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The Dynamics of Risk Premiums in Australian Electricity Futures Markets

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Abstract

We investigate the dynamics of futures risk premiums in four regional Australian electricity markets (NSW, QLD, SA and VIC). We analyse realized risk premiums for quarterly futures contracts for different time intervals during the twelve months prior to the beginning of the delivery period of the contracts. Using data from 2005 to 2012, we find that futures premiums exhibit dynamics through time and tend to become more statistically significant as the contracts get closer to the beginning of the delivery period. The magnitude and significance of the premiums, however, vary across different regions, and also depend significantly on the contract quarter, i.e. whether the contract refers to the first, second, third or fourth quarter of the year. In a second step, we investigate the determinants of realized futures premiums and propose a model to effectively capture the dynamics of the premiums. We argue that time-to-delivery of contracts, spot price levels, volatility and variance of daily spot prices as well as the recent number of price spikes in the market are determinants for the dynamics of the observed premiums. For several of the markets and quarters, our model provides a reasonably high explanatory power. Overall, we find that futures premiums tend to be higher when contracts approach the beginning of the delivery period. Premiums also have a tendency to increase with spot price levels and with the frequency of price spikes observed in the spot market. Overall, our results illustrate the risk aversion of market participants and help to better understand the hedging behaviour and dynamics of risk premiums in Australian electricity markets.

JEL Classification: Q40, G32, G13

Keywords: *Australian Electricity Markets, Futures Contracts, Risk Premiums Dynamics*

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1. Introduction

One consequence of the ongoing deregulation of power markets around the world is that electricity futures markets can provide an important tool for reducing risk exposure (Botterud et al., 2002). As pointed out by e.g. Weron (2006), Benth et al. (2008), the risks contained in electricity spot and futures markets are quite substantial. Further, it is not possible to smooth out electricity supply and demand shocks since electricity is non-storable (Bowden and Payne, 2008). Electricity is also strongly characterised by its very limited transportability (Lucia and Schwartz, 2002), and its seasonal patterns as well as mean reversion, price dependent volatilities, long term non-stationarity and the occurrence of price spikes (Burger et al., 2004; Huisman et al., 2007; Kanamura and Ohashi, 2008; Karakatsani and Bunn, 2008). These distinctive features of price behaviour in electricity markets have prompted numerous studies.

Considerable controversies are associated with the existence of futures premiums in commodity markets (So, 1987; Deaves and Krinsky, 1995). Commodity futures prices can exhibit either backwardation or contango. Backwardation occurs when futures prices are lower than spot prices, while the market is usually referred to exhibit contango, when futures prices are higher than spot prices. According to Keynes (1930), a risk-averse net short hedge will reward (pay a premium to) a risk-assuming speculator in the case of backwardation. In contango, however, a risk-averse net long hedge will reward a risk-assuming speculator (Cootner, 1960). Despite this, Dusak (1973) finds that commodity futures premiums are not economically and statistically significant and later research by Baxter et al. (1985) supports Dusak's finding. These contrary results present a conundrum in understanding the dynamics of commodity futures premiums.

For electricity markets, several studies support the existence of futures risk premiums, however, the results and implications of these studies are not clear-cut. Some studies report positive premiums, see e.g. Longstaff and Wang (2004); Hadsell and Shawky (2006); Diko et al. (2006); Bierbrauer et al. (2007); Daskalakis and Markellos (2009); Redl et al. (2009), while others find negative risk premiums, for example in the PJM (Bessembiner and Lemmon, 2002) and Nord Pool (Botterud et al., 2010) markets. Clearly, whether observed risk premiums are positive or negative may also be a question of the time to delivery of the contract. According to Benth et al. (2008), economic intuition would suggest that a long-term negative and short-term positive risk premium should be observed in electricity markets. Long-term contracts with maturities greater than several months will be mainly used by producers to hedge their future electricity production. Producers may be willing to accept prices lower than the actual expected spot price in order to guarantee that the electricity produced can be sold in the market, which may result in a negative long-term risk premium. On the other hand, in the short-term, retailers or consumers, aiming to hedge the risk of extreme price outcomes in the spot market, may be willing to pay an additional premium for their hedge. Also, as pointed out above, electricity is also a seasonal commodity and it can be expected that contracts referring to different quarters might have very different risk premiums, see e.g. Handika and Trück (2013). It can also be expected that the behaviour of spot prices such as high price levels, changes in volatility or price spikes will have an influence on observed risk premiums (Redl and Bunn, 2011). This influence could exist at any point in time when the contract is traded, but may potentially be even higher once the contract gets closer to the beginning of the delivery period. Unfortunately, so far the literature on risk premiums in electricity futures markets has not investigated these issues very thoroughly. This is true in particular for regional Australian electricity markets that are examined in this study.

This paper offers a new perspective on the topic of risk premiums in electricity markets, by examining observed premiums through time across several electricity markets in Australia. Our study focuses on the ex-post futures premium that measures the difference between the quoted futures price prior to the beginning of the delivery period and the realised spot price during delivery period of the futures contract (Redl et al., 2009). First, we investigate the magnitude of futures premiums at different time instances in order to examine the dynamics of futures premiums with respect to the time-to-delivery. We argue that futures premiums are dynamic rather than static. We analyze each region and each quarter separately in order to accommodate regional and seasonal properties of electricity markets. In a second step, we investigate the determinants of the observed risk premiums. Unfortunately, these dynamics are not easy to model. As pointed out by Huisman and Kilic (2012), most likely we cannot rely on a single model for explaining explaining risk premiums in different electricity markets. However, a number of determinants have been found to have an impact on these premiums in prior studies. Based on previous results in the literature, we therefore suggest that time to maturity (Bailey and Ng, 1991; Bessembinder and Chan, 1992; Wilkens and Wimschulte, 2007; Bhar and Lee, 2011; Gorton et al., 2012), spot prices levels (Raynauld and Tessier, 1984; Wilkens and Wimschulte, 2007; Chevillon and Riffalrt, 2009), spot price volatility (Redl et al., 2009 ; Todorov, 2010; Benth et al., 2013) as well as the occurrence of price spikes (Coulon et al., 2013; Redl and Bunn, 2013) are key determinants of dynamic futures premiums in electricity markets. Our analysis provides important and new insights on the behaviour and determinants of futures risk premiums in electricity markets.

The remainder of the paper is organized as follows. Section 2 provides a brief overview of spot and futures trading in the Australian National Electricity Market (NEM). Section 3 discusses ex-post futures premium dynamics and their potential determinants. Section 4 describes the data and reports the futures premiums at different time intervals for each market and quarter. Section 5 investigates determinants of the observed futures premiums using a regression analysis. Section 6 concludes and provides suggestions for future work.

2. The Australian Electricity Market

The Australian electricity market has experienced significant changes during the last two decades. Prior to 1997 the market consisted of vertically integrated businesses operating within each of the states, without any connection between individual states. The businesses were owned by state governments and operated as monopolies. Overall, there were approximately twenty-five electricity distributors, all protected by governments from competition. To promote energy efficiency and reduce the costs of electricity production, in the late 1990s the Australian government commenced significant structural reform which, among others, had the following objectives: the separation of transmission from electricity generation, the merger of twenty-five electricity distributors into a smaller number of distributors, and the functional separation of electricity distribution from the retail supply of electricity. Retail competition was also introduced: a state's electricity purchases could be made through a competitive retail market and customers were now free to choose their retail supplier.

The NEM began operating as a wholesale market in December 1998. It is now an interconnected grid comprising several regional networks which supply electricity to retailers and end-users. As mentioned above, the NEM includes the states of QLD, NSW, VIC, SA and the ACT, while TAS is connected to the state of VIC via an undersea inter-connector. The link between electricity producers and consumers is established through a pool which is used to aggregate the output from all generators in order to meet the forecast demand. The pool is managed by the Australian Energy Market Operator (AEMO) under the National Electricity Law in conjunction with market participants and regulatory agencies. Unlike many other markets, the Australian spot electricity market is not a day-ahead market, instead electricity is traded in a constrained real time spot market where prices are set each five minutes by the AEMO. Therefore, generators submit offers every five minutes. This information is used to determine the number of generators required to produce electricity in a more cost-efficient way based on existing demand. The final price is determined every half-hour for each of the regions as an average over the 5-minute spot prices for each trading interval. Based on the half-hourly spot prices, a daily average spot price for each regional market can also be calculated. AEMO determines the half-hourly spot prices for each of the regional markets separately.

In recent years, the market for electricity derivatives has developed rapidly including electricity forward, futures and option contracts. Anderson et al. (2007) note that there are three types of Australian electricity forward contracts: (i) Bilateral over-the-counter (OTC) transactions between two entities directly, (ii) Bilateral over-the-counter (OTC) transactions on standard products executed through brokers, and (iii) Derivatives traded on the Sydney Futures Exchange (SFE). In our study we concentrate on futures contracts traded in the SFE during the time period 2005-2012. Note that the SFE also offers a number of alternative derivatives including option contracts or $300 cap products that will not be considered in this study.

Like in almost every electricity exchange, futures contracts traded in the SFE refer to the average electricity price during a delivery period. Thus, for a base period futures contract the contract unit is one Megawatt of electricity per hour (MWH) for each hour from 00:00 hours to 24:00 hours over the duration of the contract. For a quarterly base load contract, the size (in MWH) will vary depending on the number of days within the quarter. For example, for a quarter with 90 days, a contract refers to 2,160 MWH during the delivery period while for a quarter with 92 days, a contract refers to 2,208 MWH. In addition to base load futures contracts, peak period contracts are also traded. Given that electricity prices show strong intra-day variation and are heavily affected by demand in every precise moment (Lucia and Schwartz, 2002), the distinction between the whole day and the peak delivery period is important for market participants. In Australia, the peak period refers to the hours from 07:00 to 22:00 on weekdays (excluding public holidays) over the duration of the contract quarter. This implies that the off peak period includes the hours from 22:00 to 07:00 on weekdays and all hours on Saturday and Sunday. Therefore, the size of a quarterly peak period futures contract will vary depending on the number of days and peak-load hours within the quarter: for example a contract with 62 weekdays during a quarter (a so-called 62 day contract quarter) will equate to 930 MWH.

The contracts do not require physical delivery of electricity, but rather are settled financially. Therefore, market participants can participate in electricity futures markets and increase market liquidity without owning physical generation assets. The cash settlement price of a base (peak) period contract is calculated by taking the arithmetic average of the NEM final base (peak) load spot prices on a half hourly basis, rounded to two decimal places over the contract quarter. A provisional cash settlement price is declared on the first business day after expiry of the contract, while the final cash settlement takes place on the fourth business day after expiry of the contract.

3. Ex-Post Risk Premiums in Electricity Markets

The difference between the forward price and the expected spot price can be interpreted as a compensation for bearing the spot price risk (Bessembinder and Lemmon, 2002; Longstaff and Wang, 2004). However, as the ex-ante premium is basically unobservable, empirical analysis often concentrates on the ex-post or realized futures or forward premium in these markets:

$$RP_{t,[T_1,T_2]} = F_{t,[T_1,T_2]} - \bar{S}_{[T_1,T_2]}. \quad (1)$$

Hereby, $RP_{t,[T_1,T_2]}$ denotes the realized risk premium measured as the difference between the quote for a futures base or peak load contract, $F_{t,[T_1,T_2]}$, referring to delivery period *[T1,T2]* at time *t* and the actual average base or peak load spot price, $\bar{S}_{[T_1,T_2]}$, during the delivery period.

However, none of these studies investigate futures premiums at different time instances. We argue that investigating dynamic futures premiums is essential, since Deaves and Krinsky (1995) note that risk premiums may be time varying. Therefore, this paper presents a thorough analysis on ex-post futures premiums at different time intervals ranging from 12 months up to the last trading day before the beginning of the delivery period of the contract.

Empirical studies have generally found significant positive premiums in electricity forward markets. Longstaff and Wang (2004) find positive risk premiums of up to 14 percent for the PJM day ahead market while Redl et al. (2009) find positive premiums for month-ahead forward contracts in the Nordpool and EEX market. They report premiums ranging from 8 percent for baseload forward contracts in the Nordpool market and 9 percent for baseload up to 13 percent for peak load contracts in the EEX market. Botterud et al. (2010) report premiums ranging from 1.3 to 4.4 percent for the Nord Pool market when considering forward contracts with a delivery period from one week up to six weeks ahead. A number of other studies also confirm the significance of forward premiums in various electricity markets. Significant premiums are reported, for example, by Hadsell and Shawky (2006) for the New York Independent System Operator (NYISO), by Diko et al. (2006) for the Netherland APX, Bierbrauer et al. (2007) for the EEX, by Weron (2008) for the Scandinavian Nordpool market, Kolos and Ronn (2008) and by Daskalakis and Markellos (2009) for the EEX, Nordpool and Powernext markets. Interestingly, the studies provide quite different results on the actual sign of the risk premium even for the same markets: while Redl et al. (2009) find significant positive premiums for monthly baseload and peakload futures contracts in the EEX, Kolos and Ronn (2008) find a negative forward premium for monthly, quarterly and yearly contractsint the EEX during the 2002-2003 trading period. Bierbrauer et al. (2007) find positive ex-ante risk premiums for short-term futures contracts, while for contracts with maturities more than six months ahead the observed premiums are negative. Diko et al. (2006), investigating EEX peak load contracts, find that forward premiums decrease as time to maturity increases. Overall, the majority of authors seem to find rather positive risk premiums in electricity futures markets.

In a first step, we analyse the sign and behaviour of realized risk premiums with respect to the time-to-delivery of the contracts. Note that for this part of the analysis we decided to pool the observations on realized risk premiums into different time-to-delivery intervals in order to make our results more robust. Thus, each interval involves one month, such that we have 12 intervals, i.e. 12 refers to observations during the period from 12 to 11 months before beginning of the delivery period, 11 refers to the period 11 to 10 months before the delivery period, and so on. Finally, the last interval refers to observations during the last month prior to the beginning of the delivery period of a contract.[3] Note that given the results by Handika and Trück (2013) indicating strong differences between observed risk premiums for different quarters and markets, we analyse each quarter, i.e. Q1, Q2, Q3 and Q4, and region separately.

In a second step, using regression analysis, we try to relate the observed risk premiums to explanatory variables. Given our interest in the behaviour of futures risk premiums with respect to the maturity of the contracts, a key variable will be the remaining time to the beginning of the delivery period of the futures contract. However, as mentioned above the literature also suggests a variety of other variables that may have an impact on the magnitude and behaviour of risk premiums. Therefore, we also include spot prices levels, volatility in

[3] While pooling the data will lead to more robust results with respect to observed risk premiums, it also has a disadvantage with respect to the violation of the assumption of independent observations. When testing for significance of the realized premiums, we, therefore, have to use an adjusted t-test, see e.g. Wilks (1997).

the spot market, and an additional risk measure, i.e. the number of price spikes, as explanatory variables for observed futures premiums in the examined markets. Given the substantial differences for the observed risk premiums in the markets and quarters, we estimate the models for each region and quarter separately. While it would be beneficial to have a model for all observations, we believe that the observed dynamics of the futures risk premiums would not justify such an approach.

4. Descriptive Analysis of Risk Premiums

4.1 The Data

Our sample includes electricity spot and futures prices in four Australian regions: New South Wales (NSW), Queensland (QLD), South Australia (SA) and Victoria (VIC). We choose these because they exhibit the highest demand for electricity in Australia (Higgs, 2009) and data on futures is available only for these regions. In order to obtain the daily spot price we average the half-hourly electricity prices quoted from AEMO to calculate daily spot prices. We consider spot prices from 1 January 2005 to 30 June 2012[4] in our analysis, including weekends and holidays. Based on this sample, average spot prices can be calculated for base and peak periods. We quote the settlement price from the year prior to the last trading day for the first quarter (Q1), second quarter (Q2), third quarter (Q3) and fourth quarter (Q4) from 2005 to 2012. Data on electricity futures prices is obtained from d-cypha trade. Both the spot and futures prices are quoted in Australian dollars per Megawatt hour ($/MWh).

Table 1 shows a statistical summary of electricity spot prices for base and peak periods in the four Australian regions considered.[5] Recall that peak period prices refer to the hours from 07:00 to 22:00 on weekdays only, excluding public holidays. We find that there are clear differences between the regions and quarters. The considered markets tend to be most volatile in Q1, as indicated by the highest volatility and the highest number of price spikes

[4] We exclude data from July 1, 2012 onward since on July 1, 2012 a carbon tax of $23 per ton of CO2 emission became effective, significantly increasing spot electricity prices.

[5] According to Table 1, there are some negative prices that can be explained the following way: generators may be willing to accept negative prices for a number of hours when it is cheaper for them to keep the electricity production turned on instead of a costly shut-down of the generation facility (AEMO Information Centre, 2011). Hu et al. (2005) note that generation units (used to produce electricity) cannot be switched on and off in a short time for reasons of efficiency and safety. Therefore, producers may be better off paying a negative price to consumers rather than suddenly shutting down their production. Another view by Thomas et al. (2006) suggests that is a tactical bidding strategy to ensure that the generators are dispatched.

during these quarters. Q2, Q3 and Q4 tend to be less volatile, while also the number of price spikes seems to be lower for these periods. Average daily electricity spot prices range from $28.51/MWh (VIC region Quarter 4) to $68.33/MWh (SA region Quarter 1) for base period contracts and from $35.97/MWh (QLD region Quarter 3) to $119.99/MWh (SA region Quarter 1) for peak contracts. These stylized facts confirm the strong seasonality in Australian electricity markets. Therefore, it might be more beneficial to conduct the analysis of risk premiums in Australian electricity markets separately for different quarters.

4.2 Risk Premiums

Figure 1 provides a plot of observed average futures premiums for Q1, Q2, Q3 and Q4 base load futures contracts in all regions (NSW, QLD, SA and VIC) at different time intervals. Premiums are calculated based on the pooled data for a monthly period ranging from 12 months up to the last month before the beginning of the delivery period of the contracts. Figure 2 provides the same plot for peak load contracts. From both figures, we see the changing dynamics of futures premiums in Australian electricity markets. We also observe that realized risk premiums depend heavily not only on the considered regional markets and contracts (base or peak load), but possibly even more on the quarter the futures contract refers to.

The upper left panel of Figure 1 provides results for average realized risk premiums referring to Q1 base load contracts. For NSW, we find that Q1 premiums on average are around $13, while they range from approximately $10 approximately 10 months before the beginning of the delivery period, up to a level of more than $16 approximately 8 months before the beginning of the delivery period. Interestingly, after an initial increase, observed premiums decline to a level between $10 and $14 during the last 6 months before the beginning of the delivery period. For QLD observed premiums range from approximately $7 (12 months before beginning of the delivery period) up to almost $20 (5 months before the beginning of the delivery period). Similar to the NSW market, there is a steep increase in the premiums between 12 and 7 months before the beginning of the delivery period, while premiums stay at this comparably high level for several months. Only during the last two months before the beginning of the delivery periods, futures prices on average drop such that the realized premiums are around $17 two months, and $13 during the last month before the beginning of the delivery period. A similar behaviour can also be observed for VIC, where risk premiums show an increase from approximately $8 to more than $12, before dropping

Quarter 1				
Descriptive Statistics	NSW Base	QLD Base	SA Base	VIC Base
Mean	40.66	42.54	68.33	43.10
Standard Deviation	88.95	104.05	222.76	121.89
Skewness	10.91	9.97	7.36	13.70
Number of Price Spikes	160	169	267	160
Descriptive Statistics	NSW Peak	QLD Peak	SA Peak	VIC Peak
Mean	59.62	62.68	119.99	67.21
Standard Deviation	163.31	169.62	411.54	224.10
Skewness	9.30	8.83	6.10	11.55
Number of Price Spikes	143	144	242	146
Quarter 2				
Descriptive Statistics	NSW Base	QLD Base	SA Base	VIC Base
Mean	42.33	37.25	39.20	41.17
Standard Deviation	61.86	50.50	23.00	56.19
Skewness	8.82	8.20	2.33	15.78
Number of Price Spikes	152	110	40	68
Descriptive Statistics	NSW Peak	QLD Peak	SA Peak	VIC Peak
Mean	55.88	48.81	48.35	54.03
Standard Deviation	106.32	84.36	30.00	100.37
Skewness	8.00	7.54	3.04	15.02
Number of Price Spikes	125	100	31	60
Quarter 3				
Descriptive Statistics	NSW Base	QLD Base	SA Base	VIC Base
Mean	34.61	29.65	36.39	34.46
Standard Deviation	23.29	18.39	20.83	21.10
Skewness	6.57	5.80	4.70	5.72
Number of Price Spikes	52	25	30	33
Descriptive Statistics	NSW Peak	QLD Peak	SA Peak	VIC Peak
Mean	42.63	35.97	45.22	43.32
Standard Deviation	38.83	28.95	30.47	32.72
Skewness	6.63	6.53	5.74	6.56
Number of Price Spikes	47	23	26	31
Quarter 4				
Descriptive Statistics	NSW Base	QLD Base	SA Base	VIC Base
Mean	42.81	34.38	39.95	28.51
Standard Deviation	109.68	55.96	96.51	20.30
Skewness	8.88	9.75	12.34	7.65
Number of Price Spikes	150	94	106	52
Descriptive Statistics	NSW Peak	QLD Peak	SA Peak	VIC Peak
Mean	67.08	48.51	60.81	36.97
Standard Deviation	204.18	94.00	178.70	33.62
Skewness	7.32	9.06	10.45	8.16
Number of Price Spikes	141	79	93	43

Table 1: Descriptive statistics of daily base and peak load electricity spot prices from January 1, 2005 to June 30, 2012 for different quarters and markets. The table provides the mean, standard deviation, skewness as well as the number of price spikes for the considered NSW, QLD, SA and VIC regions during base and peak load periods.

again to a level of approximately $7. Interestingly, for SA we observe a strong continuous increase in realized risk premiums for Q1 base load contracts from -$4 (12 months) up to approximately $6 during the last two months prior to the delivery period of the contract.

Results are very different when risk premiums for Q2 base load contracts are considered. Observed premiums are negative for all markets and exhibit a pattern that is very different to what can be observed for Q1 contracts. Recall that Q2 typically refers to periods lower prices and a significantly smaller number of price spikes as illustrated by Table 1. Therefore, the demand for taking long positions in the futures market may be significantly lower. The negative premiums even points towards a higher demand for short positions in the futures markets indicating that producers may be willing to even pay a premium to consumers or speculators for taking a long position.

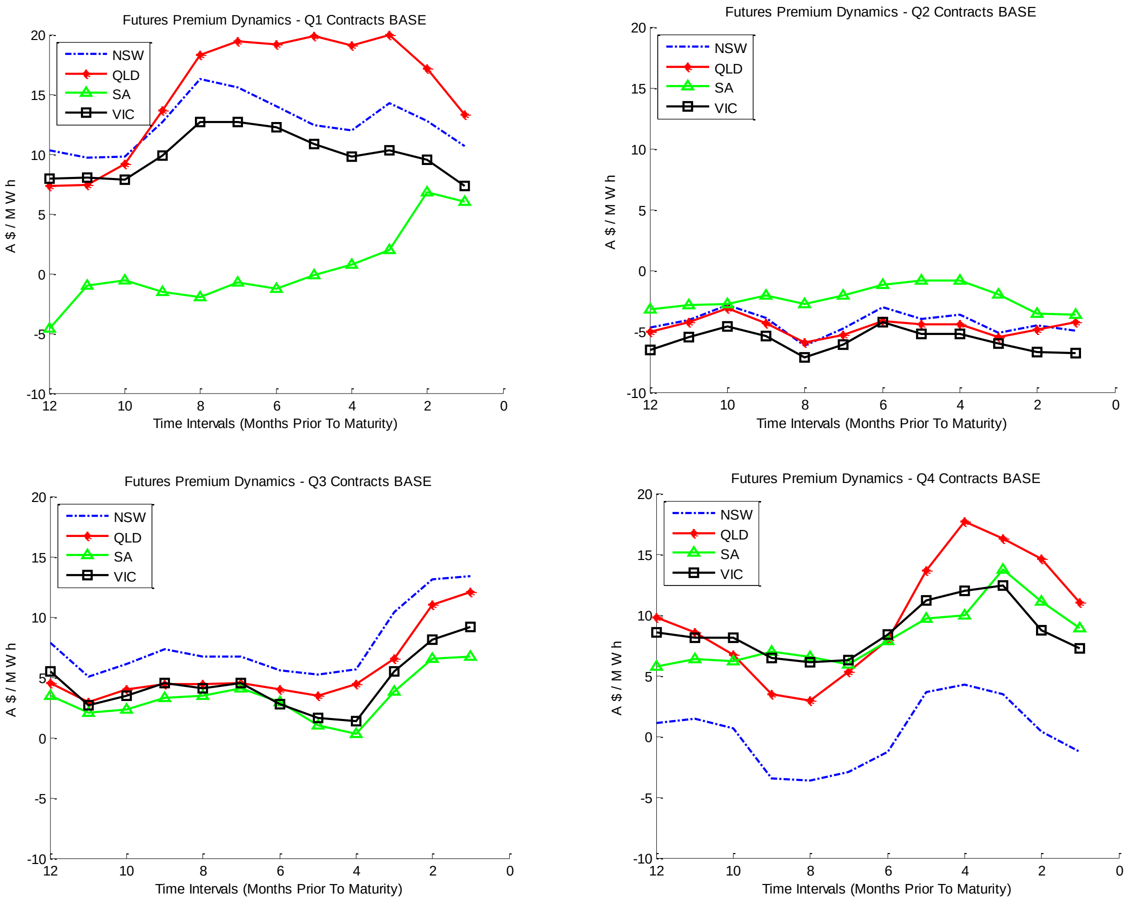

Figure 1: Average of realized futures premiums for Q1, Q2, Q3 and Q4 Futures Contracts in all regions at different time intervals (from 12 months up to 1 month prior to the beginning of the delivery period of the contract) for quarterly base load futures contracts.

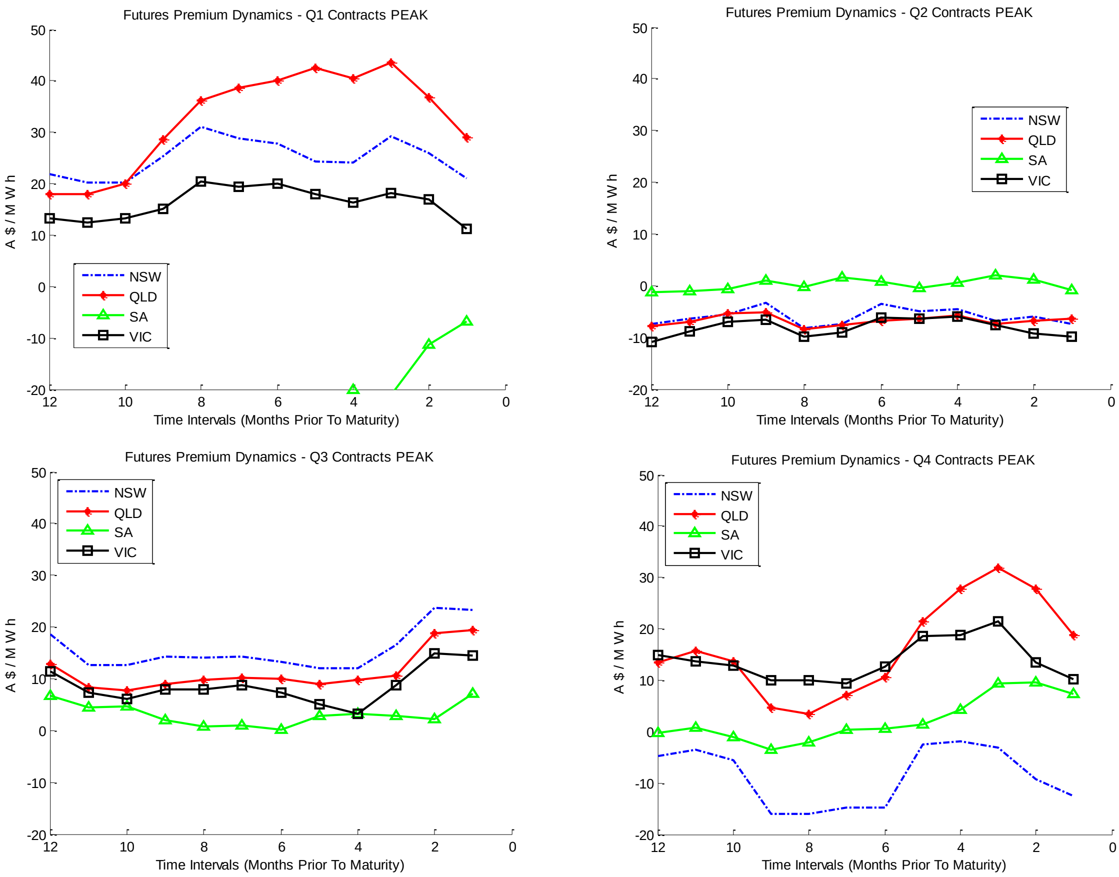

Figure 2: Average of realized futures premiums for Q1, Q2, Q3 and Q4 Futures Contracts in all regions at different time intervals (from 12 months up to 1 month prior to the beginning of the delivery period of the contract) for quarterly peak load futures contracts.

Also premiums for contracts referring to Q3 are characterized by a different behaviour through time. There is tendency for premiums to decline during the first 8 months of trading during, i.e. for the period ranging from 12 up to four months before the delivery period. However, during the last three months before the beginning of the delivery period, we observe a steep increase in realized premiums up to approximately $12 for QLD and $13 for NSW. Interestingly, we also observe that for Q3 the all markets seem to behave very similar with respect to the dynamics of futures prices. The steep increase in risk premiums closer to the delivery period is even more surprising as Q3 is usually characterized the lowest average electricity prices, low volatility in prices and a very small number of price spikes.

Finally, for Q4 we observe mainly positive risk premiums, in particular for QLD, SA and VIC markets. Interestingly, for the NSW market, we also observe negative risk premiums during the time period between nine and six months prior to the beginning of the delivery period of the contracts. For all markets, after an initial decline, premiums increase significantly between eight and four months prior to the delivery period and then decline again during the last three months. The negative premiums for NSW are surprising, since on average NSW exhibits the highest number of price spikes during Q4.

As indicated by Figure 2, we find similar patterns for the dynamics of risk premiums referring to peak period futures contracts. However, the magnitude of the premiums is even higher. For example, for Q1 peak contracts average risk premiums are between \$20 and \$31 for NSW, between \$18 and \$44 for QLD and between \$11 and \$20 for VIC. Again, the SA market shows a very different behaviour with average risk premiums increasing from approximately -\$47 to -\$7 during the year prior to the beginning of the delivery period. Again we find that for Q2 contracts observed premiums are predominantly negative, while they are usually positive for contracts referring to Q3 and Q4. Again for Q4, risk premiums are negative for the NSW markets despite the high price levels, volatility and comparably large number of price spikes. One could argue that for Q4, during the considered period from 2005 to 2012 realized spot prices were even higher than what had been anticipated by market participants.

Overall, the descriptive analysis shows that there are quite substantial differences between observed premiums for different markets and delivery quarters. While realized premiums are predominantly positive for most markets and quarters, we also find negative premiums for Q2 contracts in all markets and for NSW in Q4. It also becomes obvious that futures prices do generally not provide an accurate estimate of realized average spot prices during the delivery period. In a next step we will now analyse the significance of observed premiums for the considered intervals ranging from 12 months up to the last month prior to the beginning of the delivery period.

Table 2 and Table 3 report realized risk premiums for base and peak load futures contracts as well as results on the significance of the premiums for NSW, QLD, SA and VIC. Recall that due to the pooled data, realized risk premiums exhibit relatively high levels of autocorrelation for each contract. Therefore, it may be critical to apply a standard t-test in order to test for significance of the premiums. A solution to this problem is to adjust the variance, i.e. use the so-called variance inflation factor (VIF), before applying a t-test (Wilks, 1997). Therefore, according to Wilks (1997), we adjust the sample variance of the data by the variance inflation factor (VIF) using

$$\mathrm{var}(x) = V\frac{s_x^2}{n}, \quad (2)$$

NSW BASE LOAD CONTRACTS

INTERVALS	12	11	10	9	8	7	6	5	4	3	2	1
Q1 Premium	10.32	9.69	9.77	12.65	16.27	15.56	14.02	12.40	12.01	14.28	12.79	10.66
t-Stat	2.37	2.54	2.00	2.33	2.09	1.94	1.92	1.93	1.86	1.81	1.95	1.79
p-value	0.02	0.01	0.05	0.02	0.04	0.05	0.06	0.06	0.06	0.07	0.05	0.07
Number of Observations	142	141	154	135	154	148	151	156	151	153	151	141
Q2 Premium	-4.67	-4.09	-2.84	-3.88	-6.16	-4.77	-3.03	-4.01	-3.67	-5.16	-4.56	-4.95
t-Stat	-0.43	-0.33	-0.23	-0.36	-0.53	-0.43	-0.26	-0.35	-0.36	-0.49	-0.50	-0.58
p-value	0.67	0.74	0.82	0.72	0.60	0.67	0.79	0.73	0.72	0.62	0.62	0.56
Number of Observations	135	154	148	151	156	151	153	151	141	162	162	176
Q3 Premium	7.86	5.04	6.12	7.32	6.74	6.70	5.59	5.24	5.69	10.36	13.12	13.39
t-Stat	1.56	1.10	1.28	1.41	1.27	1.35	1.39	1.52	2.14	4.99	3.31	2.90
p-value	0.12	0.28	0.20	0.16	0.20	0.18	0.17	0.13	0.03	0.00	0.00	0.00
Number of Observations	130	133	129	132	129	121	142	141	154	135	154	148
Q4 Premium	1.12	1.40	0.62	-3.49	-3.68	-2.91	-1.27	3.63	4.29	3.45	0.41	-1.26
t-Stat	0.19	0.27	0.11	-0.67	-0.67	-0.50	-0.19	0.46	0.50	0.34	0.05	-0.17
p-value	0.85	0.79	0.91	0.50	0.50	0.62	0.85	0.65	0.62	0.74	0.96	0.87
Number of Observations	132	129	121	142	141	154	135	154	148	151	156	151

QLD BASE LOAD CONTRACTS

INTERVALS	12	11	10	9	8	7	6	5	4	3	2	1
Q1 Premium	7.35	7.38	9.19	13.64	18.27	19.40	19.16	19.91	19.07	19.99	17.18	13.30
t-Stat	1.23	1.47	1.90	2.71	2.43	2.18	2.28	2.05	1.92	1.95	1.94	1.73
p-value	0.22	0.14	0.06	0.01	0.02	0.03	0.02	0.04	0.06	0.05	0.05	0.09
Number of Observations	142	141	154	135	154	148	151	156	151	153	151	141
Q2 Premium	-5.02	-4.23	-3.11	-4.31	-5.91	-5.28	-4.20	-4.42	-4.47	-5.46	-4.90	-4.25
t-Stat	-0.54	-0.40	-0.29	-0.45	-0.58	-0.54	-0.41	-0.44	-0.50	-0.58	-0.59	-0.59
p-value	0.59	0.69	0.77	0.65	0.57	0.59	0.68	0.66	0.62	0.56	0.55	0.56
Number of Observations	135	154	148	151	156	151	153	151	141	162	162	176
Q3 Premium	4.48	2.91	3.99	4.46	4.46	4.55	4.00	3.47	4.43	6.57	10.99	12.03
t-Stat	1.06	0.63	0.85	0.87	0.86	0.99	0.98	1.04	1.99	5.14	2.59	2.43
p-value	0.29	0.53	0.40	0.39	0.39	0.32	0.33	0.30	0.05	0.00	0.01	0.02
Number of Observations	130	133	129	132	129	121	142	141	154	135	154	148
Q4 Premium	9.78	8.55	6.69	3.46	2.96	5.32	7.95	13.68	17.66	16.23	14.61	11.00
t-Stat	1.85	1.97	2.49	1.36	1.37	3.78	2.99	2.54	2.14	1.81	1.89	1.63
p-value	0.07	0.05	0.01	0.18	0.17	0.00	0.00	0.01	0.03	0.07	0.06	0.11
Number of Observations	132	129	121	142	141	154	135	154	148	151	156	151

SA BASE LOAD CONTRACTS

INTERVALS	12	11	10	9	8	7	6	5	4	3	2	1
Q1 Premium	-4.58	-1.05	-0.60	-1.57	-1.94	-0.74	-1.27	-0.16	0.75	2.02	6.84	5.97
t-Stat	-0.31	-0.06	-0.04	-0.13	-0.16	-0.07	-0.11	-0.01	0.07	0.20	0.74	0.68
p-value	0.76	0.95	0.97	0.89	0.87	0.95	0.91	0.99	0.94	0.84	0.46	0.50
Number of Observations	142	141	154	135	154	148	151	156	151	153	151	141
Q2 Premium	-3.23	-2.85	-2.75	-2.02	-2.77	-2.10	-1.16	-0.84	-0.79	-1.98	-3.52	-3.64
t-Stat	-0.51	-0.44	-0.43	-0.34	-0.47	-0.38	-0.19	-0.14	-0.14	-0.39	-0.86	-1.03
p-value	0.61	0.66	0.67	0.74	0.64	0.71	0.85	0.89	0.89	0.69	0.39	0.31
Number of Observations	135	154	148	151	156	151	153	151	141	162	162	176
Q3 Premium	3.44	2.10	2.33	3.31	3.49	4.12	2.97	0.97	0.29	3.85	6.50	6.71
t-Stat	0.54	0.36	0.42	0.56	0.56	0.64	0.55	0.22	0.07	1.13	1.61	1.69
p-value	0.59	0.72	0.68	0.57	0.58	0.52	0.58	0.83	0.94	0.26	0.11	0.09
Number of Observations	130	133	129	132	129	121	142	141	154	135	154	148
Q4 Premium	5.70	6.40	6.19	6.96	6.55	5.93	7.83	9.71	9.94	13.70	11.08	8.93
t-Stat	1.14	1.53	1.55	1.58	1.61	1.38	1.37	1.47	1.54	1.54	1.80	1.52
p-value	0.26	0.13	0.12	0.12	0.11	0.17	0.17	0.14	0.12	0.13	0.07	0.13
Number of Observations	132	129	121	142	141	154	135	154	148	151	156	151

VIC BASE LOAD CONTRACTS

INTERVALS	12	11	10	9	8	7	6	5	4	3	2	1
Q1 Premium	7.96	8.07	7.87	9.86	12.67	12.67	12.27	10.82	9.78	10.34	9.52	7.36
t-Stat	1.20	1.23	1.39	1.85	1.90	1.93	2.01	2.14	2.09	1.91	2.09	1.69
p-value	0.23	0.22	0.17	0.07	0.06	0.06	0.05	0.03	0.04	0.06	0.04	0.09
Number of Observations	142	141	154	135	154	148	151	156	151	153	151	141
Q2 Premium	-6.56	-5.46	-4.57	-5.38	-7.18	-6.14	-4.22	-5.21	-5.20	-5.99	-6.70	-6.81
t-Stat	-0.92	-0.66	-0.53	-0.75	-0.97	-0.87	-0.56	-0.74	-0.82	-0.97	-1.28	-1.47
p-value	0.36	0.51	0.59	0.46	0.33	0.39	0.58	0.46	0.41	0.33	0.20	0.14
Number of Observations	135	154	148	151	156	151	153	151	141	162	162	176
Q3 Premium	5.50	2.69	3.48	4.50	4.11	4.52	2.80	1.58	1.37	5.46	8.10	9.15
t-Stat	0.84	0.45	0.58	0.73	0.66	0.73	0.56	0.37	0.35	1.75	2.04	1.90
p-value	0.40	0.65	0.56	0.47	0.51	0.47	0.57	0.71	0.72	0.08	0.04	0.06
Number of Observations	130	133	129	132	129	121	142	141	154	135	154	148
Q4 Premium	8.56	8.11	8.15	6.44	6.11	6.25	8.39	11.18	11.99	12.42	8.76	7.21
t-Stat	2.48	2.28	2.21	1.89	1.99	2.31	3.21	3.25	2.80	2.43	3.39	4.16
p-value	0.01	0.02	0.03	0.06	0.05	0.02	0.00	0.00	0.01	0.02	0.00	0.00
Number of Observations	132	129	121	142	141	154	135	154	148	151	156	151

Table 2: Realized risk premiums, t-stats and p-values for significance of the premium for quarterly base load futures contracts with time to delivery ranging from approximately twelve months up to the last month before the beginning of the delivery period.

where s_x^2 denotes the sample variance of the realized risk premiums, *n* denotes the number of observations, and *V* is the variance inflation factor. The variance inflation factor can be calculated as

$$V = 1 + 2\sum_{k=1}^{20}\left(1 - \frac{k}{n}\right) r_k \, , \qquad (3)$$

where r_k denotes estimates of the autocorrelation at lag *k*. Note that in order to estimate r_k we use up to 20 lags since in each monthly interval we usually have 20 days of trading.

We find that futures risk premiums tend to be more significant as contracts are closer to the beginning of the delivery period. On the other hand, we observe large differences also with respect to the significance of the premiums depending on the considered market and delivery quarter of the contract. For Q1 base load contracts, observed risk premiums are positive and highly significant in all regions except SA. For Q2 base load contracts, the observed futures premiums are negative, but they are not statistically significant for any of the considered regions. For Q3 base load contracts, the observe futures premiums are positive and quite substantial for all regions. Nevertheless, they are only statistically significant during the last three months prior to the beginning of the delivery period in NSW, QLD and VIC. For Q4 base load contracts, the observed futures premiums are positive and statistically significant for the QLD, SA and VIC market. On the other hand premiums are negative, but not significantly different from zero for NSW.

For Q1 peak load contracts, observed futures risk premiums are positive and statistically significant for NSW and QLD, while they are positive but no significantly different from zero for VIC. For the SA market, Q1 risk premiums are negative and despite being of high magnitude, they are not significantly different from zero due to the high standard deviation of observed premiums. For Q2 peak load contracts, observed risk premiums tend to be negative and quite large. However, they are not statistically significant for any region. For Q3 peak load contracts, risk premiums are significant only for the NSW and QLD region, while they are still positive but not significantly different from zero for SA and VIC. Finally, for Q4 peak load contracts, observed risk premiums are positive and statistically significant in QLD and VIC. For NSW and SA, Q4 risk premiums are negative, but not statistically significant.

Overall, we find that realized risk premiums for the considered contracts, usually tend to be positive and of high magnitude. However, they are not always significantly different, in particular for the SA and VIC market. Further, the huge difference in results with respect to

NSW PEAK LOAD CONTRACTS												
INTERVALS	12	11	10	9	8	7	6	5	4	3	2	1
Q1 Premium	21.83	20.14	20.29	25.38	31.10	28.87	27.77	24.39	24.03	29.26	25.99	21.01
t-Stat	2.27	2.41	1.94	2.18	2.10	1.92	1.91	1.90	1.87	1.82	2.00	1.77
p-value	0.02	0.02	0.05	0.03	0.04	0.06	0.06	0.06	0.06	0.07	0.05	0.08
Number of Observations	142	141	154	135	154	148	151	156	151	153	151	141
Q2 Premium	-7.41	-6.37	-5.48	-3.34	-8.27	-7.37	-3.57	-4.89	-4.55	-6.85	-6.06	-7.38
t-Stat	-0.36	-0.28	-0.24	-0.16	-0.38	-0.35	-0.17	-0.23	-0.24	-0.36	-0.36	-0.45
p-value	0.72	0.78	0.81	0.87	0.70	0.72	0.87	0.82	0.81	0.72	0.72	0.65
Number of Observations	135	154	148	151	156	151	153	151	141	162	162	176
Q3 Premium	18.52	12.65	12.65	14.19	13.99	14.21	13.21	12.10	12.09	16.60	23.66	23.30
t-Stat	2.13	1.76	1.72	1.80	1.74	1.81	2.02	2.34	2.76	7.70	3.90	3.38
p-value	0.04	0.08	0.09	0.07	0.09	0.07	0.05	0.02	0.01	0.00	0.00	0.00
Number of Observations	130	133	129	132	129	121	142	141	154	135	154	148
Q4 Premium	-4.78	-3.57	-5.56	-15.99	-16.01	-14.78	-14.75	-2.44	-1.88	-3.12	-9.30	-12.56
t-Stat	-0.29	-0.23	-0.32	-1.03	-1.01	-0.90	-0.89	-0.13	-0.09	-0.13	-0.49	-0.68
p-value	0.78	0.82	0.75	0.30	0.32	0.37	0.37	0.90	0.93	0.89	0.63	0.50
Number of Observations	132	129	121	142	141	154	135	154	148	151	156	151
QLD PEAK LOAD CONTRACTS												
INTERVALS	12	11	10	9	8	7	6	5	4	3	2	1
Q1 Premium	17.99	17.90	20.09	28.55	36.15	38.55	40.12	42.60	40.53	43.61	36.82	29.00
t-Stat	1.64	2.14	2.27	2.92	2.51	2.22	2.28	2.06	1.96	1.92	2.00	1.76
p-value	0.10	0.03	0.02	0.00	0.01	0.03	0.02	0.04	0.05	0.06	0.05	0.08
Number of Observations	142	141	154	135	154	148	151	156	151	153	151	141
Q2 Premium	-7.82	-6.93	-5.41	-5.13	-8.41	-7.62	-6.77	-6.33	-5.85	-7.41	-6.76	-6.30
t-Stat	-0.47	-0.37	-0.29	-0.30	-0.46	-0.46	-0.37	-0.35	-0.37	-0.45	-0.47	-0.48
p-value	0.64	0.71	0.77	0.76	0.64	0.65	0.71	0.72	0.71	0.65	0.64	0.63
Number of Observations	135	154	148	151	156	151	153	151	141	162	162	176
Q3 Premium	12.82	8.44	7.75	8.97	9.83	10.28	9.93	9.06	9.74	10.64	18.87	19.37
t-Stat	1.87	1.34	1.29	1.23	1.31	1.50	1.63	2.10	3.16	6.16	2.98	2.89
p-value	0.06	0.18	0.20	0.22	0.19	0.14	0.11	0.04	0.00	0.00	0.00	0.00
Number of Observations	130	133	129	132	129	121	142	141	154	135	154	148
Q4 Premium	13.41	15.69	13.73	4.71	3.38	7.15	10.60	21.39	27.69	31.82	27.85	18.75
t-Stat	2.11	2.27	3.16	0.95	0.71	1.50	1.76	2.18	1.92	1.55	1.56	1.23
p-value	0.04	0.03	0.00	0.35	0.48	0.13	0.08	0.03	0.06	0.12	0.12	0.22
Number of Observations	132	129	121	142	141	154	135	154	148	151	156	151
SA PEAK LOAD CONTRACTS												
INTERVALS	12	11	10	9	8	7	6	5	4	3	2	1
Q1 Premium	-46.60	-43.35	-41.61	-43.28	-43.42	-39.05	-38.53	-31.33	-20.19	-21.13	-11.26	-6.77
t-Stat	-1.12	-1.10	-1.07	-1.17	-1.13	-1.04	-1.03	-0.86	-0.61	-0.61	-0.35	-0.24
p-value	0.26	0.27	0.29	0.25	0.26	0.30	0.30	0.39	0.54	0.54	0.72	0.81
Number of Observations	142	141	154	135	154	148	151	156	151	153	151	141
Q2 Premium	-1.23	-0.97	-0.62	0.89	-0.18	1.65	0.79	-0.36	0.50	1.91	1.11	-0.79
t-Stat	-0.12	-0.09	-0.06	0.09	-0.02	0.17	0.08	-0.04	0.05	0.21	0.16	-0.14
p-value	0.90	0.93	0.95	0.93	0.99	0.86	0.94	0.97	0.96	0.84	0.87	0.89
Number of Observations	135	154	148	151	156	151	153	151	141	162	162	176
Q3 Premium	6.73	4.46	4.71	2.07	0.85	0.98	0.19	2.75	3.21	2.78	2.23	7.03
t-Stat	0.71	0.51	0.53	0.26	0.11	0.13	0.03	0.46	0.64	0.60	0.48	1.48
p-value	0.48	0.61	0.60	0.79	0.91	0.90	0.98	0.65	0.53	0.55	0.63	0.14
Number of Observations	130	133	129	132	129	121	142	141	154	135	154	148
Q4 Premium	-0.28	0.69	-1.13	-3.55	-2.07	0.27	0.47	1.37	4.19	9.31	9.48	7.27
t-Stat	-0.02	0.05	-0.08	-0.32	-0.19	0.02	0.04	0.12	0.31	0.57	0.72	0.54
p-value	0.99	0.96	0.94	0.75	0.85	0.98	0.97	0.91	0.75	0.57	0.47	0.59
Number of Observations	132	129	121	142	141	154	135	154	148	151	156	151
VIC PEAK LOAD CONTRACTS												
INTERVALS	12	11	10	9	8	7	6	5	4	3	2	1
Q1 Premium	13.32	12.44	13.36	15.01	20.41	19.49	19.94	17.88	16.24	18.25	16.85	11.23
t-Stat	0.87	0.87	1.08	1.29	1.49	1.48	1.53	1.65	1.62	1.51	1.66	1.12
p-value	0.38	0.39	0.28	0.20	0.14	0.14	0.13	0.10	0.11	0.13	0.10	0.27
Number of Observations	142	141	154	135	154	148	151	156	151	153	151	141
Q2 Premium	-10.83	-8.81	-7.04	-6.50	-9.88	-9.10	-6.23	-6.37	-6.08	-7.70	-9.19	-9.96
t-Stat	-1.02	-0.67	-0.52	-0.55	-0.84	-0.83	-0.51	-0.54	-0.59	-0.82	-1.17	-1.34
p-value	0.31	0.50	0.60	0.59	0.40	0.41	0.61	0.59	0.55	0.42	0.24	0.18
Number of Observations	135	154	148	151	156	151	153	151	141	162	162	176
Q3 Premium	11.37	7.37	6.06	7.88	7.91	8.68	7.36	5.06	3.18	8.77	14.85	14.55
t-Stat	1.09	0.84	0.70	0.90	0.86	0.92	0.91	0.77	0.52	1.66	1.97	1.91
p-value	0.28	0.40	0.48	0.37	0.39	0.36	0.36	0.44	0.61	0.10	0.05	0.06
Number of Observations	130	133	129	132	129	121	142	141	154	135	154	148
Q4 Premium	14.91	13.74	12.75	10.04	10.04	9.34	12.70	18.54	18.86	21.44	13.43	10.16
t-Stat	2.54	2.46	2.22	1.66	1.71	1.80	2.39	2.55	2.31	2.10	2.69	3.23
p-value	0.01	0.02	0.03	0.10	0.09	0.07	0.02	0.01	0.02	0.04	0.01	0.00
Number of Observations	132	129	121	142	141	154	135	154	148	151	156	151

Table 3: Realized risk premiums, t-stats and p-values for significance of the premium for quarterly peak load futures contracts with time to delivery ranging from approximately twelve months up to the last month before the beginning of the delivery period.

the quarter a contract is referring to, suggests strong seasonal effects not only in electricity spot and futures prices, but also in the behaviour of realized risk premiums. Different results for different time intervals also respond to the question of whether observed risk premiums are positive or negative. The generally increasing pattern for the observed premiums also support economic intuition of short term positive risk premiums due to increased hedging demand by retailers or consumers, see e.g. Benth et al. (2008).

While the analysis of this section has been limited to the behavior of premiums with respect to delivery quarter, region and time to maturity of the contracts, in the following we will further investigate the determinants of the observed risk premiums. In particular we examine how spot price level and volatility as well as the number of price spikes impact on realized risk premiums in the considered markets.

5. Determinants of Realized Futures Premiums

Modeling the dynamics of risk premiums implied in electricity futures contracts can be considered as one of the most challenging tasks in these markets. As pointed out by Huisman and Kilic (2012), forward models for electricity markets with imperfect indirect storability should depend heavily on price expectations, and are required to include time-varying risk premiums. Their findings also imply that it will be difficult to rely on a one-size fits all model for various futures contracts in different regional electricity markets. Haugom and Ulrich (2012) conclude that they are unable to find support for the equilibrium forward pricing model suggested by Bessembinder and Lemmon (2002). Considering short-term electricity forward contracts, they report highly unstable parameter values when a using rolling and recursive estimations of the model. This implies that modeling electricity futures premiums is challenging because electricity markets tend to be very dynamic. Despite these complexities, we try to develop a model that can identify determinants of dynamic risk premiums in electricity futures markets.

Bailey and Ng (1991) emphasize the importance of time-varying risk premiums for both theoretical and empirical research on forward and futures markets. Bessembinder and Chan (1992) document non-random price movements, implying evidence of time-varying risk premiums in 12 different futures markets. Wilkens and Wimschulte (2007) find that the bias of futures prices depends on the remaining time to maturity of futures contracts in the European Energy Exchange (EEX) markets. This also implies that time to maturity is an essential factor in explaining electricity futures premiums. Another study by Bhar and Lee (2011) shows that the timing of hedging mismatches could raise risk premiums, implying that an the time to maturity of a contract is essential for hedging and determining risk premiums. Gorton et al. (2012) also identify time-varying risk premiums in various commodity markets. Their findings suggest that risk premiums could vary at different times and therefore, time to maturity could be an important factor for the risk premium. Given our results in the previous section, we also suggest that the remaining time to the beginning of the delivery period of a contract is a key factor for explaining dynamic risk premiums. However, the results also indicate that the impact is quite different, depending on the delivery quarter and region of a considered contract.

Raynauld and Tessier (1984) propose two elements explaining ex-post futures premiums: rational agents and co-movement. For both elements, spot price behavior may play an important role in determining the premiums. As suggested by Chevillon and Rifflart (2009), observed premiums could also depend on the deviation of nominal spot prices from their long-term price levels. Furthermore, Wilkens and Wimschulte (2007) find that electricity spot price levels could explain the bias in electricity futures prices. Therefore, in our analysis we include recent information on spot price levels and volatility as possible determinants of futures risk premiums. We also include an additional factor, namely the number of price spikes in the spot market as a proxy for the risk of extreme outcomes in the considered market.

In particular, we include the moving average of the spot price as an explanatory variable for the risk premium. We use historical daily data up to one year prior to $t<T_1$ when the quote of a futures price referring to delivery period $[T_1,T_2]$ is observed. Seminal work on the electricity premiums modeling (Bessembinder and Lemmon, 2002; Douglas and Popova, 2008; Lucia and Toro, 2008, Redl et al. 2009) also suggest volatility in the spot market or electricity demand as one of the key determinants of the risk premium. Todorov (2010) concludes that investors tend to be sensitive to recent jump activity and that their willingness to pay for protection against potential jumps in prices increases significantly immediately after the occurrence of jumps. These findings suggest that large market movements may also drive time-varying risk aversion and, therefore, realized risk premiums. This leads to two important points: (i) large market movements affect investors' willingness to pay for protection, and, (ii) investors are sensitive to recent jump activity. Therefore, we suggest that spot market volatility, a reflection of market movement, plays an essential role in explaining dynamic risk premiums. We estimate the current level of volatility in the spot market, using

an Exponentially Weighted Moving Average (EWMA) model to capture the sensitivity to recent changes in volatility. Given the convex relationship between electricity volatility and risk premiums in electricity futures markets, see e.g. Bessembinder and Lemmon (2002), Handika and Trück (2013), we might also include recent estimates of both volatility and variance of electricity spot prices into our model.

Recent research by Benth et al. (2013) models time-varying electricity risk premiums in the EEX market, using different information sets in the spot and forward market. Their findings confirm the existence of risk premiums in electricity derivatives markets. They also suggest that information about the future, for example information referring to the delivery period of a derivatives contract may be incorporated in the pricing. A more detailed multi-factor model by Redl and Bunn (2013) suggests that the occurrence of spikes in the spot market increases the electricity forward premium. Therefore, it is sensible to argue that price spikes are also an essential component of the relationship between spot and futures prices, next to other statistical properties including the mean, volatility and variance of electricity demand or prices. This implies that price spikes may also determine the magnitude of electricity futures premiums. Another detailed argument can be found in Coulon et al. (2013) where it is suggested that the electricity stack reflects the key features of load and price dynamics. The authors observe that times of high load tend to be related to price spikes. Assuming that electricity market participants are rational, we could argue that recent observations of price spikes, reflecting times of unexpected high loads, can prompt participants to worry about future electricity prices, with the result that they increase the demand for long positions in electricity futures contracts. Therefore, the occurrence of price spikes can be expected to increase risk premiums implied in electricity futures contracts. In summary, we classify current levels of spot prices, the volatility and variance of the spot prices as well as the number of price spikes as highly relevant information in electricity spot markets that might determine the sign and magnitude of electricity futures premiums.

Based on this reasoning, we suggest the following model to examine the dynamics of realized risk premiums in Australian electricity futures markets using the following model:

$$RP_{t,[T_1,T_2]} = \beta_0 + \beta_1 (T_1 - t) + \beta_2 \bar{S}_t + \beta_3 \sigma_t + \beta_4 \sigma_t^2 + \beta_5 PS_t + \varepsilon_t \qquad (4)$$

Hereby, $RP_{t,[T_1,T_2]}$ denotes the realized risk premium measured as the difference between the quote for a futures base or peak load contract referring to delivery period $[T_1,T_2]$ at time t and the actual average base or peak load spot price during the delivery period. Further,

$(T_1 - t)$ denotes the remaining time to the beginning of the delivery period, $\bar{S}_t$ is the one-year moving average of daily spot price at time *t*, σ_t is the volatility estimate for daily spot electricity prices at time t based on an EWMA model with $\lambda = 0.94$. Finally, σ_t^2 denotes the variance estimate of daily spot price volatility based on the EWMA model and PS_t is the number of price spikes exceeding $300 during the month prior to *t*.

Table 4 and Table 5 report results for the regression analysis for model (4) for quarterly base and peak load futures contracts. Note that given the substantial differences between observed risk premiums for different quarters and markets, we decided to analyze each quarter and regional market separately. Therefore, both for base load and peak load contracts a total of 16 models, referring to four quarters (Q1, Q2, Q3, Q4) and four markets (NSW, QLD, SA, VIC) are estimated. Overall, we find that the observed futures risk premiums tend to increase based on (i) a reduction in time to maturity, i.e. the beginning of the delivery period of the contract, (ii) the average level of spot prices during the last 12 months, and (iii) the number of price spikes in the most recent month prior to the observation of the futures price at time *t*. The coefficient of determination for the applied models on average is around 0.27, with R^2 ranging from 0.09 to 0.56 for base load futures contracts and from 0.04 to 0.56 for peak load contracts.

For Q1 base load contracts, the dynamics of observed futures risk premiums generally are significantly influenced by the time to maturity, recent levels of electricity spot prices, and the number of price spikes during the most recent month. For NSW, QLD and SA, time to maturity yields a negative coefficient, indicating that the closer a Q1 contract is to the beginning of the delivery period, the higher will on average be the risk premium. Observed premiums for NSW, QLD and VIC are also positively related to average spot price levels during the last year and the number of price spikes during the last month. Interestingly, for SA, the results for spot price levels and the number of price spikes are counter-intuitive, but for this market the model also yields the lowest explanatory power with a coefficient of determination equal to 0.09. Note that estimated coefficients for the volatility and variance of electricity spot prices do not provide clear-cut results. Only for the VIC region, the results support the convexity, i.e. an estimated negative coefficient for volatility and a positive coefficient for the variance, as it has been initially suggested by Bessembinder and Lemmon (2002).

For Q2 base load contracts, we find that dynamics of futures risk premiums generally are significantly influenced by the time to maturity, recent levels of electricity spot prices, and the number of price spikes. For all regions, time to maturity yields a negative coefficient, while the premiums are positively related to average spot price levels during the last year prior to *t*. Note that for NSW, QLD and VIC the coefficient for the number of price spikes is positive, while it is negative for the SA market. In all regions we obtain negative coefficients for the volatility and positive coefficient for the variance. This indicates that for Q2, the convex relationship between observed risk premiums and volatility in the spot market suggested by Bessembinder and Lemmon (2002) seems to hold.

Also for Q3 and Q4 base load contracts, the dynamics of observed futures risk premiums generally are significantly influenced by the time to maturity, recent levels of electricity spot prices, and the number of price spikes. For all regions, time to maturity yields a negative coefficient, while premiums are positively related to spot price levels and the number of price spikes. Similar to the results for Q1, the estimated coefficients for the volatility and variance of electricity spot prices do not provide clear-cut results. Only for SA and VIC (for Q3) and NSW and VIC (for Q4), our results support the convexity assumption.

REGION	Intercept	Time to Maturity	Spot Price Level	Volatility	Variance	# of Price Spikes	Adj - R^2
BASE PERIOD							
QUARTER 1							
NSW	-10.95	-3.38 **)	0.62 ***)	-0.01	-13.38 ***)	0.37 ***)	0.20
	(-4.96)	(-2.36)	(13.37)	(0.00)	(-3.05)	(12.61)	
QLD	-24.46	-11.56 ***)	1.25 ***)	7.01	-23.35 ***)	0.39 ***)	0.56
	(-16.70)	(-9.70)	(43.01)	(1.59)	(-6.44)	(10.78)	
SA	19.68	-12.11 ***)	-0.43 ***)	16.85 *)	17.34 **)	-0.80 ***)	0.09
	(4.61)	(-4.61)	(-7.50)	(1.69)	(2.43)	(-7.37)	
VIC	5.71	1.06	0.56 ***)	-90.57 ***)	59.88 ***)	0.89 ***)	0.25
	(3.20)	(0.81)	(15.62)	(-13.35)	(9.52)	(14.80)	
QUARTER 2							
NSW	-55.05	-0.25	1.36 ***)	-42.93 ***)	46.21 ***)	0.07	0.14
	(-13.25)	(-0.09)	(16.19)	(-4.55)	(5.86)	(1.25)	
QLD	-35.87	-1.45	0.95 ***)	-18.54 **)	15.35 **)	0.18 **)	0.15
	(-10.61)	(-0.53)	(16.40)	(-1.99)	(2.12)	(2.52)	
SA	-20.99	-4.21 ***)	0.56 ***)	-19.71 ***)	12.71 ***)	-0.13 **)	0.22
	(-10.55)	(-3.27)	(21.37)	(-4.22)	(3.87)	(-2.51)	
VIC	-14.74	-6.45 ***)	0.81 ***)	-89.84 ***)	63.73 ***)	0.34 ***)	0.16
	(-5.81)	(-3.72)	(16.51)	(-9.54)	(7.38)	(4.18)	
QUARTER 3							
NSW	-10.22	-7.84 ***)	0.47 ***)	5.94 *)	-8.12 ***)	0.19 ***)	0.24
	(-6.90)	(-8.60)	(16.05)	(1.72)	(-2.86)	(10.33)	
QLD	-8.15	-8.36 ***)	0.42 ***)	5.98	-5.31 *)	0.21 ***)	0.24
	(-6.52)	(-8.67)	(17.89)	(1.62)	(-1.80)	(7.07)	
SA	-17.07	-5.88 ***)	0.65 ***)	-29.84 ***)	14.67 ***)	0.10 ***)	0.46
	(-12.63)	(-7.21)	(34.50)	(-9.40)	(6.46)	(3.02)	
VIC	-15.59	-6.92 ***)	0.79 ***)	-33.44 ***)	17.93 ***)	0.31 ***)	0.39
	(-11.12)	(-7.76)	(29.54)	(-6.74)	(3.94)	(7.25)	
QUARTER 4							
NSW	-7.15	-1.73	0.31 ***)	-38.67 ***)	28.98 ***)	0.54 ***)	0.19
	(-2.86)	(-1.04)	(6.06)	(-6.75)	(6.00)	(16.31)	
QLD	-10.80	-12.33 ***)	0.60 ***)	9.62 **)	-7.18 **)	0.47 ***)	0.39
	(-8.03)	(-9.90)	(22.44)	(2.29)	(-2.17)	(13.87)	
SA	-13.72	-10.65 ***)	0.46 ***)	10.85 *)	-2.46	0.11 *)	0.14
	(-5.32)	(-6.41)	(12.98)	(1.73)	(-0.55)	(1.72)	
VIC	-7.03	-2.63 ***)	0.48 ***)	-11.64 ***)	1.64	0.51 ***)	0.48
	(-8.69)	(-4.56)	(29.13)	(-3.70)	(0.57)	(18.56)	

*Table 4: Results of regression analysis (4) for realized futures risk premium for each quarter during base load period in NSW, QLD, SA and VIC. Explanatory variables are based on the time to maturity, average spot price, volatility and variance estimates of the daily change of spot prices and the number of price spikes in the recent month. The asterisk indicates a significant risk premium at the *) 10% significance level, **) 5% significance level, and ***) 1% significance level.*

PEAK PERIOD							
QUARTER 1							
REGION	Intercept	Time to Maturity	Spot Price Level	Volatility	Variance	# of Price Spikes	Adj - R^2
NSW	17.92	0.63	0.27***)	-19.04 **)	-17.60***)	1.18***)	0.20
	(4.43)	(0.23)	(4.74)	(-2.34)	(-3.27)	(17.39)	
QLD	-59.54	-20.75***)	1.68***)	81.48***)	-82.56***)	0.88***)	0.56
	(-20.28)	(-8.19)	(40.46)	(9.75)	(-13.15)	(10.81)	
SA	37.83	-62.25***)	-0.94***)	74.83***)	27.12	-3.91***)	0.14
	(3.76)	(-7.77)	(-11.17)	(3.07)	(1.63)	(-9.57)	
VIC	25.30	6.59 **)	0.50***)	-174.91***)	106.51***)	2.19***)	0.21
	(7.03)	(2.19)	(9.17)	(-14.90)	(10.75)	(14.37)	
QUARTER 2							
REGION	Intercept	Time to Maturity	Spot Price Level	Volatility	Variance	# of Price Spikes	Adj - R^2
NSW	-52.85	-3.71	1.20***)	-103.81***)	71.55***)	0.30 **)	0.10
	(-7.37)	(-0.72)	(12.06)	(-7.29)	(7.54)	(2.42)	
QLD	-28.76	-12.72***)	1.14***)	-114.40***)	71.19***)	0.60***)	0.15
	(-5.23)	(-2.85)	(16.53)	(-8.12)	(6.80)	(4.45)	
SA	-18.80	-7.25***)	0.51***)	-47.27***)	35.84***)	-0.73***)	0.36
	(-9.06)	(-4.27)	(29.09)	(-9.66)	(10.59)	(-8.55)	
VIC	-16.70	-10.46***)	0.86***)	-127.71***)	72.45***)	0.76***)	0.19
	(-4.80)	(-3.90)	(16.23)	(-11.45)	(7.55)	(5.11)	
QUARTER 3							
REGION	Intercept	Time to Maturity	Spot Price Level	Volatility	Variance	# of Price Spikes	Adj - R^2
NSW	6.93	-8.75***)	0.25***)	-6.73	-4.96 *)	0.50***)	0.18
	(3.09)	(-6.30)	(8.59)	(-1.52)	(-1.73)	(14.71)	
QLD	-7.72	-10.28***)	0.43***)	5.43	-8.42 **)	0.46***)	0.26
	(-4.39)	(-7.68)	(18.87)	(1.15)	(-2.39)	(10.28)	
SA	-17.04	-4.42***)	0.41***)	-25.65***)	14.45***)	-0.08	0.45
	(-10.77)	(-4.10)	(34.45)	(-7.23)	(6.04)	(-1.43)	
VIC	-20.08	-10.77***)	0.84***)	-44.99***)	21.34***)	0.46***)	0.43
	(-9.56)	(-8.06)	(30.67)	(-7.58)	(4.36)	(6.24)	
QUARTER 4							
REGION	Intercept	Time to Maturity	Spot Price Level	Volatility	Variance	# of Price Spikes	Adj - R^2
NSW	-9.37	-2.02	0.38***)	-104.77***)	65.25***)	1.30***)	0.14
	(-1.47)	(-0.48)	(4.46)	(-8.56)	(8.01)	(12.88)	
QLD	-16.04	-18.71***)	0.84***)	-17.91***)	4.50	1.37***)	0.39
	(-5.94)	(-8.11)	(22.40)	(-2.37)	(0.79)	(18.61)	
SA	-14.67	-22.52***)	0.06	68.52***)	-28.47***)	-0.14	0.04
	(-2.95)	(-5.60)	(1.44)	(5.57)	(-3.41)	(-0.67)	
VIC	-14.63	-3.77***)	0.61***)	-14.09***)	0.21	1.01***)	0.49
	(-10.22)	(-3.61)	(29.18)	(-3.15)	(0.06)	(17.82)	

*Table 5: Results of regression analysis (4) for realized futures risk premium for each quarter during peak load period in NSW, QLD, SA and VIC. Explanatory variables are based on the time to maturity, average spot price, volatility and variance estimates of daily change of spot prices and the number of price spikes in the recent month. The asterisks indicate a significant risk premium at the *) 10% significance level, **) 5% significance level, and ***) 1% significance level.*

We obtain similar results for the analysis of risk premiums referring to peak load futures contracts. For Q1 contracts, the dynamics of observed futures risk premiums generally are significantly influenced by the time to maturity, spot price levels, and the number of price spikes. For QLD and SA, time to maturity yields a negative coefficient, indicating that the closer a Q1 contract is to the beginning of the delivery period, the higher will on average be the risk premium. Interestingly, for NSW and VIC the estimated coefficients are positive what can be explained by the relatively low risk premiums during the last month prior to delivery of the contract. Estimated coefficients for spot price level and the number of price spikes are positive and significant for all markets, except SA, where the results for spot price levels and the number of price spikes are counter-intuitive. However, similar to the results for base load contracts, the model yields a relatively low explanatory power for this market. Again, estimated coefficients for the volatility and variance do not provide clear-cut results. Only for the VIC region, the results support the convex relationship between risk premiums and volatility levels. Also for Q2, Q3 and Q4 peak load contracts, the dynamics of observed futures risk premiums in most cases are significantly influenced by time to maturity, spot price levels, and the number of price spikes. The coefficient for time to maturity is negative for all equations and significant for 10 out of 12 estimated models. Also the coefficient for the level of spot prices is positive and significant for all markets, except for Q4 peak load contracts in SA. Results are not that clear-cut for the impact of price spikes on realized risk premiums. While the variable is significant for 10 of the estimated 12 models, the estimated coefficient is negative for Q2, Q3 and Q4 contracts in SA. However, for all other markets estimated coefficients are positive. We also find support for the assumed convex relationship between spot market volatility and realized futures risk premiums for peak load contracts in Q2 and Q4.

Overall, our analysis strongly supports the assumption that the dynamics of observed futures risk premiums are significantly influenced by the time to maturity, recent levels of electricity spot prices, and the number of price spikes during the most recent month. The negative coefficient for time to maturity points towards increasing risk premiums as futures contracts get closer to the beginning of the delivery period. Furthermore, observed premiums are almost unanimously positively related to average spot price levels and the number of price spikes in the spot market. Finally, while results on the relationship between spot price volatility and realized risk premiums are not clear-cut, we find some support for the convex relationship between these variables that has been suggested by Bessembinder and Lemmon (2002). However, the explanatory power of the models, as well as the significance and sign of estimated coefficients show strong variations for considered markets and delivery quarters. In particular, the substantial differences in the estimated coefficients support results by earlier studies such as Huisman and Kilic (2012) and Haugom and Ullrich (2012), who find time-varying risk premiums and unstable parameter estimates. Our results also emphasize the difficulties one may face in finding a single model for the determinants of risk premiums that is valid for various electricity futures markets.

6. Summary and Conclusions

This paper investigates the dynamics of realized futures risk premiums in the four major Australian electricity markets NSW, QLD, SA and VIC. We analyze futures risk premiums for quarterly contracts at different time instances. In particular we focus on the relationship between realized risk premiums and the remaining time until the beginning of the delivery period of a contract. We provide a new perspective on risk premiums in electricity markets, by examining the dynamics and determinants of risk premiums across several electricity markets in Australia that are considered to be among the most volatile markets in the world.

Using data from 2005 to mid-2012, we find that futures premiums are statistically significant and are generally higher as a contract is to the beginning of the delivery period. The magnitude and significance of the observed premiums, however, varies significantly for different regions and even more for contracts referring to different delivery periods, i.e. the first, second, third or fourth quarter of the year. Based on these findings, we suggest that there are strong seasonal effects and time-variation in futures risk premiums for regional Australian electricity markets.

In a second step we also investigate the determinants of the observed risk premiums. We develop a model for the dynamics of realized risk premiums and suggest time to maturity, spot price levels, volatility and variance of spot prices, as well as the number of price spikes in the most recent month as explanatory variables. Overall, we find that futures premiums tend to increase with (i) a reduction in the time to the beginning of the delivery period of the contract, (ii) recent spot price levels, and (iii) the frequency of price spikes in the spot market. Furthermore, we find some support for the convex relationship between risk premiums and volatility in the spot market that has been initially suggested by Bessembinder and Lemmon (2002). However, we find that our results vary quite significantly across the examined quarters and regions. Therefore, we confirm results by previous studies pointing towards the difficulties one may face in finding a general model for the dynamics and determinants of risk premiums in electricity futures markets. It remains a very challenging task to find such a model that is valid not only for different electricity markets with unique features but also at different points in time. In particular the latter is particularly demanding due to strong seasonal effects in the relationship between electricity spot and futures prices.

Our results also suggest several areas for future work. In our study we investigate realized, or ex-post, futures premiums only. An analysis of ex-ante premiums in the considered Australian markets should also be of significant interest to market participants and would complement our analysis using a different perspective. Another possible area of research might be to apply robust regression analysis using panel data. However, integrating contracts referring to different markets and quarters into a panel framework needs to be carried out very carefully, due to the seasonal behaviour of electricity spot and futures markets and the time-varying relationship between these markets. The time-varying and seasonal dynamics of electricity spot and futures prices also distinguishes these markets clearly from other financial markets.

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