,96*	*0,84*	*15,10*	*0,61*	*0,36*	*18,25*	*1,35*	*1,53*	*10,42*
October	*-0,06*	*-0,78*	*20,38*	*0,2*	*-1,16*	*23,82*	*-0,36*	*-0,24*	*15,18*
November	*2,33*	*0,03*	*69,60*	*4,48*	*-0,02*	*93,58*	*-0,24*	*0,28*	*11,47*
Decemeber	*1,82*	*1,20*	*23,05*	*2,9*	*1,13*	*28,47*	*0,43*	*1,33*	*13,00*

Table 8

Term Structure of Risk Premia

Term strucutre of risk premia. The risk premia are estimated with the last price on the intraday market on working days. ***, ** and indicate significance at the 1, 5 and 10 % level; the Newey-West estimator is used in order to obtain robust standard errors.

	Block Contracts			Day-Ahead Contracts		
	Mean	Median	Std.Dev.	Mean	Median	Std.Dev.
Base	*1,60*	*1,62*	*11,63*	*0,42*	*1,16*	*9,47*
Peak	*3,04****	*1,92*	*18,10*	*1,76***	*1,04*	*15,17*
Off-Peak	*0,07*	*0,55*	*6,73*	*0,33*	*0,37*	*5,36*