
Risk Premiums in Interconnected Australian Electricity Markets

Rangga Handika and Stefan Trück,

Working Paper 14-01

The Centre for Financial Risk brings together Macquarie University's researchers on uncertainty in capital markets to investigate the nature and management of financial risks faced by institutions and households.

Research conducted by members of the centre straddles international and domestic issues relevant to all levels of the economy, including regulation, banking, insurance, superannuation and the wider corporate sector, along with utility and energy providers, governments and individuals.

The nature and management of financial risks across these diverse sectors are analysed and investigated by a team of leading researchers with expertise in economics, econometrics and innovative modelling approaches.

Risk Premiums in Interconnected Australian Electricity Futures Markets

Rangga Handika[1], Stefan Trück[2,#]

Macquarie University, Sydney, Australia

Abstract

We provide an empirical analysis of the relationship between spot and futures prices in interconnected regional Australian electricity markets. Examining ex-post risk premiums in futures markets, we find positive and significant risk premiums for several of the considered regions. Therefore, electricity futures prices cannot be considered as an unbiased estimator of the average realized spot price during the delivery period. Market participants are willing to pay a significant additional compensation to hedge their exposure to price shocks and spikes in the spot market. We further demonstrate seasonal effects in the observed premiums as well as strong and positive correlations between the risk premiums across the considered markets. Overall, the observed premiums indicate risk aversion of market participants, in particular for the Queensland and Victoria electricity market. We also relate realized premiums to variables such as spot price levels, volatility, skewness and kurtosis prior to the delivery period. Due to the high correlation of the observed premiums across the regions, we apply a seemingly unrelated regression (SUR) approach. We find that in particular spot price levels, but also skewness and kurtosis of spot prices contribute significantly to the explanation of the realized risk premiums.

JEL Classification: Q40, G32, G13

Keywords: *Electricity Markets, Spot and Futures Prices, Risk Premiums, Regional Markets, Seemingly Unrelated Regression*

---

[1] Rangga Handika is a PhD student at Macquarie University, Department of Applied Finance and Actuarial Studies, email: rangga.handika@mq.edu.au.

[2] Stefan Trück is a Professor of Finance at Macquarie University, Department of Applied Finance and Actuarial Studies, email: stefan.trueck@mq.edu.au.

[#] This work was supported by funds from the Australian Research Council through grant no. DP1096326.

1. Introduction

The deregulation of electricity markets worldwide has led to a significant change in market structure from monopolies to liberalized markets. With the introduction of power exchanges, as pointed out by Shawky et al. (2003), the behaviour of electricity market prices now tends to be much more affected by the nature of electricity production and consumption: inelastic demand, seasonal effects, and the non-storability of electricity. Consequently, electricity as a flow commodity exhibits price behaviour that is almost unique in financial markets. Electricity spot prices can be characterized by mean-reversion, seasonality, extreme volatility and brief but quite pronounced price spikes, see e.g. Lucia and Schwartz (2002), Burger et al. (2004), Weron (2006), Bierbrauer et al. (2007), Huisman et al. (2007), Kanamura and Ohashi (2008), Karakatsani and Bunn (2008). Lucia and Schwartz (2002) suggest that electricity is strongly characterised by its very limited transportability and storability. Given the extremely volatile behaviour of electricity spot prices, market participants are required to hedge these risks at least partially by entering forward and futures contracts for electricity. Early studies on electricity forward markets (Bessembinder and Lemon, 2002; Longstaff and Wang, 2004) point out that the non-storability of electricity limits the standard no-arbitrage approach in modelling futures prices: inventories cannot be used to smooth out electricity supply and demand shocks (Bowden and Payne, 2008). Therefore the dynamic relationship between electricity spot and futures prices reflects expectations about the future supply and demand characteristics of electricity as well as risk aversion amongst agents, with heterogeneous requirements for hedging the uncertainty of future spot prices (Shawky et al., 2003).

This paper presents a pioneering study examining the relationship between spot and futures prices in regional electricity markets in Australia. To the best of our knowledge this is also the first study to investigate the dependence between risk premiums in interconnected electricity markets. The National Electricity Market (NEM) began operating as a wholesale market in Australia in December 1998. The NEM includes the states of New South Wales (NSW), Queensland (QLD), South Australia (SA), Victoria (VIC) and Tasmania (TAS). Tasmania joined the NEM in 2005 and is connected to the other NEM regions via an undersea inter-connector to VIC. Existing studies on the Australian NEM include Bateson and Swan (1989), Swan (1990), Kim (1997), Worthington et al. (2005), Reedman et al. (2006), Higgs and Worthington (2008), Becker et al. (2007), Higgs (2009), and Thomas et al. (2011). However these authors focus on the costs of supplying electricity (Bateson and Swan, 1989; Swan, 1990), the effects of profit regulation (Kim, 1997), the timing of the uptake of various electricity generation technologies under a carbon tax scheme (Reedman et al., 2006) or modelling the behaviour of electricity spot prices (Worthington et al., 2005; Higgs and Worthington, 2008; Becker et al., 2007; Higgs, 2009; Thomas et al, 2011). The relationship between spot and futures prices across different regional Australian markets has not yet been investigated. Analysis of these markets is of particular interest for a number of reasons: first, as pointed out by Higgs and Worthington (2008), Australian electricity markets are significantly more volatile and spike-prone than other comparable markets. Second, the Australian NEM operates on one of the world's longest interconnected power systems comprising several regional networks supplying electricity to retailers and end-users. Consequently, analysis of the relationship between spot and futures prices may provide important insights into risk premiums and risk aversion on the part of market participants in extremely volatile markets. Further, analysis of observed risk premiums in different interconnected markets will help participants to understand whether risk premiums, i.e. expectations about future supply and demand are transferred across regional electricity markets. Therefore, this study focuses on the futures risk premium, defined as the excess of the futures price over the expected realized spot price in the markets under consideration. Using an extended version of the general equilibrium model initially suggested by Bessembinder and Lemon (2002), we also examine whether the bias in electricity futures prices can be explained by the behaviour of the spot price during periods prior to delivery.

First, we start by investigating the magnitude of futures risk premiums at different time instances. The literature suggests that in electricity markets short term futures prices often exceed the actual average spot price during the delivery period (Botterud et al., 2002; Longstaff and Wang, 2004; Hadsell and Shawky, 2006; Diko et al., 2006; Bierbrauer et al., 2007; Daskalakis and Markellos, 2009; Redl et al., 2009, Redl and Bunn, 2013). On the other hand, this stream of literature usually argues that there is no exact relationship between the current spot price and forward prices due to the non-storability of electricity. However, as suggested by Bessembinder and Lemmon (2002) or Redl et al. (2009) the behaviour of electricity spot prices and demand, e.g. volatility and skewness of prices or demand prior to the delivery period of the futures contracts, may have a significant impact on risk premiums observed in the market. Botterud et al. (2010) suggest that in Scandinavian electricity markets spot and the futures prices are related to the physical state of the system, such as demand, reservoir levels, and hydro inflows.

We find that futures risk premiums in Australian electricity markets are positive and economically significant different from zero. However, when pooling all quarterly contracts together, from a statistical point of view, only the premiums in the QLD and VIC market are significantly different from zero. We also distinguish between base and peak load contracts and investigate the seasonal behaviour of risk premiums by separately examining contracts for different seasons. Considering the quarters separately, significant positive premiums can be detected for the first quarter in the QLD and VIC markets, while for the third quarter the premiums are significantly greater than zero for three of the considered markets. Furthermore, in our study we also examine the dependence of futures risk premiums observed across different regional electricity markets and find that they are significantly correlated. We further observe that adjoining regions usually exhibit higher degrees of correlation than markets that are geographically more distant.

In a second step we also investigate whether the bias in futures prices can be explained by the behaviour of spot prices during the month or quarter previous to delivery. To examine this issue we apply an extended version of the model initially suggested by Bessembinder and Lemmon (2002) including explanatory factors such as realized skewness and kurtosis of the spot prices. Further, since observed risk premiums in the considered markets are highly correlated, we apply a seemingly unrelated regression (SUR) model to investigate the issue. The obtained results are not entirely clear-cut. We find that the level of the spot price during the month or quarter prior to the delivery period has a significantly positive impact on the realised risk premium. This is true for most of the contracts and states considered. On the other hand, the majority of the other considered explanatory variables are insignificant: only in the NSW market skewness and kurtosis of the spot electricity contracts during the month prior to delivery are significant. This confirms similar results in previous studies by e.g. Redl et al. (2009), Botterud et al. (2010) or Furio and Meneu (2010) who also find only limited evidence for an impact of spot price variance and skewness on the futures risk premium.

The remainder of the paper is organised as follow. Section 2 provides a brief overview on spot and futures trading in the Australian NEM. Section 3 reviews previous studies on the relationship between electricity spot and futures markets and explains the theoretical framework adopted in this paper. Section 4 describes the data and discusses the empirical results. Section 5 concludes and provides suggestions for future research.

2. The Australian Electricity Market

The Australian electricity market has experienced significant changes over the last two decades. Prior to 1997 the market consisted of vertically integrated businesses operating in each of the states and there was no connection between individual states. The businesses were owned by governments and operated as monopolies. Overall, there were twenty-five electricity distributors protected 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 had the following objectives, among others: the separation of electricity generation from transmission, the merger of twenty-five electricity distributors into a smaller number, and the functional separation of electricity distribution from its retail supply. Retail competition was introduced as part of reform: states' electricity purchases could be made through the competitive retail market and customers were now free to choose their retail supplier.

The NEM is now an interconnected grid comprising several regional networks which supply electricity to retailers and end-users. The link between electricity producers and electricity consumers is established through a pool which is used to aggregate the output from all generators in order to meet forecast demand. The pool is managed by the Australian Energy Market Operator (AEMO) which follows 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 5 minutes by the AEMO. Generators submit offers every five minutes and this information is used to determine the number of generators required to produce electricity in a more cost-efficient way based on the 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 a market for electricity derivatives has also 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 will concentrate on futures contracts traded in the

SFE during 2003-2012. 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.

As in almost every electricity exchange, futures contracts traded in the SFE refer to the average electricity price during a delivery period. 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. 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 of electricity 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. By implication the off peak period covers from 22:00 to 07:00 on weekdays and all hours on Saturday, Sunday and public holidays. 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 (so-called 62 day contract quarter) will equate to 930 MWh.

The contracts do not require physical delivery of electricity but 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.

3. Modelling Framework

In the following section we describe the theoretical framework applied in our empirical analysis in order to investigate the relationship between spot and futures prices. Generally, there are two theories explaining the relationship between spot and futures prices in commodity markets, see e.g. Botterud et al. (2002), Redl et al. (2009).

The first theory argues that the cost and convenience of holding inventories explains the difference between the spot and futures price of a commodity. This theory is well known as the ‘cost of carry’ approach and goes back to Kaldor (1939). According to the ‘cost of carry’ approach, the forward price can be determined as a function of the current spot price, the interest rate and cost of storage. As mentioned previously, electricity as a flow commodity is produced and consumed instantaneously and continuously. Therefore, a standard cost of carry approach towards spot and forward markets cannot be applied.

Instead the literature usually follows the second theory that considers equilibrium in expectations, and risk aversion amongst agents with heterogeneous requirements for hedging the uncertainty of future spot prices (Keynes, 1930). Using this approach, the electricity forward price is determined as the expected spot price plus an ex-ante risk premium of the market. The difference between the forward and the expected spot price can then be interpreted as 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 realized or ex-post forward premium

$$PREM_{t,T} = F_{t,T} - S_T \tag{1}$$

Hereby, $F_{t,T}$ denotes the forward price quoted at time t, for delivery at time or period T, while S_T refers to the (average) spot price realized at time or period T. As illustrated by Redl et al. (2009) the realized forward premium equals the ex-ante premium plus a random error in the (rational) spot price expectation that is a result of shocks to the electricity price between t and T. Based on a random error distribution with zero mean, the realized premium can then be considered as a consistent estimator of the ex-ante premium. Decomposing ex-post premiums, one could argue that only a part of the premium reflects compensation for the spot price risk while the other part can be considered as due to errors in expectations by market participants about the actual spot price during the delivery period.

In their seminal paper, Bessembinder and Lemmon (2002) suggest a general equilibrium model where the ex-ante one-month forward premium in the Pennsylvania, New Jersey, Maryland (PJM) and California Power Exchange (CALPX) markets is modelled as dependent on the mean, standard deviation and variance of electricity demand:

$$PREM_{it} = \alpha_0 + \alpha_1 MEAN_{it} + \alpha_2 STD_{it} + \alpha_3 VAR_{it} + \eta_{it} \tag{2}$$

Hereby, $PREM_{it}$ equals the forward premium as the one-month-forward price for delivery in month t minus the cost-based estimate of the expected spot price in month t for market i, $MEAN_{it}$ is the average normalized load for month t in the market i, STD_{it} is the standard deviation of the daily load during month t in market i, and VAR_{it} is the square of STD_{it}. Based on their theoretical model, the authors suggest that the forward premium should increase with mean demand and should be convex, initially decreasing and then increasing in demand risk. Thus, one would expect a negative coefficient for the standard deviation and a positive coefficient for the variance. In their empirical study, the authors find significant forward premiums in the market. With respect to explaining the premium, however, they obtain rather insignificant results for the coefficients. While the level of demand seems to have a significantly positive impact on the forward premium, both the standard deviation and variance of the demand are insignificant. Note that also Haugom and Ullrich (2012) suggest that they are unable to find support for the Bessembinder and Lemmon (2002) model, since their rolling and recursive estimations provide highly unstable values of the estimated parameters. However, the Bessembinder and Lemmon (2002) model can still be considered as the foundation of examining risk premiums in electricity futures markets, that has been used widely in recent studies, e.g., Pietz (2009), Redl et al. (2009), Lucia and Torro (2011), Ullrich (2012).

A similar approach has been suggested by Redl et al. (2009) who examine the ex-post premium in the European Energy Exchange (EEX) and Scandinavian Nordpool electricity markets. They suggest a slightly different model for considering monthly forward contracts that incorporates the volatility and skewness of daily spot prices in the month prior to the delivery period as well as a consumption and generation index. Therefore, they suggest the following model for the realized forward premium:

$$PREM_{t,T} = F_{t,T} - S_T = b_1 + b_2 Var(S_t) + b_3 Skew(S_t) + b_4 Cons_T + b_5 Gen_T + \varepsilon_t \tag{3}$$

In this model, $PREM_{t,T}$ denotes the ex-post forward premium measured by the difference $F_{t,T}$–S_T, where $F_{t,T}$ is the futures price on the last trading day in month t (before the start of the delivery period) for delivery in month T, S_T is the observed average spot price in month T, $Var(S_t)$ is the variance of daily spot prices in month t, $Skew(S_t)$ is the skewness of daily spot prices in month t, $Cons_T$ is the consumption index in month T and Gen_T is the generation index of hydro and nuclear power generation in month T.

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 considered baseload forward contracts in the Nordpool market and 9 percent for baseload and 13 percent for peak load contracts in the EEX market. Pietz (2009) finds positive futures premiums in the EEX market for six different monthly futures contracts. He reports premiums ranging from -0.03 to 5.45 Euro/MWh, however, only for few contracts the premiums are statistically significant. Botterud et al. (2010) report premiums ranging from 1.3 to 4.4 percent for the Nord Pool market when considering forward contracts from one week up to six weeks ahead.

A number of other studies confirm the significance of forward premiums in various electricity markets. Significant premiums are reported, for example, by Hadsell and Shawky (2006) for the NYISO, Diko et al. (2006) for the APX, Bierbrauer et al. (2007) for the EEX, Weron (2008) for the Nordpool, Kolos and Ronn (2008) and Daskalakis and Markellos (2009) for the EEX, Nordpool and Powernext markets. Interestingly, the studies provide quite different results on the actual sign (positive or negative) 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 market, Kolos and Ronn (2008) find a negative forward premium for monthly, quarterly and yearly contracts at the EEX during the 2002-2003 trading period. Bierbrauer et al. (2007) find positive ex-ante risk premiums for short-term futures contracts while observed premiums are negative for contracts with delivery periods more than six months ahead. Diko et al. (2006), investigating EEX peak load contracts, find that forward premiums decrease as the time to maturity increases. More recently, Lucia and Torro (2011) report significant and positive realized futures premiums ranging from 1.17 to 4.42 percent in the Nord Pool market. Haugom and Ullrich (2012) find positive and significant daily ex-post forward premiums in the PJM market, while Veraart and Veraart (2013) find positive ex-post futures premiums in the EEX market for the 2010-2012 time period. Therefore, the majority of authors seem to find rather positive risk premiums in electricity futures markets, even for the same market.

Empirical studies on the significance of variance and skewness in the risk premium so far provide rather mixed results, see e.g. Bessembinder and Lemmon (2002), Douglas and Popova (2008), Lucia and Torro (2008), Redl et al. (2009), Botterud et al. (2010), and Furio and Meneu (2010). Bessembinder and Lemmon (2002) find a positive coefficient for the standard deviation and a negative coefficient for the variance of the daily load in the PJM and CALPX markets. However, their results are not statistically significant. Douglas and Popova (2008) estimate a negative coefficient for the variance and a positive coefficient for the skewness of the recent spot price in the PJM market. Most of their results are statistically significant. Lucia and Torro (2008) observe a positive coefficient for the variance and a negative coefficient for the skewness of spot prices during the delivery period in the Nord Pool power market from mid 2003 until the end of 2007. However, they find a negative coefficient for the variance and a positive coefficient for the skewness when considering futures prices from early 1998 to mid 2002. Their results are statistically significant for the skewness while for the variance, significant results are obtained only for the so-called pre-shock periods from 1998-2002. Redl et al. (2009) find positive coefficients for both variance and skewness of spot prices in the month prior to the delivery period when examining the EEX market. However, they also obtain a positive coefficient for the variance and a negative coefficient for the skewness parameter for the Nord Pool market. Their results are statistically significant only for the estimated variance coefficient (EEX peak period) and the skewness coefficient (EEX base period). Botterud et al. (2010) find mainly negative coefficients for both variance and skewness of the spot price in the week prior to the delivery period in the Nord Pool market. However, only the coefficient for the variance one week prior to the delivery period is statistically significant. Finally, Furio and Meneu (2010) find negative coefficients for both variance and skewness in the Spanish electricity market. Only the coefficient for the variance is found to be statistically significant.

As mentioned previously, to date no study has investigated the significance of risk premiums or the influence of spot price characteristics on the forward premium in regional Australian electricity markets. The analysis of this relationship may be of particular interest given the comparably high frequency of price spikes and periods of extreme volatility in the spot market. In such volatile markets one may expect to find significant premiums in the futures market as well as empirical evidence for the theory that equilibrium futures prices are bid up to compensate for skewness or extreme variance in the spot price distribution, as has been suggested by Bessembinder and Lemmon (2002) and other authors.

Therefore, in our empirical analysis we examine the following model for the ex-post futures premium in the considered markets:

$$PREM_{t,Q} = b_1 + b_2 Mean(S_{tq}) + b_3 Std(S_{tq}) + b_4 Var(S_{tq}) + b_5 Skew(S_{tq}) + b_6 Kurt(S_{tq}) + \varepsilon_t \qquad (4)$$

Hereby $PREM_{t,Q}$ denotes the difference between the quote for the futures contract with delivery in quarter Q on the last trading day t before the beginning of the delivery period and the average spot price during the delivery period (quarter Q). $Mean_{tq}$ is the average spot price during period t denoting either the last month or last quarter before the delivery period Q. Further Std_{tq} is the realized standard deviation, Var_{tq} the realized variance, $Skew_{tq}$ the realized skewness and $Kurt_{tq}$ the realized kurtosis of the spot price during period t, again, denoting either the last month or last quarter before the delivery period Q.

Since Australian electricity markets are interconnected, it is likely that unobserved variables (the errors) among different markets are correlated at the same point in time. This situation leads a strong economic argument that contemporaneous correlation exists. Therefore, utilizing a joint estimation procedure may be more suitable than applying separate least square regression models for each market (Hill et al., 2011). According to Hill et al. (2011), a panel framework (either fixed or random effect) is more appropriate when the panel data is *short and wide*, i.e. when the number of cross sectional units is large and the number of time periods is small. The authors argue that if the number of time series observations is sufficiently large and the number of cross sectional units is small, we can estimate a separate equation for each individual. The authors also suggest that if the error terms among (separate) equations, at the same point in time, are correlated, it may be favourable to use Seemingly Unrelated Regression (SUR) and to perform a test for contemporaneous correlations. Our quarterly data set contains 46 observations (from Q1 2003 to Q2 2012) and four states, NSW, QLD, SA and VIC, which means that the time series is sufficiently larger than the number of units. Therefore, in our analysis we argue that the SUR approach is more appropriate than a panel (fixed or random effect) framework.

SUR is a generalized least square (GLS) method that estimates the equations jointly, accounting for contemporaneous correlations among the errors of the NSW, QLD, SA and VIC electricity premium equations. Further technical details of the SUR procedure can be found in Greene (2011). The SUR model can be formulated as follows:

$$PREM_{i,t,Q} = b_{1i} + b_{2i}Mean(S_{i,tq}) + b_{3i}Std(S_{i,tq}) + b_{4i}Var(S_{i,tq}) + b_{5i}Skew(S_{i,tq}) + b_{6i}Kurt(S_{i,tq}) + \varepsilon_{i,t} \quad (5)$$

$PREM_{i,t,Q}$ denotes the difference between the quote for the futures contract with delivery in quarter Q on the last trading day t before the beginning of the delivery period and the average spot price during the delivery period (quarter Q) in market i. $Mean_{i.tq}$ is the average spot price during period t denoting either the last month or last quarter before the delivery period Q at market i. Further, $Std_{i,tq}$ is the realized standard deviation, $Var_{i,tq}$ the realized variance, $Skew_{i,tq}$ the realized skewness and $Kurt_{i,tq}$ the realized kurtosis of the spot price during period *t*, again denoting either the last month or last quarter before the delivery period Q in market *i*. The *i* subscript for the coefficients (including the intercept) indicates that the coefficients will differ across each market.

4. Empirical Analysis

4.1 The Data

Our sample includes electricity spot and futures prices in four Australian regional markets: NSW, QLD, SA and VIC. These states show by far the highest electricity demand in Australia (Higgs, 2009) and are the only regions that also offer futures contracts traded on an exchange. In our analysis we consider daily electricity spot prices for the period from January 1, 2000 to June 30, 2012 provided by AEMO. Note that for the Australian market only quarterly and yearly futures contracts are traded on an exchange. Data for quarterly base load and peak load futures contracts from 2003 to 2012 were obtained from d-cypha Trade Limited[3]. Base load futures are settled during the delivery quarter with reference to the average half-hourly spot price, while peak load futures are cash settled with reference to the average of only those half hours during the quarter between 7am to 10pm on working weekdays. In the following, both spot and futures prices are quoted in Australian dollars per Megawatt hour ($/MWh).

Table 1 shows descriptive statistics of daily electricity spot prices for the base and peak (7am-10pm working weekdays) periods from January 1, 2003 to June 30, 2012 in the considered regions. Note that data from July 2012 onwards was excluded from this analysis, since on July 1, 2012 a carbon tax of $23 per ton of CO_2 emission became effective, significantly increasing spot electricity prices. Since the newly introduced tax might also have an impact on the relationship between spot and futures prices and realized risk premiums we decided to exclude data after June 2012 from the analysis.

~~In the Quarter 1, the average quarterly electricity spot prices range from 39.45 $/MWh in VIC to 62.59 $/MWh in SA for the base load, while they range from 62.13 $/MWh in~~

---

[3] https://asxenergy.com.au/

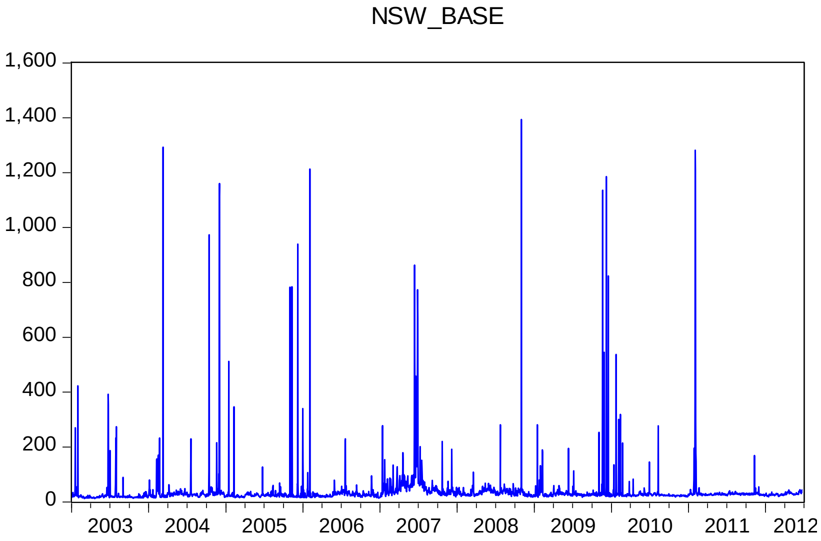
~~NSW to 118.95 $/MWh in SA during the peak period. In the Quarter 2, the average quarterly electricity spot prices range from 34.92 $/MWh in QLD to 39.79 $/MWh in NSW for the base load, while they range from 46.66 $/MWh in SA to 54.92 $/MWh in NSW during the peak period. In the Quarter 3, the average quarterly electricity spot prices range from 28.77 $/MWh in QLD to 34.82 $/MWh in SA for the base load, while they range from 36.28 $/MWh in QLD to 43.55 $/MWh in SA during the peak period. In the Quarter 4, the average quarterly electricity spot prices range from 28.65 $/MWh in VIC to 43.34 $/MWh in NSW for the base load, while they range from 39.21 $/MWh in VIC to 75.69 $/MWh in NSW during the peak period.~~

Descriptive Statistics	QUARTER 1							
	BASE PERIOD				PEAK PERIOD			
	NSW	QLD	SA	VIC	NSW	QLD	SA	VIC
Mean	40.34	40.18	62.64	39.42	62.15	63.78	118.31	65.88
Standard Deviation	92.08	100.56	201.07	109.59	185.54	190.75	427.20	236.29
Minimum	12.08	9.72	-41.14	-8.94	15.26	5.48	10.32	15.09
Maximum	1293.00	1487.33	2533.96	2376.06	2365.74	2726.58	4654.74	4304.45
Number of Observation	903	903	903	903	627	627	627	625
Descriptive Statistics	QUARTER 2							
	BASE PERIOD				PEAK PERIOD			
	NSW	QLD	SA	VIC	NSW	QLD	SA	VIC
Mean	39.80	34.93	37.25	38.49	54.83	47.39	46.67	52.62
Standard Deviation	58.02	47.08	21.46	52.08	113.15	88.38	29.48	107.40
Minimum	12.20	11.14	-103.16	9.90	14.60	13.09	-85.45	14.68
Maximum	863.13	669.65	188.52	1276.86	1494.39	1097.96	253.50	2338.40
Number of Observation	910	910	910	910	625	623	625	625
Descriptive Statistics	QUARTER 3							
	BASE PERIOD				PEAK PERIOD			
	NSW	QLD	SA	VIC	NSW	QLD	SA	VIC
Mean	33.41	28.77	34.82	32.27	42.95	36.23	43.49	41.42
Standard Deviation	26.15	21.53	20.30	20.34	50.76	40.09	32.29	35.07
Minimum	15.03	2.74	1.12	13.11	17.36	-7.68	12.52	11.30
Maximum	281.18	282.67	277.46	295.07	490.55	502.73	444.48	479.41
Number of Observation	828	828	828	828	592	592	592	592
Descriptive Statistics	QUARTER 4							
	BASE PERIOD				PEAK PERIOD			
	NSW	QLD	SA	VIC	NSW	QLD	SA	VIC
Mean	43.34	33.84	39.50	28.65	75.82	51.30	63.78	39.22
Standard Deviation	115.89	53.93	88.74	21.43	254.64	107.14	193.54	42.06
Minimum	13.07	-13.98	-95.78	-4.89	15.83	-32.58	-1.38	13.09
Maximum	1394.18	841.17	1751.95	323.30	2538.49	1538.04	3210.11	570.48
Number of Observation	828	828	828	828	572	573	572	573

Table 1: Descriptive Statistics for quarterly spot prices for NSW, QLD, SA and VIC base and peak loads contracts from January 1, 2003 to June 30, 2012.

As expected, spot electricity prices are driven by demand and supply mechanisms such that electricity prices and volatility are generally higher during the peak load period, where demand is usually significantly higher and more volatile. As indicated by Table 1, negative prices could also be observed in the QLD, SA and VIC markets. According to the AEMO Information Centre (2011), negative spot prices can be explained by electricity generators bidding negative prices since they want to ensure that their supplies are dispatched, as it is actually cheaper for them to continue running rather than ramping down their power plants. Generating units cannot usually be switched on and off in a short time due to efficiency and safety reasons (Hu et al., 2005). Therefore producers might actually be better off paying retailers for the consumption of electricity for a short period of time. This is also referred to as a tactical strategy (Thomas et al., 2011) to ensure that the generators will get the contract. For a modelling framework that can also be used to model negative price spikes, see e.g. Fanone et al. (2011).

Figure 1 provides a plot of the time series of electricity spot prices in NSW during base and peak periods. We can see considerable variations in the spot price, particularly during the peak period. We find that the most pronounced features of Australian electricity prices are short periods of significantly increased volatility as well as infrequent but very extreme price spikes. These spikes yield daily electricity prices of up to $2,500 markets during the base period and even more than $4,000 during the peak period in VIC and SA markets. They are less extreme for NSW and QLD markets, but here prices of up to $1,500 and $2,700 respectively could be observed during the base and peak load periods.



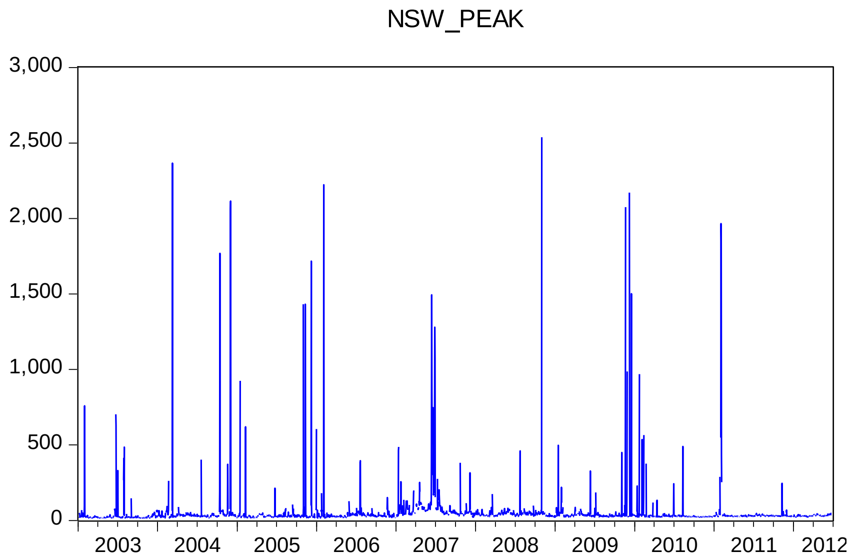


Figure 1: Daily electricity spot prices for base and peak load periods from January 1, 2003 to June 30, 2012 for the NSW market.

We also examine seasonality in the market by calculating average spot prices for the calendar months. Table 2 displays the descriptive statistics of quarterly average spot prices of base and peak load contracts. We find strong evidence of seasonality in electricity spot prices: ~~the highest average prices can be observed during the second quarter for NSW and during the first quarter for QLD, SA and VIC. On the other hand, the lowest prices for base load contracts are observed in the third quarter for NSW, QLD and SA and in the fourth quarter for VIC. The highest average prices for peak load contracts are observed during the first quarter for QLD, SA and VIC and during the fourth quarter for NSW. The lowest average prices for peak load contracts can be observed in the third quarter for NSW, QLD and SA and during the fourth quarter for VIC~~. Note that strong seasonal effects in electricity prices have been reported by many authors, see e.g. Bessembinder and Lemmon (2002), Lucia and Schwartz (2002), Weron (2006), and Bierbrauer et al. (2007) to name a few.

Descriptive Statistics	QUARTER 1							
	BASE PERIOD				PEAK PERIOD			
	NSW	QLD	SA	VIC	NSW	QLD	SA	VIC
Mean	40.36	40.17	62.59	39.45	62.13	63.79	118.95	65.87
Standard Deviation	13.01	15.08	39.76	16.07	25.21	27.52	106.35	37.07
Minimum	25.79	21.65	26.19	21.10	28.56	27.17	30.46	26.91
Maximum	68.28	67.94	152.29	64.61	114.31	106.43	361.55	125.04
Number of Observation	10	10	10	10	10	10	10	10

Descriptive Statistics	QUARTER 2							
	BASE PERIOD				PEAK PERIOD			
	NSW	QLD	SA	VIC	NSW	QLD	SA	VIC
Mean	39.79	34.92	37.24	38.48	54.92	47.43	46.66	52.62
Standard Deviation	29.67	26.43	14.54	19.66	53.98	45.81	18.82	30.55
Minimum	25.84	21.57	26.15	25.78	29.28	25.01	34.75	32.13
Maximum	123.38	109.02	76.24	90.91	207.51	176.68	97.33	131.37
Number of Observation	10	10	10	10	10	10	10	10

Descriptive Statistics	QUARTER 3							
	BASE PERIOD				PEAK PERIOD			
	NSW	QLD	SA	VIC	NSW	QLD	SA	VIC
Mean	33.41	28.77	34.82	32.27	43.00	36.28	43.55	41.49
Standard Deviation	9.08	10.04	10.00	11.11	12.89	14.15	13.53	15.57
Minimum	27.12	20.92	24.39	22.18	32.89	23.45	30.03	27.97
Maximum	55.33	53.35	56.93	57.43	71.40	69.57	73.06	74.47
Number of Observation	9	9	9	9	9	9	9	9

Descriptive Statistics	QUARTER 4							
	BASE PERIOD				PEAK PERIOD			
	NSW	QLD	SA	VIC	NSW	QLD	SA	VIC
Mean	43.34	33.84	39.50	28.65	75.69	51.25	63.67	39.21
Standard Deviation	21.25	12.13	17.50	6.93	53.77	24.50	45.26	11.49
Minimum	19.76	19.42	20.78	18.59	24.17	22.47	30.74	21.91
Maximum	77.23	51.70	81.76	40.99	164.58	86.49	179.91	57.07
Number of Observation	9	9	9	9	9	9	9	9

Table 2: Descriptive Statistics of average quarterly spot prices for NSW, QLD, SA and VIC base and peak loads contracts from January 1, 2003 to June 30, 2012.

4.2 Realized Risk Premiums in the Futures Market

In the next step we analyse the ex-post or realized futures risk premium in the markets under consideration. We calculate the premium as the difference between the quote for the futures contract on the last trading day before the beginning of the delivery period and the realized average spot price during the delivery period. Here we do not distinguish between different quarters such that for each market the realized premiums for the first (Q1), second (Q2), third (Q3) and fourth quarter (Q4) are jointly examined. However, we distinguish between regional markets as well as between base and peak load futures contracts. Thus, for the considered time period from Q1 2003 to Q2 2012 we have 38 base load contracts and the same number of peak load contracts for each market.

Results for the futures risk premiums realized in each market are provided in Table 3. We find that for all markets we observe a positive ex-post premium indicating that futures quotes immediately before the beginning of the delivery period are on average higher than the average spot price realized during the delivery period. The size of the premium varies dependent on the market under consideration but is also different for base load in comparison to peak load contracts. For the base load period we find that the premium is the highest in QLD where the futures quote per MWh exceeds the realized spot price during the delivery period by $7.19. Note that for a quarter with, for example, 90 days where a contract refers to 2,160 MWh this corresponds to a price difference of approximately $15,528 per contract. The average realized premium is the lowest for NSW at $3.36 while in SA and VIC the corresponding figures are $5.18 and $4.89, respectively. For peak load contracts we also find positive premiums that range from $3.31 in NSW up to $13.29 in the QLD market. The sign of the premiums observed indicates that buyers such as retailers or large customers are willing to pay an additional premium in the futures market in order to avoid potentially extreme losses that might occur when the spot market exhibits extreme prices due to high volatility or price spikes.

We also conduct statistical tests to investigate whether the realized risk premiums are statistically significant. Table 3 provides the t-statistics for the premiums. Interestingly, only the QLD and VIC market exhibit risk premiums that are significantly greater than zero at the 5 percent, respectively at the 10 percent significance level for both base and peak load contracts. The realized premiums for the NSW and SA markets are not statistically significant. We conclude that for Australian electricity markets there is a tendency of futures quotes to be higher than average realized spot prices during the delivery period, but only in the QLD and VIC region these premiums are significantly greater than zero.

Futures Premium	NSW Base	QLD Base	SA Base	VIC Base
Average	3.36	7.19	5.18	4.89
Standard Deviation	22.99	19.92	19.67	16.30
# of Observation (n)	38	38	38	38
t-Statistic	0.90	2.23 **)	1.62	1.85 *)

Futures Premium	NSW Peak	QLD Peak	SA Peak	VIC Peak
Average	3.31	13.29	6.64	8.30
Standard Deviation	45.55	36.69	42.13	29.15
# of Observation (n)	38	38	38	38
t-Statistic	0.45	2.23 **)	0.97	1.75 *)

*Table 3: Realized futures premiums for NSW, QLD, SA and VIC base load and peak load contracts for the time period Q1 2003 to Q4 2012. The asterisk indicate a significant risk premium at the *) 10 percent significance level, **) 5 percent significance level, ***) 1 percent significance level.*

Note that our results on positive risk premiums for nearest term futures contracts are in line with the suggestions of theoretical models regarding the sign of the risk premium. 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 will 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 price spikes may be willing to pay an additional premium for locking in prices in the short term. Such behaviour will result in a positive short-term risk premium as it can be observed in our study and also for a variety of other markets, 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). However, there are also empirical studies reporting negative electricity premiums, for example in the PJM (Bessembiner and Lemmon, 2002) and Nord Pool (Botterud et al., 2010) markets.

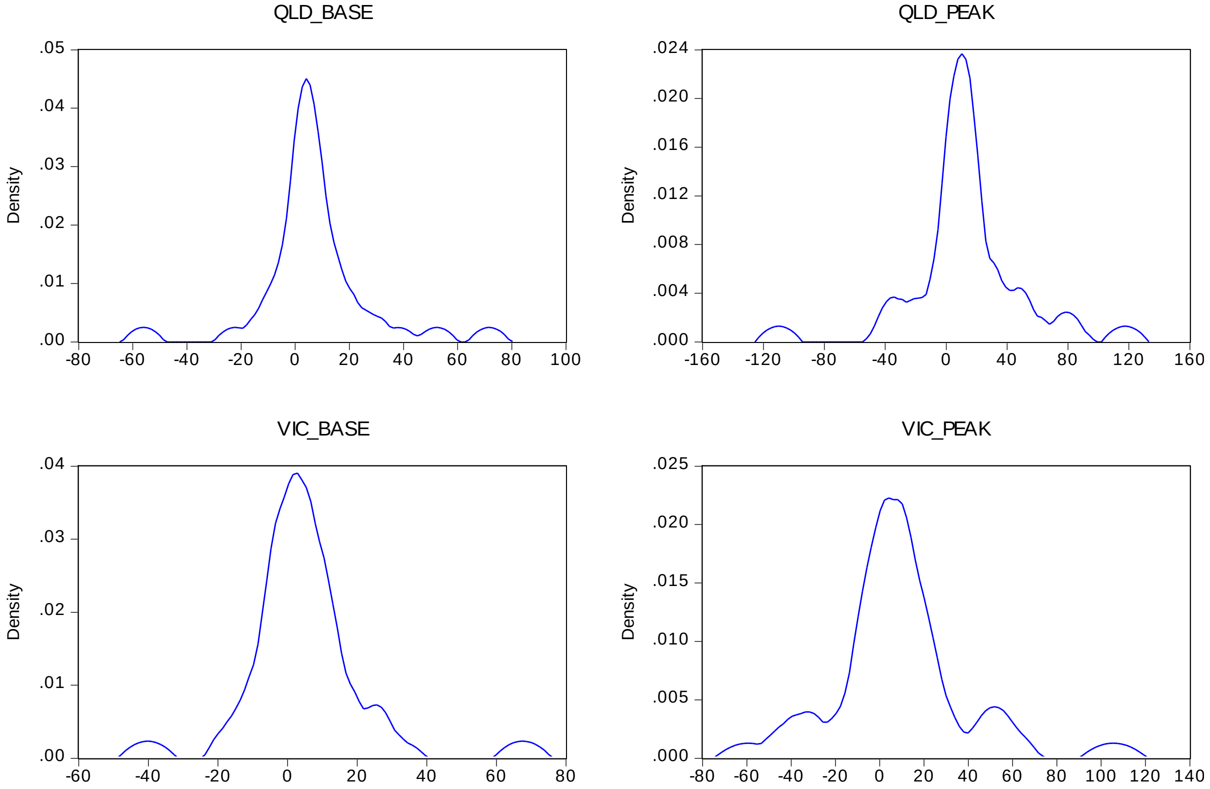


Figure 2: Distribution of realized risk premiums in the QLD and VIC markets for Q1 2003 – Q2 2012 base load (left panel) and peak load (right panel) futures contracts based on the Epanechnikov Kernel density estimation. The density estimate illustrates the positive mean and median of the distribution as well as the high volatility and a number of extreme positive and negative outcomes for the premium.

Figure 2 provides a plot of the probability distribution of the ex-post risk premium observed for base load and peak load futures contracts in the QLD and VIC markets. Hereby the probability density is estimated using the Epanechnikov kernel estimator that spreads the probability mass symmetrically around the actual observation (Kvam and Vidakovic, 2007). The plot illustrates that even though the mean and median of the distribution are positive, the premiums exhibit high volatility with a number of negative realizations for both the QLD and VIC market. Notably, for both base load and peak load contracts we observe one instance where the realized premium is highly negative with approximately \$60 (QLD) and \$40 (VIC) for the base period \$120 (QLD) and \$70 (VIC) for the peak period. This suggests that risk-averse market participants might be discouraged from exploiting the average positive futures risk premium due to the risk of potential significant losses.

Figure 3 plots the realized futures risk premiums for electricity base load futures contracts from Q1 2003 to Q2 2012. The figure illustrates the high volatility of realized risk premiums over time, while premiums are highly correlated across different markets. The premiums usually show the same sign and sometimes also a similar magnitude. The figure also illustrates some seasonal patterns: while the risk premium usually seems to be positive for the first and third quarter of the year, it sometimes becomes highly negative for the second and fourth quarter.

Figure 4 provides a plot of the average realized risk premiums for base and peak load contracts from Q1 2003 to Q2 2012 across all markets. The figure further illustrates very similar behaviour for the ex-post premiums for base and peak load contracts. While the realized premiums are more volatile and higher in terms of absolute values for peak load contracts, premiums for base and peak load contracts for the same period usually show the same sign. The figure also illustrates more clearly the seasonal pattern detected in the risk premiums.

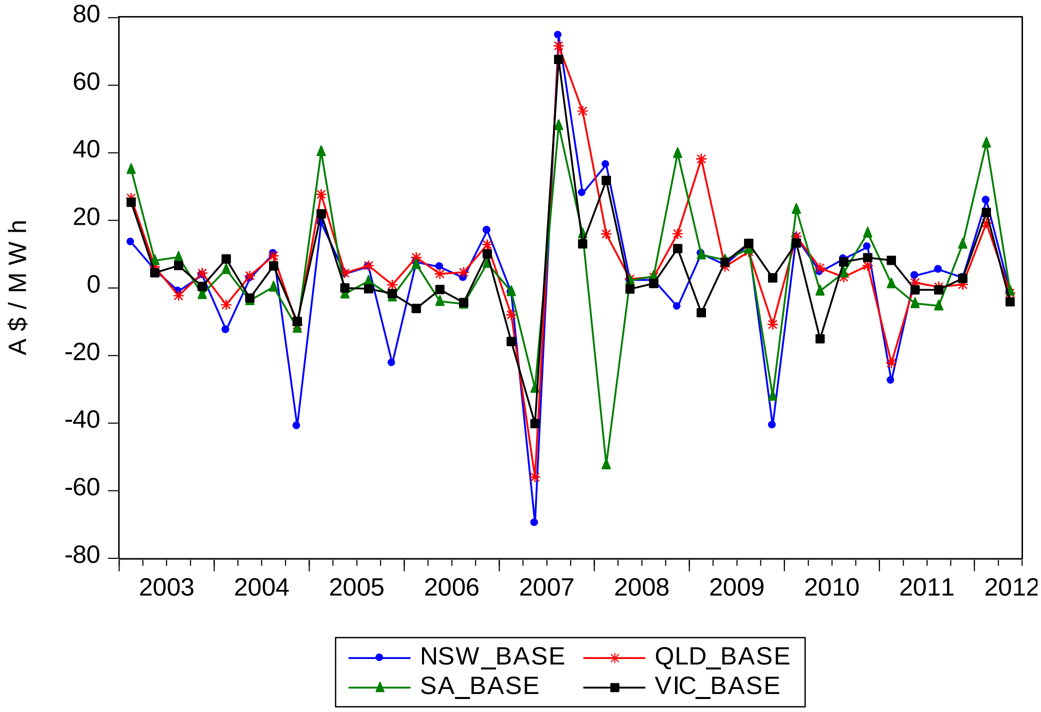


Figure 3: Realized risk premiums for NSW, QLD, SA and VIC base load contracts from Q1 2003 to Q2 2012.

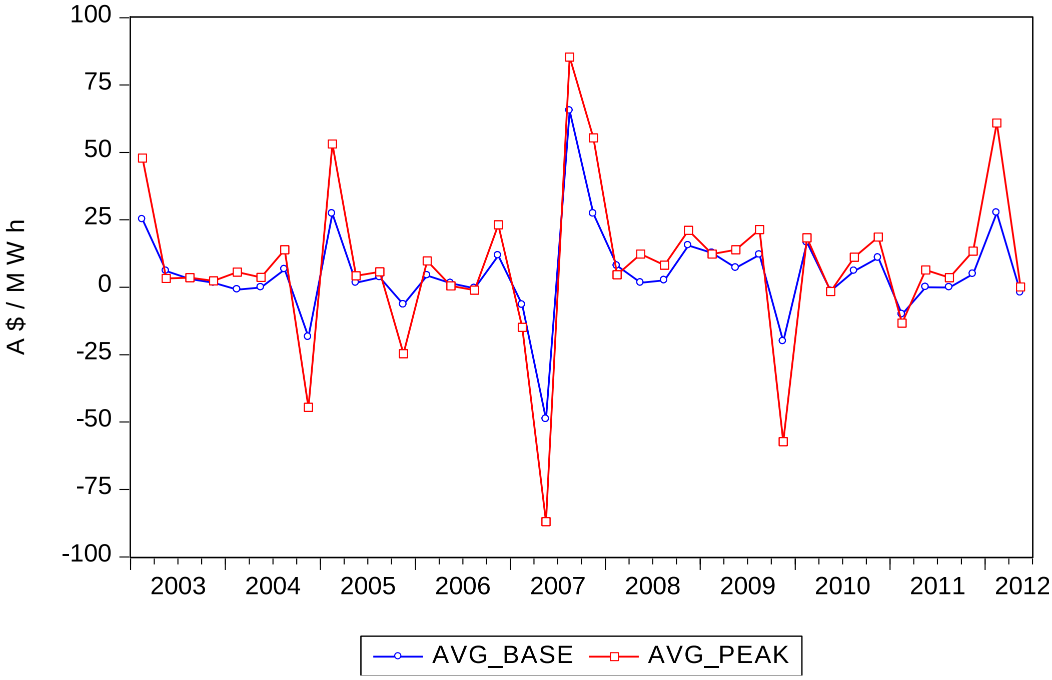


Figure 4: Realized risk premium for base load and peak load contracts averaged over all markets from Q1 2003 to Q2 2012.

All Quarters

	NSW Premium Base	QLD Premium Base	SA Premium Base	VIC Premium Base
NSW Premium Base	1.0000			
(P-value)				
QLD Premium Base	0.8677	1.0000		
(P-value)	(0.0000)			
SA Premium Base	0.4985	0.6261	1.0000	
(P-value)	(0.0037)	(0.0001)		
VIC Premium Base	0.7953	0.7821	0.4960	1.0000
(P-value)	(0.0000)	(0.0000)	(0.0039)	
	NSW Premium Peak	QLD Premium Peak	SA Premium Peak	VIC Premium Peak
NSW Premium Peak	1.0000			
(P-value)				
QLD Premium Peak	0.8274	1.0000		
(P-value)	(0.0000)			
SA Premium Peak	0.3257	0.3312	1.0000	
(P-value)	(0.0689)	(0.0641)		
VIC Premium Peak	0.6224	0.5895	0.2517	1.0000
(P-value)	(0.0001)	(0.0004)	(0.1646)	

Table 4: Estimated correlation between realized risk premiums for base load and peak load contracts in the NSW, QLD, SA and VIC markets.

		Quarter 1		
Premium	NSW Base	QLD Base	SA Base	VIC Base
Average	8.64	11.66	11.16	10.19
t Statistic	1.47	1.99 **)	1.27	2.04 **)
Premium	NSW Peak	QLD Peak	SA Peak	VIC Peak
Average	17.35	24.67	12.68	19.04
t Statistic	1.60	2.09 **)	0.58	1.71 *)
		Quarter 2		
Premium	NSW Base	QLD Base	SA Base	VIC Base
Average	-3.50	-2.30	-2.72	-5.19
t Statistic	-0.47	-0.38	-0.82	-1.20
Premium	NSW Peak	QLD Peak	SA Peak	VIC Peak
Average	-6.05	-3.63	0.15	-8.15
t Statistic	-0.41	-0.31	0.03	-1.14
		Quarter 3		
Premium	NSW Base	QLD Base	SA Base	VIC Base
Average	13.56	11.94	7.64	10.83
t Statistic	1.75 *)	1.57	1.42	1.48
Premium	NSW Peak	QLD Peak	SA Peak	VIC Peak
Average	19.79	18.30	12.58	16.77
t Statistic	1.91 *)	2.43 **)	1.82 *)	1.46
		Quarter 4		
Premium	NSW Base	QLD Base	SA Base	VIC Base
Average	-5.08	8.02	4.87	4.24
t Statistic	-0.62	1.27	0.72	1.71 *)
Premium	NSW Peak	QLD Peak	SA Peak	VIC Peak
Average	-18.36	14.43	1.19	6.16
t Statistic	-0.92	0.97	0.08	1.32

*Table 5: Realized futures risk premiums for each quarter in NSW, QLD, SA and VIC. Results are reported for base load and peak load contracts for Q1 2003 to Q2 2012. The asterisk indicate a significant risk premium at the *) 10 percent significance level, **) 5 percent significance level, ***) 1 percent significance level.*

To further investigate the relationship between realized futures risk premiums, in a next step we examine the correlation between the premiums across the markets under consideration. Table 4 presents the estimated correlation coefficients for the ex-post risk premiums for both base load and peak load contracts. We observe strong and significant positive correlations in the futures risk premium across the markets. We further observe that adjoining regions such as, for example, NSW-QLD or NSW-VIC usually exhibit higher degrees of correlation than markets that are geographically more distant, e.g. QLD-SA or NSW-SA. Given the nature of the Australian market operating as an interconnected grid this does not come as a surprise. Within the national power grid, electricity can be transmitted between different regions via so-called interconnectors. The interconnectors may be of particular importance when the price of electricity in adjoining regions is low enough to displace local supply, but also when the energy demand in a particular region is higher than the amount of electricity that can be provided by local generators. Therefore, one could expect adjoining regions to exhibit similar price behaviour and also, therefore, higher correlations between realized risk premiums.

Note that overall correlations between the realized premiums seem to be lower for peak load contracts. This can probably be explained by the higher volatility and number of price spikes during peak periods. In cases where there are a number of price spikes during the same quarter in one market, this can have significant impact on the realized risk premiums. Recall that a quarterly peak load futures contract refers to less than 1,000 MWh while a base load contract refers to more than 2,000 MWh. Therefore, the usual brief periods of spikes or extreme prices will have a higher impact on average prices, and, therefore on realized risk premiums in each market for the peak period. This could explain the lower degree of correlation in risk premiums for peak load contracts.

Given the obvious seasonality in the risk premiums observed, in a next step we examine the ex-post futures risk premiums for each quarter separately in Table 5. Note that with 38 observations in total, we only observe risk premiums for around nine (Q3 and Q4) or ten (Q1 and Q2) contracts for each of the quarters. Therefore, results for the size of the premium and statistical tests have to be considered with care. We find that realized base load and peak load futures risk premiums are positive in all markets for contracts referring to Q1 and Q3 while they are almost invariably negative for Q2. For Q4 the results are rather mixed, suggesting a negative premium for NSW and a positive premium for QLD, SA and VIC. Overall, seasonality throughout the year seems to have a strong impact on the risk premium. In most cases the magnitude of the premium is higher for peak load contracts, where the average realized premiums range from -$18.36 for Q4 NSW contracts to $24.67 for Q1 QLD contracts. Recall that a peak load contract refers to delivery of approximately 930 MWh during a quarter. Therefore, market participants in QLD on average paid an additional $22,943 per purchased Q1 futures contract in comparison to what they would have paid in the spot market. For base load contracts the highest average premium is observed for Q3 NSW contracts with $13.56, while the highest negative premium is observed for Q2 VIC contracts with -$5.19. While average realized premiums seem to be quite large for several of the quarters and markets, from a statistical perspective, base load risk premiums are significantly greater than zero only for Q1 in QLD and VIC at the 5 percent significance level and for Q3 in NSW at the 1 percent significance level. For peak load contracts, the Q1 premiums in QLD and VIC are significant at the 5 percent, respectively 1 percent, level, while Q3 premiums are greater than zero for QLD at the 5 percent significance level and for NSW and SA at the 10 percent level of significance. Note, however, that for none of the quarters with average negative risk premiums, these premiums are significant.

As mentioned before, the literature provides a number of reasons for the comparably large premiums in electricity futures markets. According to Benth et al. (2008), closer to the delivery period of the futures contract, retailers or consumers aiming to hedge the risk of price spikes may be willing pay an additional premium for locking in prices in the short term. This explains the large positive risk premiums for several of the contracts observed in our study. Our results are also in line with studies on other markets, see e.g. Longstaff and Wang (2004); Hadsell and Shawky (2006); Diko et al. (2006); Bierbrauer et al. (2007); Redl et al. (2009).

According to Shawky et al. (2003), the non-storability and presence of relatively few big players in electricity markets requires a high premium for market participants. Furthermore due to high volatility, the skewed distribution of electricity spot prices, and the risk of extreme price spikes, buyers of electricity might be willing to pay a large premium in the futures market in order to avoid the risk of substantial losses when buying in the spot market (Bessembinder and Lemmon, 2002; Longstaff and Wang, 2004). Note that for Australian electricity markets, Anderson et al. (2007) conducted interviews with retailers who argue that if they had not bought electricity futures contracts, the spot price may have risen even higher than the futures price. These findings also imply that the futures risk premium can be seen as compensation for market participants bearing the high risk of extreme spot prices.

4.3 Explaining the Futures Risk Premium

In the following section we investigate whether the bias in futures prices can be explained by the behaviour of the spot price during the month or quarter prior to delivery of the futures contract. As pointed out in Section 3, our reasoning follows work by e.g. Bessembinder and Lemmon (2002), Lucia and Torro (2008), Redl et al. (2009) and Botterud et al. (2010). We use equation (4) in order to examine whether realized futures risk premiums in regional markets can be explained by the level, standard deviation, variance, skewness and kurtosis of electricity spot prices prior to the delivery period of the futures contract.

The explanatory variables in the regression model were based on the spot price behaviour either during the last month or the last quarter prior to the delivery period. With respect to the explanatory power of the model, we obtained clearer results when the calculated moments were based on the last month's spot prices instead of the last quarter. In the following we will therefore only report results based on spot price behaviour during the month prior to the delivery period[4]. While futures contracts refer to a quarterly delivery period, we find that market participants seem to use rather information on the spot price during the most recent month for their hedging decisions.

Coefficient	Constant (t-Stat)	Mean (t-Stat)	Stdev (t-Stat)	Var (t-Stat)	Skew (t-Stat)	Kurt (t-Stat)	R^2	Adj R^2	F-stat
Premium	Using last month data for independent variables								
NSW Base	-8.11	0.54 ***)	-0.29	0.000774	-15.09 **)	3.22 **)	0.42	0.33	4.61
	(-1.20)	(3.62)	(-0.92)	(0.63)	(-2.13)	(2.70)			
QLD Base	-1.61	0.43 **)	-0.03	0.000011	-3.49	0.31	0.35	0.25	3.43
	(-0.21)	(2.38)	(-0.11)	(0.01)	(-0.49)	(0.25)			
SA Base	2.06	0.23	0.04	-0.000387	-0.24	-0.49	0.10	-0.04	0.71
	(0.17)	(0.59)	(0.08)	(-0.43)	(-0.11)	(-0.78)			
VIC Base	-8.22	0.60 **)	-0.82	0.006839	-1.71	0.74	0.38	0.28	3.90
	(-1.09)	(2.44)	(-1.23)	(1.01)	(-0.65)	(1.16)			
NSW Peak	2.77	0.44 **)	-0.22	0.000233	-36.83 **)	8.57 ***)	0.31	0.21	2.91
	(0.18)	(2.51)	(-0.73)	(0.44)	(-2.37)	(2.81)			
QLD Peak	9.63	0.24	-0.04	0.000086	-0.99	-0.71	0.17	0.04	1.28
	(0.71)	(1.12)	(-0.12)	(0.16)	(-0.09)	(-0.30)			
SA Peak	2.47	0.40	-0.26	0.000024	-5.45	0.64	0.06	-0.09	0.41
	(0.10)	(0.68)	(-0.56)	(0.07)	(-0.42)	(0.19)			
VIC Peak	-11.63	0.76 ***)	-0.57	0.001421	-9.80	2.83	0.33	0.22	3.13
	(-1.17)	(3.21)	(-1.10)	(0.54)	(-1.07)	(1.28)			

*Table 6: Results of regression analysis (4) for realized futures risk premium of quarterly base load and peak load contracts in NSW, QLD, SA and VIC. Explanatory variables are based on the spot price behaviour during the month prior to the delivery period of the futures contract. The asterisks indicate a significant risk premium at the *) 10 percent significance level, **) 5 percent significance level, ***) 1 percent significance level.*

Since several of the explanatory variables considered were not statistically significant, we also apply a stepwise regression analysis to the data. Hereby, we use stepwise backward regression, starting with a model that includes all explanatory variables and then sequentially removing the insignificant variables from the model. Results for the estimated models

---

[4] Results for the regression using moments based on the spot price behaviour during the quarter prior to the delivery period are available upon request to the authors.

including all variables and the optimal model based on the stepwise regression with an exit significance level of 0.1 are reported in Tables 6 and 7.

Examining the explanatory power of the models in Table 6 we find considerable differences across the considered regional markets and contracts. For base load contracts, results for the coefficient of determination range from 0.10 for SA up to 0.38, respectively 0.42, for VIC and NSW. The explanatory power of the regression model for peak load contracts is usually slightly lower and ranges from 0.06 for SA to 0.33 for NSW. While these results indicate only a limited explanatory power of the model, the coefficients of determination are still roughly in the same range or even higher than what has been reported in earlier studies. For example, using a similar approach, Lucia and Torro (2008) find values for R^2 ranging from 0.01 to 0.30 for short term risk premiums in the Nordpool market while Redl et al. (2009) obtain values of R^2 between 0.02 and 0.11 when modelling monthly futures contracts in the European EEX and Nordpool markets.

Note that for some of the considered markets, none of the variables turns out to be significant. However, for most markets the average spot price during the month prior to the beginning of the delivery period is significant, while estimated coefficients are positive for all markets and contracts. This indicates that the higher the spot price prior to the delivery period, the more pronounced is the realized risk premium, i.e. the more the futures quote will overestimate the average spot price during the delivery period. While not being significant, estimated coefficients for the standard deviation are negative and coefficients for the realized variance are positive. This somehow confirms the convex, initially decreasing and then increasing relationship of the risk premium with price risk suggested by Bessembiner and Lemmon (2002).

On the other hand, estimated coefficients for skewness are negative for all markets and contracts. Also coefficients are significant at the 5 percent level for risk premiums exhibited by NSW base and peak load contracts. The negative sign of these coefficients suggests a general tendency for the realized risk premium to decrease with increasing skewness of the spot prize prior to the delivery period. These results somehow contradict the relationship between skewness and the forward premium as it has been suggested by, e.g. Bessembiner and Lemmon (2002): since positive skewness implies the possibility of higher upward spikes, both the forward price and the forward premium should be positively related to skewness. On the other hand, our results are in line with several other empirical studies, e.g. Lucia and Torro (2008) and Botterud et al. (2010) in the Nord Pool market or Furio and Meneu (2010) in the Spanish electricity market. These authors also find negative coefficients for the skewness parameter, while, similar to our results the coefficients in these studies are usually not significant. Estimated coefficients for kurtosis are mainly positive, however, only significant for risk premiums inherent in NSW base and peak load contracts. Note that also a higher kurtosis suggests an increased risk of price spikes and extreme observations. Therefore, the effects of increasing skewness and kurtosis, i.e. the effects of a higher probability for extreme prices in the spot market on the risk premium are not clear cut for the considered markets.

Table 7 provides results for included variables and explanatory power of the model, when a stepwise regression is applied. The obtained results confirm previous results for the model with all variables and suggest that for several markets and considered contracts, only the level of the spot price is significant. Applying stepwise regression we obtain coefficients of determination ranging from 0.30 to 0.39 for base load and between 0.23 and 0.28 for peak load contracts. Note that for the NSW market where the variables spot price level, skewness and kurtosis are included, we also obtain the highest explanatory power for the estimated regression models. On the other hand, the stepwise regression results suggest that for SA base load as well as for QLD and SA peak load contracts the considered models do not provide significant explanatory power.

We also conduct residual diagnostic checks to test the robustness of our regression results. In particular we conduct White tests for heteroskedasticity (White, 1980) and Durbin-Watson tests for autocorrelation in the residuals[5]. Note that we do not conduct these tests for the SA (base and peak periods) and QLD (peak only) regions, since none of the considered variables was significant and the model only provides very limited explanatory power. The results for the White test suggest that there are no issues with heteroskedasticity in the residuals for the NSW and QLD markets. For VIC base load contracts, the test suggests heteroskedastic residuals at the 5 percent significance level such that White's heteroskedasticity-consistent estimator (HCE) was applied to adjust the t-statistics (as indicated by an asterisk *) in Table 7. Conducted Durbin Watson tests suggest that there is no presence of autocorrelation in the residuals.

---

[5] Results for these tests are not reported here but are available upon request to the authors.

Coefficient	Constant (t-Stat)	Mean (t-Stat)	Stdev (t-Stat)	Var (t-Stat)	Skew (t-Stat)	Kurt (t-Stat)	R^2	Adj R^2	F-stat	
Premium	Using last month data for independent variables									
NSW Base	-4.16	0.39			-16.37	3.07	0.39	0.33	7.10	
	(-0.70)	(4.22)	( )	( )	(-2.41)	(2.62)				
QLD Base	-5.79	0.37					0.31	0.29	16.48	
	(-1.38)	(4.06)	( )	( )	( )	( )				
SA Base	5.18									
	(1.62)	( )	( )	( )	( )	( )				
VIC Base	-9.11	0.44					0.30	0.28	15.65	
	(-2.38)	(3.27)	( )	( )	( )	( )				*)
NSW Peak	8.79	0.27			-37.48	7.95	0.28	0.22	4.50	
	(0.58)	(4.88)	( )	( )	(-1.79)	(1.97)				
QLD Peak	13.29									
	(2.23)	( )	( )	( )	( )	( )				
SA Peak	6.64									
	(0.97)	( )	( )	( )	( )	( )				
VIC Peak	-9.27	0.40					0.23	0.21	10.78	
	(-1.54)	(3.09)	( )	( )	( )	( )				*)

*) Using White heteroskedasticity-consistent standard errors & covariance

Table 7: Results for stepwise regression for realized futures risk premium of quarterly base load and peak load contracts in NSW, QLD, SA and VIC. Explanatory variables are based on the spot price behaviour during the month prior to the delivery period of the futures contract.

Recall that in Section 4.2 we found high correlations between observed risk premiums across the regional markets. Therefore, we decided to also apply a seemingly unrelated regression (SUR) model to the data, see equation (5). The SUR estimation technique estimates the equations jointly, accounting for contemporaneous correlations between the errors as well as for different variances of the error terms in the four markets. Results for the applied SUR model are reported in Table 8. We can see that also for this model spot price levels during the month prior to delivery are positive and statistically significant at the 1 percent or, at least at the 5 percent level for all markets except the SA region. This is true for both base load and peak load risk premiums. The estimated coefficients for the standard deviation are mostly negative (except for base load contracts in SA), while the sign of the coefficients for the variance varies and is positive for NSW and QLD, but negative for SA and VIC. Therefore, for the NSW and QLD market, our results are in line with the suggested convex relationship between risk premiums and price risk in the spot market suggested by Bessembiner and Lemmon (2002). Skewness and kurtosis of spot prices during the month prior to delivery are positive and statistically significant at the 5 percent significance level for NSW (both base and peak) and VIC (base only). The explanatory power of the model is 0.24 for risk premiums associated with base load contracts and 0.20 for peak load contract risk premiums.

Coefficient	Constant (t-Stat)	Mean (t-Stat)	Stdev (t-Stat)	Var (t-Stat)	Skew (t-Stat)	Kurt (t-Stat)	R^2	Adj R^2	F-stat
Premium	Using last month data for independent variables								
NSW Base	-8.53	0.47 ***	-0.12	0.000046	-7.56	1.55 **	0.24	0.10	1.74
	(-1.62)	(3.78)	(-0.53)	(0.05)	(-1.65)	(1.99)			
QLD Base	-8.44	0.48 ***	-0.15	0.000169	1.65	-0.14			
	(-1.56)	(3.35)	(-0.74)	(0.22)	(0.37)	(-0.17)			
SA Base	-0.09	0.24	0.11	-0.000522	-1.36	-0.22			
	(-0.01)	(0.70)	(0.29)	(-0.71)	(-0.81)	(-0.44)			
VIC Base	-14.46	0.67 ***	-0.03	-0.002151	-4.15 **	0.95 **			
	(-2.48)	(3.50)	(-0.05)	(-0.44)	(-2.16)	(2.07)			
NSW Peak	-1.46	0.42 ***	-0.18	0.000121	-21.80 **	4.98 **	0.20	0.05	1.36
	(-0.13)	(2.87)	(-0.84)	(0.33)	(-2.19)	(2.56)			
QLD Peak	-3.84	0.36 **	-0.20	0.000225	3.89	-0.34			
	(-0.38)	(2.12)	(-0.90)	(0.60)	(0.53)	(-0.22)			
SA Peak	2.59	0.40	-0.20	-0.000047	-6.93	0.77			
	(0.12)	(0.77)	(-0.49)	(-0.15)	(-0.62)	(0.26)			
VIC Peak	-13.63	0.72 ***	-0.17	-0.000652	-8.89	2.21			
	(-1.58)	(3.55)	(-0.41)	(-0.30)	(-1.18)	(1.22)			

Table 8: Results for the applied seemingly unrelated regression (SUR) model for realized risk premium of quarterly base load and peak load contracts in NSW, QLD, SA and VIC. Explanatory variables are based on the spot price behaviour during the month prior to the delivery period of the futures contract.

Finally, we test for the significance of contemporaneous correlations between the four different electricity markets. We use the Lagrange Multiplier (LM) test to examine the null hypotheses of zero correlation (Hill et al., 2011):

$$H_0 : \sigma_{NSW,QLD} = \sigma_{NSW,SA} = \sigma_{NSW,VIC} = \sigma_{QLD,SA} = \sigma_{QLD,VIC} = \sigma_{SA,VIC} = 0 \qquad (6)$$

with a chi-square distribution test statistic:

$$LM = T(r^2_{NSW,QLD} + r^2_{NSW,SA} + r^2_{NSW,VIC} + r^2_{QLD,SA} + r^2_{QLD,VIC} + r^2_{SA,VIC}) \qquad (7)$$

The SUR residuals correlation matrix as well as results for conducted LM tests are provided in Table 9. Our results illustrate that the null hypothesis of zero correlation is rejected at all significance levels, so we conclude that contemporaneous correlation exists across the four different electricity markets. Therefore, the panel SUR method should be preferred over applying a separate ordinary least squares (OLS) regression model for each market.

Residuals Correlation Matrix				
BASE	**NSW**	**QLD**	**SA**	**VIC**
NSW	1.0000			
QLD	0.8467	1.0000		
SA	0.4104	0.4678	1.0000	
VIC	0.7006	0.6901	0.4954	1.0000
PEAK	**NSW**	**QLD**	**SA**	**VIC**
NSW	1.0000			
QLD	0.8365	1.0000		
SA	0.2785	0.2228	1.0000	
VIC	0.5484	0.5361	0.2278	1.0000

PERIOD	LM	p-value
BASE	**64.87**	**4.59E-12**
PEAK	**41.08**	**2.80E-07**

Table 9: Residuals correlation matrix, LM test statistic and p-values of the test for contemporaneous correlation of error terms for NSW, QLD, SA, and VIC markets.

Overall, we find that a significant fraction of the variation in realized futures risk premiums can be explained by the spot price behaviour during the month prior to delivery of the contract. Our results also partially support the framework suggested by Bessembinder and Lemmon (2002). Their model predicts that the forward bias reflected in the realized or ex-post forward premium should increase with the expected demand for electricity and therefore, also with the mean price level. The authors also suggest that the equilibrium premium is convex, initially decreasing and then increasing in the variability of power demand and electricity spot prices. This means that in our model we would expect the coefficient for the standard deviation to be negative while the coefficient for the variance should be positive. Table 6 shows that in the estimated models for NSW, QLD, SA (peak) and VIC, the coefficients generally show the expected signs. Only for SA (base) the coefficient for standard deviation is negative and for variance is positive. Results for the conducted SUR regression in Table 8 also confirm the significant impact of spot price levels on the risk premium. They also provide some indication of the convex relationship between volatility and the forward risk premium for NSW and QLD markets. Our results are also in line with Anderson et al. (2007) who reported that most retailers participating in Australian electricity markets are highly risk-averse.

5. Summary and Conclusions

This paper studies the relationship between spot and futures prices as well as realized risk premiums in regional Australian electricity markets. The National Electricity Market (NEM) in Australia began operating in December 1998 and operates in an interconnected grid comprising several regional networks in different states. Australian electricity markets can be considered as significantly more volatile and spike-prone than other comparable markets (Higgs and Worthington, 2008). While there have been a number of publications on the behaviour of electricity spot prices in Australia, we provide a pioneering study focusing on futures markets and risk premiums. In our analysis we focus on realized or ex-post futures risk premiums in the four major states of New South Wales (NSW), Queensland (QLD), South Australia (SA) and Victoria (VIC).

We find that Australian electricity markets exhibit significant risk premiums for several of the regions considered such that futures prices cannot be considered as unbiased estimators of realized spot prices. Since average realized futures risk premiums are positive for all markets, we conclude that there is a clear tendency for futures prices to overstate average spot prices during the delivery period. In particular, we find economically and statistically significant positive ex-post futures premium for futures contracts referring to the first quarter of the year in QLD and VIC as well as the third quarter of the year in NSW, QLD and SA. There also seems to be a strong impact of seasonality with significantly positive risk premiums during the first and third quarter and negative premiums during the second quarter. Observed premiums are quite substantial for several of the examined contracts: for example, on the last trading day prior to the beginning of the delivery period, market participants on average paid an additional $22,943 per purchased Q1 futures contract in QLD, in comparison to what they would have paid in the spot market without hedging. Not taking into account seasonality or the behaviour during specific quarters, the QLD and VIC regions still yield statistically significant futures premiums with an average magnitude of A$7.19 (QLD) and A$4.89 (VIC) for base load and A$13.29 (QLD) and A$8.30 (VIC) for peak load contracts.

We also observe significant positive correlations between the observed risk premiums across different regional markets. This can be explained by interconnectors between the regional markets allowing for export or import of electricity from one market to the other. Correlations are higher for adjoining regions than for markets that are geographically more distant.

Further investigating the issue, we find that price formation in the considered markets seems to be influenced by historical spot price behaviour. Our results suggest that for some of the markets the bias can at least be partially explained by the level, volatility, skewness and kurtosis of spot prices during the month prior to delivery. In particular, we find that realized risk premiums significantly increase with the level of the spot price. Overall, our results suggest that retailers in Australian electricity markets are risk averse and willing to pay an additional risk premium in the futures market to avoid the risk of price shocks and spikes in the spot market.

Our results also suggest directions for future research. While on average we find positive realized futures risk premiums in all regional markets, in our analysis we only consider futures prices immediately prior to the start of the delivery period. Analysis examining the evolution of the risk premiums over time might provide additional insights into the dynamics of the premium and thus, market participants' changing views on the relationship between futures prices and expected or realized spot prices. Such analysis might also prove helpful to develop optimal trading and risk management strategies for electricity producers or retailers in Australian markets. Further, in our analysis we consider realized or ex-post futures risk premiums only. Alternatively, one could investigate ex-ante futures risk premiums, i.e. compare futures quotes to the expected, instead of the realized spot price, during the delivery period. We recommend such an analysis for future work.

Bibliography

Anderson, EJ, Hu, X & Winchester, D 2007, 'Forward Contracts in Electricity Markets: The Australian Experience', *Energy Policy*, no. 35, pp. 3089 – 3103.

AEMO Information Centre <aemo@reference-service.info>, 'Response to the General Information Query Question Q22582', 13 May 2011.

Australian Energy Market Operator 2010, 'About AEMO – Overview', http://www.aemo.com.au/corporate/aboutaemo.html, viewed 29 December 2010.

Bateson, J & Swan, PL 1989, 'Economies of Scale and Utilization: An Analysis of the Multi-Plant Generation Costs of the Electricity Commission of New South Wales', *The Economic Record*, vol. 65, pp. 329 – 344.

Becker, R, Hurn, S & Pavlov, V 2007, 'Modelling Spikes in Electricity Prices', *The Economic Record*, vol. 83, pp. 371-382.

Benth, F, Benth, S & Koekebakker, S 2008, *Stochastic Modelling of Electricity and Related Markets*, 2nd edition, World Scientific. Advanced Series on Statistical Science and Applied Probability.

Bessembinder, H & Lemmon, ML 2002, 'Equilibrium Pricing and Optimal Hedging in Electricity Forward Markets', *The Journal of Finance*, vol. 57 no. 3, pp. 1347 – 1381.

Bierbrauer, M, Menn, C, Rachev, ST & Trück, S 2007, 'Spot and Derivative Pricing in the EEX Power Market', *The Journal of Banking & Finance*, no. 31, pp. 3462 – 3485.

Botterud, A, Bhattacharyya, AK & Ilic, M 2002, 'Futures and Spot Prices – An Analysis of the Scandinavian Electricity Market', *Working Paper*, pp. 1 – 8.

Botterud, A, Kristiansen, T & Ilic, M 2010, 'The Relationship between Spot and Futures Prices In The Nord Pool Electricity Market', *Energy Economics*, no. 32, pp. 967 – 978.

Bunn, DW & Gianfreda, A 2010, 'Integration and Schock Transmission across European Electricity Forward Markets', *Energy Economics*, no. 32, pp. 278 – 291.

Bowden, N & Pane, JE 2008, 'Short Term Forecasting of Electricity Prices for MISO Hubs: Evidence From ARIMA-EGARCH Models', *Energy Economics*, no. 30, pp. 3186–3197.

Burger, M, Klar, B, Müller, A & Schindlmayr, G 2004, 'A Spot Market Model for Pricing Derivatives in Electricity Markets', *Quantitative Finance*, vol. 4, pp. 109 – 122.

Daskalakis, G & Markellos, RN 2009, 'Are Electricity Risk Premia Affected by Emission Allowance Prices? Evidence from the EEX, Nord Pool and Powernext', *Energy Policy*, no. 3, pp. 2594 - 2604.

Diko, P, Lawford, S & Limpens, V 2006, 'Risk Premia in Electricity Forward Markets', *Studies in Nonlinear Dynamics & Econometrics*, vol. 10 no. 3, pp. 1 – 22.

Douglas, S & Popova, J 2008, 'Storage and the Electricity Forward Premium', *Energy Economics*, no. 30, pp. 1712 - 1727.

Eydeland, A & Geman, H 1999, *Energy Modelling and the Management of Uncertainty*, Riskbooks, London UK.

Fanone, E, Gamba, A, & Prokopczuk, M 2011. 'The Case of Negative Day-ahead Electricity Prices'. Working Paper.

Furio, D & Meneu, V 2010, 'Expectations and Forward Risk Premium in the Spanish Deregulated Power Market', *Energy Policy*, no. 38, pp. 784 - 793.

Greene, WH 2011, *Econometric Analysis 7th Edition*, Pearson Prentice Hall, USA.

Hadsell, L & Shawky, HA 2006, 'Electricity Price Volatility and the Marginal Cost of Congestion: An Empirical Study of Peak Hours in the NYISO Market 2001-2004', *The Energy Journal*, vol. 27 no. 2, pp. 157 - 179.

Haugom, E & Ullrich, CJ 2012, 'Market Efficiency and Risk Premia in Short Term Forward Prices', *Energy Economics*, no. 34, pp. 1931 – 1941.

Higgs, H 2009, ‘Modeling Price and Volatility Inter-Relationship in the Australia Wholesale Spot Electricity Markets’, *Energy Economics*, no. 31, pp. 748 – 756.

Higgs, H & Worthington, A 2008, ‘Stochastic Prices Modeling Of High Volatility, Mean Reverting, Spike-Prone Commodities: The Australia Wholesale Spot Electricity Market’, *Energy Economics*, no. 30, pp. 3172 – 3185.

Hill, RC, Griffiths, WE & Lim, GC 2011, *Principles of Econometrics 4th Edition,* John Wiley & Sons Inc., New Jersey USA.

Huisman, R, Huurman, C & Mahieu, R 2007, ‘Hourly Electricity Prices in Day-Ahead Markets’, *Energy Economics*, no. 29, pp. 240 – 248.

Hu, X, Grozev, G & Battern, D 2005, ‘Empirical Observations of Bidding Patterns in Australia’s National Electricity Market’, *Energy Policy*, no. 33, pp. 2075 – 2086.

Kaldor, N 1939. ‘Speculation and Economic Stability’, *The Review of Economic Studies*, vol. 7, no. 1, pp. 1 – 27.

Kanamura, T & Ohashi, K 2008, ‘On Transition Probabilities of Regime Switching in Electricity Prices’, *Energy Economics*, no. 30, pp. 1158 – 1172.

Karakatsani, NV & Bunn, DW 2008, ‘Intra-Day and Regime-Switching Dynamics in Electricity Price Formation’, *Energy Economics*, no. 30, pp. 1176 – 1797.

Keynes, JM 1930, *A Treatise On Money*. Macmillan, London.

Kim, PR 1997, ‘The Effect of Profit Regulations on Combined Two-Part and Peak-Load Pricing’, *The Economic Record*, vol. 73, pp. 238 – 247.

Kolos, SP & Ronn, EI 2008, ‘Estimating the Commodity Market Price of Risk for Energy Prices’, *Energy Economics*, no. 30, pp. 621 - 641.

Kvam, PH & Vidakovic, B 2007, *Nonparametric Statistics with Applications to Science and Engineering,* John Wiley & Sons Inc., New Jersey USA.

Longstaff, FA & Wang, AW 2004, ‘Electricity Forward Prices: A High Frequency Empirical Analysis’, *The Journal of Finance*, vol. 59, no. 4, pp. 1877 – 1900.

Lucia, JJ & Schwartz, ES 2002, ‘Electricity Prices and Power Derivatives: Evidence from the Nordic Power Exchange’, *Review of Derivatives Research*, no. 5, pp. 5 – 50.

Lucia, JJ & Torro, H, 2008, ‘Short-Term Electricity Futures Prices: Evidence on the Time-Varying Risk Premium’, *Working Paper*, pp. 1 – 34.

Lucia, JJ & Torro, H, 2011, ‘On the Risk Premium in Nordic Electricity Futures Prices’, *International Review of Economics and Finance*, pp. 750 – 763.

Pietz, M 2009, ‘Risk Premia in the German Electricity Futures Market’, *Working Paper Series CEFS*, pp. 1 – 36.

Redl, C & Bunn, DW 2013, ‘Determinants of the Premium in Forward Contracts’, *Journal of Regulatory Economics*, no. 43(1), pp. 90-111.

Redl, C, Haas, R, Huber, C & Böhm, B 2009, ‘Price Formation in Electricity Forward Markets and the Relevance of Systematic Forecast Errors’, *Energy Economics*, no. 31, pp. 356 – 364.

Reedman, L, Graham, P & Coombes, P 2006, ‘Using A Real-Options Approach to Model Technology Adoption under Carbon Price Uncertainty: An Application to the Australian Electricity Generation Sector’, *The Economic Record*, vol. 82, pp. 64 – 73.

Shawky, AH, Marathe, A & Barrett, CL 2003, ‘A First Look at the Empirical Relation between Spot and Futures Electricity Prices in the Unites States’, *The Journal of Futures Markets*, vol. 23, no. 10, pp. 931 – 955.

Swan, PL 1990, ‘Real Rates of Return in Electricity Supply: New South Wales, Tasmania and Victoria’, *The Economic Record*, vol. 66, pp. 93 – 109.

Thomas, S, Ramiah, V, Mitchell, H & Heaney, R 2011, ‘Seasonal Factors and Outlier Effects in Returns on Electricity Spot Prices in Australia’s National Electricity Market’, *Applied Economics*, vol. 43 no. 3, pp. 355 – 369.

Ullrich, CJ 2012, ‘Equilibrium Forward Risk Premiums in Electricity Markets’, *Journal of Energy Markets*, vol. 6 no. 3, pp. 29 – 49.

Veraart, AED & Veraart, LAM 2013, ‘Risk Premia in the Energy Markets’, *Creates*, http://econ.au.dk/fileadmin/site_files/filer_oekonomi/Working_Papers/CREATES/2013/rp13_02.pdf, viewed on 31 October 2013.

Weron, R 2006, *Modeling and Forecasting Loads And Prices In Deregulated Electricity Markets*, John Wiley & Sons Inc., New Jersey USA.

Weron, R 2008. ‘Market Price of Risk implied by Asian-style Electricity Options and Futures’, *Energy Economics*, no. 30, pp. 1098 - 1115.

White, H 1980, ‘A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroskedasticity’, *Econometrica*, vol. 48, no. 4, pp. 817 – 838.

Worthington, A, Kay-Spratley, A & Higgs, H 2005, ‘Transmission of Prices and Price Volatility in Australian Electricity Markets’, *Energy Economics*, no. 27, pp. 337 – 350.