Seasonal Factors and Outlier Effects in Returns on Electricity Spot Prices in Australia's National Electricity Market.

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Abstract

This paper documents seasonal patterns and other characteristics of electricity spot prices in the Australian National Electricity Market (NEM), over a seven-year sample period. The goal is to investigate more specifically the influence of seasonalities and outliers noted in the body of literature on electricity prices. The results confirm that electricity prices exhibit significant time-of-day and day-of-week effects and that monthly and yearly effects are significant to a lesser degree. Extremely high spikes in the price series are an important characteristic of electricity prices and are shown to be a highly significant component of returns behaviour. Negative prices are unusual in financial time series data but occur in Australian electricity prices and are found to be influential on returns. The implications of these finding are that seasonal and outlier effects should not be ignored in efforts to model electricity prices.

Keywords: Electricity, Power, Price, Returns, Seasonal Effects, Outliers.

JEL Classification Numbers: C13, C22, L94, Q41

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1. Introduction

Electricity is a homogeneous commodity that has physical characteristics unlike most traded commodities. It is physically the same no matter when and where it is produced or consumed. Its generation and consumption are for all practical purposes simultaneous. Electricity is completely perishable and as such cannot be stored[1]. The "non-storability" of electricity ensures that electricity markets clear at each moment in time through an adjustment of prices. There is no practical prospect for generators to make use of productive capacity in hours when demand for electricity may be substantially less than supply and inventories cannot be used to "smooth" supply or demand shocks, resulting in market-clearing prices that can be extremely volatile, especially within an intra-day time frame. The market-clearing spot price is subject to various influences that at times create significant volatility. Variation may be caused by unplanned generation unit outages, transmission network failure, generator pool price re-bidding, unexpected weather variation and physical constraints on transmission between regions. Electricity price time series exhibit a greater incidence of extreme price spikes than financial data and at times negative prices are observed.

The literature on electricity price modelling frequently identifies the presence of extreme price jumps with rapid reversion to the mean as a cause of extreme volatility in electricity prices (Bunn (2004), Alvaro, Peña, and Villaplana (2002), Hadsell, Marathe and Shawky (2004)). Modelling electricity prices in the Australian and other national markets is a difficult process and this provides a strong incentive for further

[1] To date no technology has been developed to provide a viable storage medium for wholesale quantities of electric power. While it can be argued that hydroelectric generation technologies can provide de-facto storage by holding water in reservoirs, it is not physical storage of the commodity as is traditionally defined and understood.

research into the electricity price market. Many stochastic models applied to conventional financial time-series data have been applied to electricity time series but they have some way to go in revealing the main components of price structure. Knittel and Roberts (2001) emphasised the need to explore this structure and include it in price specifications. Goto and Karolyi (2004) further note that their jump models fail to capture apparently significant effects of extreme price jumps and the effects of these jumps warrant further investigation.

The main contribution of this paper is twofold. First, we examine a seven-year sample of half hourly spot prices for five regions in Australia's National Electricity Market (NEM) and report on the actual occurrence of outliers in the form of extreme price spikes and the incidence of negative prices. Second, we present a model that captures the sensitivity of returns to these outliers, along with seasonal factors including time-of-day, day-of-week, monthly and yearly effects. We show that seasonal effects vary across regions and time of day effects are more significant than other seasonalities. We further show that the extreme values represented by high price spikes and negative prices are highly significant.

The rest of the paper is organised as follows: Section two describes briefly the institutional features of the NEM and its method of deriving the spot price[2]. Section three surveys the related literature on electricity price behaviour to clearly distinguish our contribution. Our data and preliminary statistical analysis is provided in section four. Our models and main estimation results are presented in sections five and six and section seven summarizes our findings and suggests further related research.

[2] It should be noted that the method used by the NEM to derive its half-hourly spot price is generally ignored in the current body of literature.

2. Background to the Australian National Electricity Market (NEM)

Following the 1993 report of the Independent Committee of Inquiry into the Australian Electricity Utilities Industry (the Hillmer Report), the Australian electricity industry has been progressively deregulated. The Hillmer reforms led to the disaggregation of vertically-integrated government-owned electricity authorities into separate generation transmission and distribution and retail sales sectors in each state. The wholesale market was organised into two separate electricity "pools", centred in Victoria and New South Wales until 1998 when Queensland and South Australia joined to form the National Electricity Market (NEM). The NEM is segmented into five regional pools along state lines: VIC1 (Victoria), NSW1 (New South Wales), QLD1 (Queensland), SA1 (South Australia), SNOWY1 (Incorporating the generation assets of the Snowy Mountains' Hydroelectric scheme) and TAS1 (Tasmania) commenced operation in May 2005[3]. Physical transmission of power between regions is achieved via interconnectors that physically link Queensland with New South Wales, New South Wales with Victoria, Victoria with South Australia and Victoria with Tasmania. The National Electricity Market Management Company (NEMMCO) operates the NEM on behalf of the participating states. Western Australia and the Northern Territory are not expected to join the NEM in the foreseeable future, primarily for reasons of geographic isolation.

2.1 The Spot Market for Electricity:

The spot electricity market in the NEM is where all market generators and market customers settle their electricity sales and purchases based on a spot price. The spot

[3] Tasmania (TAS1) joined the NEM in May 2005 and is connected to the mainland grid via the "Basslink" submarine interconnector under Bass Strait. At the time of writing the TAS1 pool has been operating less than a year and as such does not provide a data sample of sufficient scope for inclusion in this study.

price is a derived price per trading interval, calculated by a two-step procedure based on the offers to supply made by generators in the pool. The NEM trading day is divided into 48 half-hour “trading intervals”, each defined by the local time at the end of the trading interval. Each half-hour trading interval is further divided into five-minute “dispatch intervals”. A “dispatch price” is recorded as the marginal price of supply to meet demand for each five-minute interval in a given half-hour period. This marginal price is typically the dispatch offer price of the last generator brought into production to meet demand at that interval. The spot price is then calculated as an arithmetic average of the six dispatch prices in a half hour[4]. All generators who are called into production during a given half-hour trading interval receive this spot price for the quantity of electricity delivered during the trading interval.

3. Literature Review

The literature in the field of electricity price behaviour reveals several typical characteristics of electricity price behaviour in its various markets. These characteristics include non-normality manifested as positive skewness and extreme leptokurtosis (e.g. Huismann and Huurman, 2003, Goto and Karolyi, 2004), mean-reversion to a long-run level (e.g. Johnson and Barz, 1999), multi-scale seasonality (intra-day, weekly, seasonal), calendar effects, and extreme behaviour with fast-reverting spikes (e.g. Kaminski, 1997, Clewlow and Strickland, 1999). Spot prices display excessive volatility, compared to other commodities and financial assets (Bunn and Karakatsani, 2003). Escribano *et al* (2001) show volatility to be time-

[4] The National Electricity Code sets a maximum spot price of $10,000 per megawatt hour as the maximum price at which generators can bid into the market. Referred to as the Value of Lost Load (VoLL), it is the price at which NEMMCO directs network service providers to interrupt customer supply to maintain balance and stability in the system.

varying with evidence of heteroscedasticity both in unconditional and conditional variance for daily spot prices in Argentina, New Zealand, Nordpool (Norway and Sweden) and Spain. Much of the work on empirical price modelling attempts to adapt some of the familiar models from financial assets to the characteristics of electricity. Knittel and Roberts (2001), apply various financial models of asset prices to hourly prices in the California market, including mean-reversion, time-varying mean, jump-diffusion, time-dependent jump intensity, ARMAX and EGARCH, concluding that forecasting performance is relatively poor for most standard financial asset models. Kaminsky (1997) provides an early example where the spiky characteristic is addressed through a random walk jump-diffusion model, adopted from Merton (1976), but this model ignores the persistent mean-reversion in electricity prices first identified by Johnson and Barz (1997) and explored further in Clewlow and Strickland (2000). One of the limitations of the jump-diffusion approaches is the assumption that all shocks affecting the price series die out at the same rate. Escribano *et al.* (2001) suggests two additional price features; volatility clustering in the form of GARCH effects and seasonality (emphasised by Lucia and Schwartz, 2001), both in the deterministic component of prices and the jump intensity.

There is some support in the literature for regime-switching as an alternative modelling framework to jump-diffusion and this may be more suitable for actual price forecasting. Huisman and Mahieu (2001) propose an isolation of two effects assuming three market regimes; a regular state with mean-reverting price, a jump regime that creates the spike and finally, a jump reversal regime that ensures with certainty that prices revert to their previous normal level. This regime-transition structure is restrictive in that it does not allow for consecutive irregular prices. De

Jong and Huisman (2002) relax this constraint and propose a two-state model of lognormal prices that assumes a stable mean-reverting regime and an independent spike regime.

Goto and Karolyi (2004) provide some insight into Australian electricity price in their comparison of electricity prices drawn from the US, NORDPOOL (Norway and Sweden) and Australia, with evidence to support the existence of volatility jumps in their data. Goto and Karolyi (2004) and Wolack (2000) in their comparative studies of markets note that jump characteristics appear to be closely related to the institutional structure of markets, with extreme price spikes more prevalent in markets with compulsory participation, as is the case in Australia's NEM. Higgs and Worthington (2005) estimate five different GARCH volatility processes (GARCH, RiskMetrics, Normal, student and skewed student APARCH) over a sample of half-hourly price data for the period January 1 2002 to June 1 2003. Their results indicate that time-of-day, day-of-week and month-of-year effects proxy the arrival of new market information. They further find that positive price spikes, early-morning, late-afternoon and early evening hours are associated with high volatility and that negative price spikes, and other times of the day, week and year are associated with relatively lower volatility.

According to Bunn and Karakatsani (2003), a common feature of finance-inspired stochastic models is to model the statistical properties of spot price behaviour with a view towards derivatives pricing. In order to retain simplicity and/or analytical tractability, the models include only a few factors and typically focus on daily average prices, which are sensitive to outliers. While convenient for options pricing, disregarding evident seasonal and structural effects present in the market data is unhelpful from a forecasting perspective. The majority of the literature treats electricity as a single commodity traded and delivered at different times of the day. An interesting alternative approach is proposed in Guthrie and Videbeck (2002). In a study of half-hourly prices in the New Zealand Electricity Market (NZEM), support is found for the treatment of electricity delivered at different times of the day as different commodities that trade on a small number of distinct intra-day markets, however in the interests of model parsimony, variation in intra-day structure between weekdays and weekends and across seasons is ignored.

Much of the extant literature documents behaviour of daily or hourly price and returns series over sample periods of one to two years or less. The Australian wholesale electricity market is based on prices determined at half-hourly trading intervals and we believe the use of daily data may lead to the loss of important information present in the higher-frequency time series. Many stochastic models applied to conventional financial time-series data have been applied to electricity time series but they have some way to go in revealing the main components of price structure. As noted in the introduction to this study, Knittel and Roberts (2001) emphasised the need to explore this structure and include it in price specifications. Goto and Karolyi (2004) further note that their jump models fail to capture apparently significant effects of extreme price jumps and the effects of these jumps warrant further investigation. This paper extends the current body of empirical work by examining how half-hourly returns are sensitive to seasonalities and other structural factors over a seven year sample period. Seasonalities examined include time-of-day, day-of-week, monthly and yearly effects and structural effects examined include extreme-value influences such as price spikes and negative prices. The effects of price spikes are more finely examined in this paper and occurrences of negative price are generally not considered in the literature but are explicitly investigated in this study.

4. Data

4.1 Price data:

The price data used are half-hourly pool price observations sourced directly from NEMMCO[5] for the period from 1st January, 1999 to 31st January 2006. Prices are expressed in Australian Dollars per Megawatt Hour ($/MWh). The sample size is 124,224 observations for each of five NEM regions under examination, these being NSW1, QLD1, SA1, SNOWY1 and VIC1. Descriptive statistics for the price series are shown in table 1(a).

Insert Table 1 about here

We report the mean, standard deviation, minimum, maximum, range, skewness, kurtosis and Augmented Dickey-Fuller statistics for each region's price series. Mean prices vary between regions, from $30.19 for VIC1 and $41.91 for SA1. We believe this is most likely attributable to the nature of generation technology prevalent in each state. New South Wales, Queensland and Victoria rely on relatively low-cost brown coal and black coal fired generators for their base-load electricity needs, compared to South Australia's greater reliance on higher-cost gas-turbine generation. The standard deviation of prices is generally high, is widely dispersed across the regions and broadly consistent with the pattern of means, ranging from $103.26 for VIC1 to

[5] Available for download from NEMMCO's website at
http://www.nemmco.com.au/data/market_data.htm

$178.11 for NSW1. The highest maximum price of $9909.03 is observed in NSW1 and the lowest in VIC1 at $7416.16. All five regions exhibit negative minimum prices, with SA1's minimum price extremely low at -$822.45. The existence of negative prices is a characteristic of the electricity market that is not commonly found in financial time series data and is most likely attributable to the market practices of generators[6]. Figure 1 illustrates an extreme occurrence of negative price in VIC1, where the pool price fell to -$161.48 at 12:30a.m. on April 15, 2001.

Insert Figure 1 about here

Figure 1 suggests that negative prices exhibit similar rapid mean-reverting tendencies to the extreme price spikes discussed in the existing literature. Occurrences of negative price are rare and typically short-lived, usually persisting for half to one hour. The longest observed interval of negative price occurred simultaneously in NSW1, SNOWY1 and VIC1 for a period of two and a half hours, between 04:00am and 06:30 am on October 10, 1999.

The distributions of price for all five regions demonstrate positive excess skewness with coefficients higher than 0.5, and extremely high positive kurtosis with some coefficients in the order of 1000 or more. This extreme fat-tailed character is consistent with the findings of earlier studies (see Huisman and Huurman (2002), Higgs and Worthington (2005) and Wolack (2000) and is likely driven by the

[6] It is market practice for generators to provide their bids to supply electricity to the pool one day ahead of actual supply. The bid specifies a minimum level of generator output known as the "self-dispatch" level. A generator may bid a negative price into the pool for its self-dispatch quantity (in effect, an offer to pay to produce) as a tactical move to ensure that they are among the first to be called in to generate. Demand usually outstrips the self-dispatch level of supply, so it is rare that generators actually pay to generate but on occasion a generator may not be called in and is "caught short", effectively paying to generate for a short period. Trades are settled in the NEM daily on a net basis, so "paying to generate" does not usually require a cash outlay on the part of the generator.

prevalence of extremely high prices (see Figure 2) and the occurrence of negative prices (see Figure 1). Consistent with these statistics, Jarque-Bera (JB) statistics are extremely high and reject the null hypothesis of normal distribution at the 1% level of significance for all five regions. Augmented Dickey-Fuller (ADF) statistics robustly reject the hypothesis of a Unit Root at the 1% level of significance for all five regions, consistent with the earlier findings of Goto and Korolyi (2004).

Figure 2 illustrates the occurrence of extreme spikes in the price series over a 10-day period in April 2000.

Insert Figure 2 about here.

4.2 Returns:

The returns series are of interest because there are a growing number of over-the-counter and exchange-traded derivative products available for hedgers and speculators in the Australian and overseas electricity markets. Pricing models for derivatives are informed by the behaviour of returns. Figure 3 shows price and returns over a 10-day period and indicates that returns appear to exhibit some time-of-day effects but may not clearly exhibit the seasonal effects evident in the price series.

Insert Figure 3 about here

In light of the existence of negative prices in the series, and that NEMMCO's pool prices are reported at half-hourly intervals in discrete time, the returns series used in this study were generated as half-hourly discrete returns rather than log returns, according to Equation (1) as follows:

$$RET_t = \frac{(P_t - P_{t-1})}{P_{t-1}}. \qquad \textbf{(1)}$$

Where RET_t is discrete return at time t, P_t is half-hourly price at time t and P_{t-1}

is the previous half-hourly Price, i.e. at time $t-1$. The results of tests for the presence of a unit root give us confidence that the price and returns series are stationary, and we prefer this discrete returns specification over log returns. A log returns specification will dampen the extreme spike effects we are attempting to capture, and is incompatible with negative prices, the effects of which are also examined.

We define a spike in returns as any observed return greater than four standard deviations larger than the mean. Table 2 collates the occurrences of spikes as defined. Panel (a) shows the occurrence of spikes by region and in aggregate for weekday, month and year. Panels (b) and (c) show the occurrence of spikes by half-hourly trading interval.

Insert Table 2 about here

Table 2 Panel (a) shows that there are 511 extreme returns spikes observed across all regions during the sample period. QLD1 has the highest incidence of extreme price spikes by state (with 173 occurrences (34%), followed by SA1 with 159 (31%), both markedly higher incidence than VIC1 with 96 (19%), NSW1 with 79 (15%) and SNOWY1 with six occurrences (<1%). By day of the week Monday shows the highest incidence with 115 (23%) tapering gradually to Sunday with 45 occurrences (9%). June shows the highest incidence by month with 81 (16%). The highest incidences by year occur in 2002 with 147 spikes (29%) and 2000 with 116 spikes

(23%), both markedly higher than any other full year in the study period[7]. It should be noted that the incidence of extreme price spikes appears to be declining from 2003 onwards. At the time of writing we believe that this “settling down” is a feature of a maturing market combined with the development and wider use of bilateral hedge contracts between generators and distributors/retailers.

Table 2, Panel (b) shows the incidence of extreme spikes in returns by half-hourly trading interval. There is evidence of a concentration of spikes occurring between the hours 06:30 to approximately 10:00 and between 15:30 and 19:00 hours, with a marked increase in frequency concentrated at the 18:00 trading interval. A sub-period analysis of returns shows that this high concentration at 18:00 is transient. The concentration of extreme returns is not present in 1999-2001, arises in 2002 and 2003 in all regions and dissipates from 2003 onwards. Figure 4 shows the pattern of extreme returns for NSW1 from 2001 to 2004 and is illustrative of the patterns in the other regions.

Insert Figure 4 about here

Descriptive statistics for the half-hourly returns series are shown in table 3. We report the mean, standard deviation, minimum, maximum, range, skewness, kurtosis and Augmented Dickey-Fuller statistics for each region’s returns series.

[7] The sample data set includes the full years 1999-2005. 2006 only includes observations for January.

Insert Table (3) about here.

Mean returns vary widely between regions, from 0.026% for VIC1 to 0.088% for SNOWY1. The standard deviation of returns is generally high, is widely dispersed across the regions and is consistent with the pattern of means, ranging from 1.05% for VIC1 to an extremely high 16.05% for SNOWY1. The highest maximum return of 4542.50% is observed in SNOWY1 and lowest in VIC1 at $142.43%. SNOWY1 also exhibits a markedly wider range of returns than the other regions. The extreme character of returns evident for SNOWY1 is most likely attributable to the nature of generation technology employed. All generation plant in SNOWY1 is hydroelectric, whereas more than 80% of generation capacity in NSW1, VIC1 and QLD1 is provided by coal-fired plant. Coal-fired generation is described as a “slow-start” technology, with orderly shutdown and start-up procedures taking up to 48 hours. By contrast, hydroelectric plant is a “fast-start” technology that can be called into production and shut down within a few minutes, with the result that hydroelectric generators are able to behave more opportunistically than coal-fired generators, with the ability to opt out of supply when pool prices are low and respond rapidly when prices are high.

The distributions of returns for all five regions demonstrate positive skewness and extremely high positive kurtosis. Computed Jarque-Bera (JB) statistics reject the null hypothesis of normal distribution at the 1% level of significance for all five regions. This fat-tailed character is consistent with earlier studies (see Huisman and Huurman (2002), Higgs and Worthington (2005) and Wolack (2000) and like price is driven by the prevalence of extremely large spikes in returns. Computed Augmented Dickey-

Fuller (ADF) statistics clearly reject the hypothesis of a Unit Root at the 1% level of significance for all five regions, again consistent with the findings of the earlier studies.

5. Method:

In section three, our survey of the literature on electricity prices suggests that further exploration of the significance of seasonalities and extreme values is justified. To that end we develop an ordinary-least-squares regression model in which the dependent variable is half-hourly return and the independent variables are dummy variables representing trading interval (half-hourly time of day), day of the week, and month of the year for NSW1, QLD1, SA1, SNOWY1 and VIC1. The model also incorporates dummy variables for "spikes", as defined in section four, and dummy variables are set for each occurrence of a negative value in the price series. The model used for this study captures seasonalities and controls for extreme price spikes and negative prices and is specified in equation (2), as follows:

$$RET_{it} = \alpha_0 + \beta_1 \sum_{t=1}^{5} LR_t + \beta_2 \sum_{n=1, i \neq Sat}^{6} DAY_i + \beta_3 \sum_{n=1, i \neq Sep}^{11} MTH_i + \beta_4 \sum_{n=1999, i \neq 2001}^{2006} YR_i$$
$$+ \beta_5 \sum_{n=1, i \neq 1130hrs}^{47} HH_i + \beta_6 \sum_{n=1}^{N_S} SPIKE_i + \beta_7 \sum_{n=1}^{N_N} NEG_i + \varepsilon_t \quad \textbf{(2)}$$

Where:

RET_{it} represents the discrete return for region i at time t;

α_0 represents the constant term;

LR_{it} represents the lagged return for region i at time t;

DAY_i represents the dummy variable for each day of the week;

MTH_i represents the dummy variable for each month;

YR_i represents the dummy variable for each year included in the sample period (1999 to 2006);

HH_i represents the dummy variable for each half-hourly trading interval from 00:00hrs to 23:30 hrs;

$SPIKE_i$ represents the dummy variable set for each occurrence of extreme return as previously defined, with N_S representing the number of extreme positive returns observed in each region for the period of the study (see table 2);

NEGi represents the dummy variable for return associated with an occurrence of negative price, with N_N representing the number of occurrences of negative prices in each region for the period of the study.

The trading interval at 1130hrs, Sunday, September and the year 2001 were incorporated into the constant term α in the model as the base case for each dummy series. These base cases were selected as the trading interval, day, month and year in which returns activity was consistently lowest in all five regions.

6. Empirical Results:

Results of the regression analysis are presented in table 4. Coefficients and t-statistics are presented for each seasonal dummy variable and for lagged returns. In view of the very large number of individual spikes in returns (511 spikes identified for the sample period), coefficients for individual outliers are not explicitly reported but results for these outliers are discussed.

(Insert Table 4 about here)

We find that day-of-week effects are positive and significant in returns for Monday, Tuesday, Wednesday, Thursday and Friday in all regions except SNOWY1, in which Friday is not found to have significant effect. No significant effect is found for

Saturday in any region. With some minor variation Monday, Tuesday and Wednesday generally contribute greater influence than the other days. There appears to be no clear pattern evident for monthly effect across regions, although a small but significant negative effect is noted for October in NSW1, SNOWY1 and VIC1. Positive effects are noted for winter months in SA1 and QLD demonstrates significant positive effects in spring and summer months. There is no clear pattern evident in yearly effect, with wide variation in direction and significance between regions. Lagged returns exhibit variation in direction and significance of effect between regions, with lags 1,3 and 5 generally significant.

Half-hourly time-of-day effects offer more interesting results and are broadly more consistent across regions than the seasonal effects previously discussed. In general significant negative returns are found for the small hours of the morning between 12:30 a.m. and approximately 4:00 a.m. in all regions. NSW1 exhibits an unexplained positive return at 1:30 a.m., reverting to negative returns until for the remainder of the early morning. The hours between 5:00 a.m. and 9:30 a.m. inclusive exhibit significant positive effect in all regions, reverting to generally negative returns in the late morning. Negative returns are found in SA1 and SNOWY1 during mid-afternoon. Significant positive effects are observed for all regions in the early evening, generally between the hours of 5:00 to 7:00 pm, reverting to significant negative effect for the remainder of the evening, until positive effects emerge in late evening at 10:30 p.m. and at midnight. The periods of positive return in the morning and early evening are consistent with peaks in activity in the population. The positive returns observed around 11:00 p.m. are consistent with increased demand for electricity arising from off-peak hot water systems generally switching on at 11:00 pm.

We find that all observed spikes contribute significant positive effect on returns in all regions, consistent with expectations and with the extant literature. There is some variation evident in the effect of negative prices, with all occurrences having significant negative effect on returns in QLD1, SA1 and VIC1 and fewer instances having effect in NSW1 and SNOWY1.

6. Conclusions:

The deregulation of the electricity supply chain and its reorganisation into wholesale markets offers a rich opportunity for researchers. The physical nature of electricity and the mode of organisation of its various markets give rise to price characteristics and behaviours that are not widely found in more traditional financial markets. We note that several contributors to the current body of empirical work, including Knittel and Roberts (2001), Goto and Karolyi (2004) and Higgs and Worthington (2005) identify seasonal factors in electricity prices as critical component of price behaviour and therefore worthy of further study. A number of studies document and attempt to model extreme behaviour with fast-reverting spikes (e.g. Kaminski, 1997, Clewlow and Strickland, 1999). Knittel and Roberts (2001) find that in the presence of these seasonal effects and extreme behaviour the forecasting performance of standard financial models is relatively poor without adjustment for these effects.

This study investigates these seasonalities and outlier effects in Australian electricity prices in greater detail and over a longer sample period than the existing literature. We find that over seven-year period time-of-day effects in returns are significant and consistent across all five regions of the NEM, with positive returns generally occurring at times of peak population activity in the morning and early evening and negative returns observed at most other times. We note that a transient extreme positive effect on returns arises in 2002 and 2003 and dissipates quickly over subsequent years. Day-of-week effects generally appear stronger for Monday, Tuesday and Wednesday, than other days of the week. Monthly effects are not found to be consistent across regions, nor are yearly effects.

The physical nature of electricity and aspects of the organisation of the Australian market give rise to the occurrence of extreme spikes in prices and in the returns series. Extreme spikes in returns, although representing less than 0.1% of observations in any region, are found to have highly significant positive effect on returns. The occurrence of negative prices, although relatively rare and unique to electricity markets is found to have significant negative effect on returns. These findings reinforce the assertions of previous researchers that seasonal and outlier effects should be incorporated into stochastic models of electricity price behaviour.

Planned extensions to this study include an investigation of the prevalence of seasonal and outlier effects in demand for electricity, with a view to examining the extent to which any of these effects are transmitted from demand to price. As a caveat we recognise that while the ordinary-least-squares approach to modelling adopted for this study is a simple but very effective tool for capturing these effects, with many variables it becomes cumbersome for forecasting purposes. A further proposed extension follows Bystrom (2005), who proposes a potentially more practical description of electricity prices involving extreme-value theory. Bystrom introduces an AR-GARCH price process with a seasonal component in volatility. The advantage of this approach is that the residuals are modelled with distributions from extreme value theory, thus avoiding the estimation complexities and forecasting limitations of previous stochastic models introduced by sudden and fast-reverting spikes. Another extension is suggested by the apparent intra-day switching between positive and negative returns, which may provide support for further development of regime-switching models, and provide support for multiple intra-day markets such as proposed by Guthrie and Videbeck (2002).

References:

Álvaro, E, Peña, J, and Villaplana, P. (2002). “Modelling Electricity Prices: International Evidence”, Economics Working Papers we022708, Universidad Carlos III, Departamento de Economía.

Bunn, D. and Karakatsani, N. (2003). v1, Forecasting Electricity Prices, Working Paper, London Business School.

Bunn D. (2004). Modelling prices in competitive electricity markets, John Wiley & Sons Ltd.

Bystrom, H. (2005). “Extreme Value Theory and Extremely Large Electricity Price Changes”, International Review of Economics and Finance 14, 41-55

Clewlow, L. and Strickland, C. (2000). “Valuing Energy Options In A One-Factor Model Fitted To Forward Prices”. Working paper, University of Sydney.

Davison M., L., Anderson, L., Marcus, B. and Anderson, K. (2002). “Development of a Hybrid Model for Electrical Power Spot Prices”, IEEE Transactions on Power Systems, 17, 2.

de Jong, C. and Huisman, R. (2002). “Option Formulas for Mean-Reverting Power Prices with Spikes”. Working Paper, Erasmus University.

Deng S. (2000). “Stochastic Models of Energy Commodity Prices and their applications: Mean Reversion with Jumps and Spikes”. Working paper, PWP-073, University of California Energy Institute.

Escribano A.J., Peaea J. and P. Villaplana, P. (2002). “Modelling Electricity Prices: International Evidence”. Working paper, Universidad Carlos III de Madrid.

González, A.M., San Roque A.M, and Javier García-González J., (2005”. “Modelling and Forecasting Electricity Prices with Input/Output Hidden Markov Models”, IEEE Transactions on Power Systems, 20, 1.

Goto, M. and Karolyi, G.A. (2004), “Understanding Electricity Price Volatility within and Across Markets.” Dice Centre Working Paper 2004-12, 1-41.

Green, R.J. and Evans, J. (2005). “Why did British electricity prices fall after 1998?” Working Paper, from http://www.ksg.harvard.edu/hepg/

Green R.J. (1999). The Electricity Contract Market in England and Wales. Journal of Industrial Economics, XLVII, 107-124.

Guthrie, G. and Videbeck, S. (2002). “High Frequency Electricity Spot Price Dynamics: An Intra-Day Markets Approach, New Zealand Institute for the Study of Competition and Regulation”.

“Hadsell, L., Marathe, A., and Shawky, H. (2004). “Estimating the volatility of electricity spot prices in the U.S”. The Energy Journal, 25, 4., 23-40

Harris, C. (2003). “Forecasting Higher Moments of the Medium term Power Price Curve using Equilibrium Economics and the Option Value of the Security of Supply.” In Bunn, D.W, (ed). *Modelling Prices in Competitive Electricity Markets*. Wiley

Higgs, H. and Worthington, A.C. (2005). “Systematic Features of High-Frequency Volatility in Australian Electricity Markets: Intraday Patterns, Information arrival and Calendar Effects.” The Energy Journal, Vol 26, No.4

Huisman R. and R. Mahieu, R. (2001). “Regime Jumps In Power Prices.” Working paper, Energy & Power Risk Management.

Johnson and Barz, (1999). “Selecting Stochastic Processes For Modelling Electricity Prices”. *Energy Modelling and the Management of Uncertainty*, Risk Publications.

Kaminski, V. (1997). “The Challenge of Pricing And Risk Managing Electricity Derivatives”. The U.S. Power Market, 149-71.

Knittel C.R. and Roberts, M. (2001). “An Empirical Examination of Deregulated Electricity Prices.” Working paper, PWP-087, University of California Energy Institute.

Lucia, J. and Schwartz, E.S. (2002). “Electricity Prices And Power Derivatives: Evidence From The Nordic Power Exchange”. Review of Derivatives Research, 5, 5-50.

Merton R.C., 1976. “Option Pricing When Underlying Stock Returns are Discontinuous.” Journal of Financial Economics, 3, 125-144.

Stevenson M. (2001). “Filtering and Forecasting Spot Electricity Prices In The Increasingly Deregulated Australian Electricity Market.” Quantitative Finance Research Centre, University of Technology Sydney, Research Paper. Series 63.

Wolack, F. (1997). “Market Design and Price Behaviour in Restructured Electricity Markets: An International Comparison”. Working paper, Program on Workable Energy Regulation, University of California Energy Institute.

Worthington, A., Kay-Spratley, A. and Higgs, H. (2003). “Transmission of Prices and Price Volatility in Australian Electricity Spot Markets: A Multivariate GARCH Analysis.” Working Paper, School of Economics and Finance, Queensland University of Technology.

Table 1: Descriptive Statistics for Spot Price by Region, January 1999 to January 2006.

Spot Price	**NSW1**	**QLD1**	**SA1**	**SNOWY1**	**VIC1**
Mean	34.02	36.65	41.91	31.43	30.19
S.D.	178.11	158.45	155.18	120.72	103.26
Maximum	9909.03	8942.60	8999.98	7500.00	7416.16
Minimum	-3.10	-156.14	-822.45	-3.15	-329.91
Range	9912.13	9098.74	9822.43	7503.15	7746.07
Skewness	35.37	28.56	25.40	37.12	35.38
Kurtosis	1468.54	1058.17	800.35	1663.18	1502.93
JB Stat	89701	46527	26598	115071	93950
ADF Stat*	-41.81*	-43.86*	-353.92*	-352.35*	-42.14*
N	124224	124224	124224	124224	124224

*Augmented Dickey-Fuller (ADF) Statistic rejects the hypothesis of a Unit Root at the 1% level of confidence.

Table 2: Panel (a) Summary of occurrences of extreme price spikes by region, day of week, month and year.

	NSW	QLD	SA	Snowy	VIC	Total
Sun	8	20	11	0	6	45
Mon	22	28	33	1	31	115
Tue	12	36	20	2	19	89
Wed	18	22	26	3	13	82
Thu	8	25	25	0	16	74
Fri	2	19	23	0	7	51
Sat	9	23	19	0	4	55
Total	***79***	***173***	***157***	***6***	***96***	***511***
Jan	5	23	18	0	8	54
Feb	2	9	21	1	7	40
Mar	0	11	16	0	2	29
Apr	0	3	11	0	1	15
May	14	16	13	0	18	61
Jun	21	26	11	2	21	81
Jul	12	26	12	1	13	64
Aug	6	12	8	1	7	34
Sep		3	7	0	7	23
Oct	4	21	13	0	2	40
Nov	7	10	17	0	5	39
Dec	2	13	10	1	5	31
Total	***79***	***173***	***157***	***6***	***96***	***511***
1999	2	28	32	1	3	66
2000	14	50	33	0	19	116
2001	4	14	22	0	11	51
2002	34	55	24	0	34	147
2003	15	13	10	3	13	54
2004	3	8	19	1	5	36
2005	7	4	12	1	6	30
2006	0	1	5	0	5	11
Total	***79***	***173***	***157***	***6***	***96***	***511***

Table 2: Panel (b) Occurrence of Extreme Price Spikes by Half-Hourly Trading Interval (T.I.) 0000hrs to 2330hrs

T.I.	NSW1	QLD1	SA1	SNOWY1	VIC1	Total
H0000	0	0	2	0	0	2
H0030	0	0	1	0	0	1
H0100	0	0	6	0	0	6
H0130	0	0	3	0	3	6
H0200	0	0	1	0	0	1
H0230	0	1	1	0	0	2
H0300	0	1	0	0	0	1
H0330	0	0	1	0	0	1
H0400	0	0	0	0	0	0
H0430	0	0	1	0	0	1
H0500	0	1	0	0	0	1
H0530	0	0	0	0	1	1
H0600	0	0	1	0	1	2
H0630	3	2	5	0	5	15
H0700	5	1	6	1	6	19
H0730	0	12	1	0	0	13
H0800	0	4	1	0	1	6
H0830	0	10	4	0	2	16
H0900	1	4	5	0	2	12
H0930	1	5	0	0	0	6
H1000	1	4	6	0	1	12
H1030	0	2	2	1	0	5
H1100	0	3	3	0	0	6
H1130	0	1	1	0	0	2
H1200	0	3	1	0	0	4
H1230	0	3	6	0	2	11
H1300	2	2	5	0	2	11
H1330	1	3	5	0	3	12
H1400	1	5	6	0	0	12
H1430	3	5	3	0	3	14
H1500	0	0	6	0	2	8
H1530	4	2	12	0	4	22
H1600	1	3	5	0	2	11
H1630	1	5	4	0	2	12
H1700	1	5	7	1	2	16
H1730	11	9	3	0	8	31
H1800	38	38	19	3	37	135
H1830	2	7	5	0	2	16
H1900	0	9	5	0	2	16
H1930	0	3	1	0	1	5
H2000	0	4	3	0	1	8
H2030	0	1	2	0	0	3
H2100	0	0	2	0	0	2
H2130	1	1	1	0	0	3
H2200	0	0	0	0	0	0
H2230	2	7	5	0	1	15
H2300	0	2	0	0	0	2
H2330	0	5	0	0	0	5

Table 3: Descriptive Statistics for Half-Hourly Returns, by Region, January 1999 to January 2006.

Returns	**NSW1**	**QLD1**	**SA1**	**SNOWY1**	**VIC1**
Mean	0.0301	0.0611	0.0603	0.0878	0.0262
S.D.	1.36	1.74	1.68	16.05	1.05
Maximum	231.00	369.24	390.80	4542.50	142.43
Minimum	-222.00	-11.25	-32.94	-220.00	-209.50
Range	453.00	380.49	423.74	4762.50	351.93
Skewness	41.46	111.49	123.00	255.74	-15.41
Kurtosis	15480.38	19122.19	24820.63	66926.22	17959.48
JB Stat	9981513	15233050	25665638	186624152	13434834
ADF Stat	-41.81*	-43.86*	-353.92*	-352.35*	-42.14*
N	124223	124223	124223	124223	124223

*Augmented Dickey-Fuller (ADF) Statistic rejects the hypothesis of a Unit Root at the 1% level of confidence.

Table 4: Panel (a) - Results Of Regression Analysis For Returns Against Seasonal Dummy Variables, By Region For Day, Month Year and Lagged Return [LR(-*n*)].

	NSW1		QLD1		SA1		SNO1		VIC1	
	Coeff	**t-Stat**	**Coeff**	**t-Stat**	**Coeff**	**t-Stat**	**Coeff**	**t-Stat**	**Coeff**	**t-Stat**
C	-0.022	3.168	-0.002	-0.288	0.015	3.718	-0.036	-1.821	-0.018	-1.225
MON	0.022	2.746	0.015	4.074	0.011	2.874	0.033	3.746	0.022	3.305
TUE	0.019	2.584	0.014	3.790	0.009	3.321	0.027	3.138	0.019	2.842
WED	0.018	3.076	0.012	3.092	0.010	3.017	0.026	2.996	0.018	2.796
THU	0.021	2.535	0.014	3.793	0.009	2.339	0.031	3.544	0.019	2.893
FRI	0.018	1.341	0.013	3.330	0.007	-1.133	0.017	1.937	0.017	2.623
SAT	0.009	0.156	-0.001	-0.171	-0.003	0.158	0.010	1.095	0.009	1.312
JAN	0.001	0.169	0.017	3.517	0.001	1.562	-0.003	-0.229	0.004	0.416
FEB	0.002	-0.175	0.010	2.015	0.006	-0.879	-0.001	-0.108	0.004	0.491
MAR	-0.002	0.123	0.023	4.662	-0.004	0.471	-0.008	-0.708	-0.001	-0.090
APR	0.001	0.525	0.003	0.572	0.002	0.970	-0.006	-0.495	0.003	0.368
MAY	0.005	0.712	0.012	2.338	0.004	0.453	0.016	1.427	0.005	0.616
JUN	0.007	0.481	0.015	2.933	0.002	2.222	0.013	1.141	0.007	0.751
JUL	0.004	0.383	0.014	2.763	0.009	1.849	0.020	1.786	0.004	0.506
AUG	0.004	-2.578	0.013	2.539	0.007	0.416	0.004	0.393	0.005	0.534
OCT	-0.024	-0.276	0.007	1.417	0.002	2.010	-0.028	-2.463	-0.022	-2.555
NOV	-0.003	-0.085	-0.001	-0.298	0.008	-0.935	0.001	0.047	-0.002	-0.278
DEC	-0.001	-1.038	0.011	2.230	-0.004	13.269	-0.001	-0.071	0.001	0.064
1999	-0.007	1.960	0.023	6.019	0.041	7.649	-0.009	-1.060	-0.013	-1.953
2000	0.014	1.241	0.036	9.642	0.023	2.091	0.023	2.584	0.008	1.210
2002	0.009	0.049	0.013	3.431	0.006	0.093	0.028	3.163	0.002	0.325
2003	0.000	0.583	-0.008	-2.178	0.000	1.014	0.008	0.955	-0.003	-0.520
2004	0.004	0.425	-0.006	-1.512	0.003	0.840	0.005	0.595	0.002	0.342
2005	0.003	-0.095	-0.007	-1.948	0.003	2.599	0.008	0.890	-0.004	-0.532
2006	-0.002	3.168	-0.008	-0.785	0.021	-1.705	0.056	2.409	0.003	0.186
LR(-1)	0.005	3.430	-0.005	-8.343	-0.007	-14.525	0.001	3.490	0.001	0.339
LR(-2)	-0.006	-4.549	-0.004	-7.215	-0.001	-2.366	-0.001	-1.450	-0.008	-4.671
LR(-3)	-0.006	-4.290	0.000	0.451	0.001	1.624	0.001	0.917	-0.008	-4.554
LR(-4)	-0.002	-1.359	-0.001	-1.515	0.000	-1.019	-0.001	-0.334	-0.003	-1.861
LR(-5)	-0.002	-1.668	0.008	14.547	-0.001	-2.565	0.001	1.413	-0.005	-2.697
R^2	0.768		0.959		0.971		0.997		0.650	
Adj R^2	0.767		0.959		0.971		0.997		0.649	

Note: The equation was initially estimated for each region with 20 lagged returns. F-Tests for redundant variables were performed and for all regions AIC and SBC values indicated that lags 1 through 5 were significant. Lags 6 onwards were not found to be significant and were discarded. Standard tests and residual diagnostics revealed no misspecification in the above model.

Table 4, Panel (b): Results of regression analysis for returns against seasonal dummy variables, by half-hourly trading interval by region, 0000hrs to 1100hrs.

	NSW1		QLD1		SA1		SNO1		VIC1	
	Coeff	t-Stat	Coeff	t-Stat	Coeff	t-Stat	Coeff	t-Stat	Coeff	t-Stat
H0000	-0.101	-5.512	-0.160	-16.236	-0.014	-4.792	-0.095	-4.162	-0.103	-5.957
H0030	-0.059	-3.220	-0.112	-11.408	-0.038	-5.047	-0.062	-2.708	-0.079	-4.545
H0100	-0.064	-3.484	-0.093	-9.452	-0.040	-9.747	-0.067	-2.927	-0.082	-4.732
H0130	0.088	4.798	-0.033	-3.302	-0.078	-23.001	0.108	4.753	0.187	10.828
H0200	-0.109	-5.954	-0.092	-9.367	-0.184	-14.700	-0.112	-4.930	-0.137	-7.931
H0230	-0.082	-4.494	-0.072	-7.269	-0.117	-19.164	-0.090	-3.968	-0.116	-6.694
H0300	-0.065	-3.583	-0.055	-5.615	-0.153	-17.339	-0.073	-3.193	-0.099	-5.702
H0330	-0.068	-3.701	-0.051	-5.192	-0.138	-12.775	-0.072	-3.178	-0.097	-5.615
H0400	-0.039	-2.127	-0.041	-4.175	-0.102	-3.935	-0.042	-1.839	-0.061	-3.548
H0430	0.021	1.170	-0.009	-0.891	-0.031	-0.844	0.021	0.928	0.010	0.587
H0500	0.027	1.493	-0.005	-0.523	-0.007	13.969	0.030	1.311	0.029	1.658
H0530	0.143	7.856	0.054	5.465	0.111	9.022	0.149	6.549	0.160	9.234
H0600	0.077	4.196	0.018	1.784	0.072	21.992	0.090	3.975	0.115	6.628
H0630	0.159	8.707	0.098	9.986	0.176	24.891	0.197	8.648	0.222	12.794
H0700	0.075	4.115	0.117	11.918	0.199	-5.693	0.112	4.927	0.119	6.886
H0730	-0.058	-3.189	0.061	6.144	-0.045	16.938	-0.065	-2.853	-0.059	-3.380
H0800	0.155	8.512	0.134	13.636	0.135	18.225	0.150	6.589	0.175	10.089
H0830	0.106	5.837	0.109	11.051	0.146	3.630	0.108	4.745	0.133	7.695
H0900	0.013	0.702	0.037	3.771	0.029	2.060	0.016	0.710	0.030	1.706
H0930	0.066	3.614	0.059	5.970	0.016	-2.159	0.064	2.818	0.073	4.238
H1000	-0.002	-0.107	-0.026	-2.595	-0.017	-4.940	-0.001	-0.042	0.004	0.234
H1030	-0.001	-0.061	-0.023	-2.315	-0.039	-1.471	0.000	0.000	0.003	0.165
H1100	0.014	0.782	-0.021	-2.161	-0.012	-1.174	0.018	0.781	0.015	0.888
H1200	0.011	0.591	-0.007	-0.733	-0.009	1.394	0.010	0.433	0.007	0.383
H1230	0.023	1.275	-0.023	-2.302	0.011	-0.265	0.022	0.957	0.017	0.960
H1300	0.003	0.171	-0.022	-2.243	-0.002	-0.237	0.013	0.570	0.000	0.024
H1330	0.043	2.345	0.015	1.553	-0.002	-0.584	0.048	2.093	0.043	2.476
H1400	-0.002	-0.131	-0.014	-1.410	-0.005	-5.036	0.010	0.444	-0.005	-0.292
H1430	0.005	0.276	0.001	0.054	-0.040	-3.295	0.008	0.346	-0.007	-0.380
H1500	-0.005	-0.277	-0.040	-4.015	-0.026	-4.681	0.035	1.518	-0.001	-0.077
H1530	0.002	0.092	-0.012	-1.225	-0.037	-1.311	0.027	1.169	-0.005	-0.282
H1600	0.017	0.931	0.001	0.140	-0.010	-5.028	0.032	1.401	0.020	1.138
H1630	-0.011	-0.601	-0.008	-0.824	-0.040	0.033	-0.002	-0.082	-0.007	-0.390
H1700	0.029	1.580	0.044	4.423	0.000	4.446	0.039	1.701	0.035	2.018
H1730	0.085	4.665	0.113	11.442	0.035	20.313	0.100	4.414	0.068	3.930
H1800	0.239	13.053	0.277	28.041	0.162	8.455	0.426	18.718	0.203	11.700
H1830	0.057	3.134	0.079	8.008	0.068	-5.077	0.071	3.099	0.058	3.361
H1900	-0.024	-1.305	0.038	3.855	-0.041	-13.074	-0.024	-1.041	-0.024	-1.363
H1930	-0.082	-4.486	-0.106	-10.737	-0.104	-5.919	-0.079	-3.485	-0.074	-4.292
H2000	-0.048	-2.614	-0.059	-6.014	-0.047	-8.711	-0.041	-1.823	-0.033	-1.904
H2030	-0.037	-2.006	-0.120	-12.172	-0.070	-10.730	-0.032	-1.392	-0.032	-1.822
H2100	-0.068	-3.726	-0.088	-8.901	-0.086	-6.199	-0.063	-2.763	-0.067	-3.888
H2130	-0.002	-0.124	-0.052	-5.326	-0.049	-12.484	0.004	0.182	-0.026	-1.509
H2200	-0.091	-4.967	-0.091	-9.247	-0.100	6.279	-0.087	-3.814	-0.101	-5.818
H2230	0.192	10.521	0.146	14.823	0.050	-7.983	0.193	8.499	0.139	8.054
H2300	-0.069	-3.807	-0.076	-7.761	-0.064	16.893	-0.064	-2.816	-0.067	-3.856
H2330	0.189	10.342	0.122	12.376	0.135	2.118	0.208	9.158	0.298	17.225

Figure 1: Plot of VIC1 price for the month of April 2000, illustrating the occurrence of an extreme negative price spike at 12:30a.m. on April 15, 2001

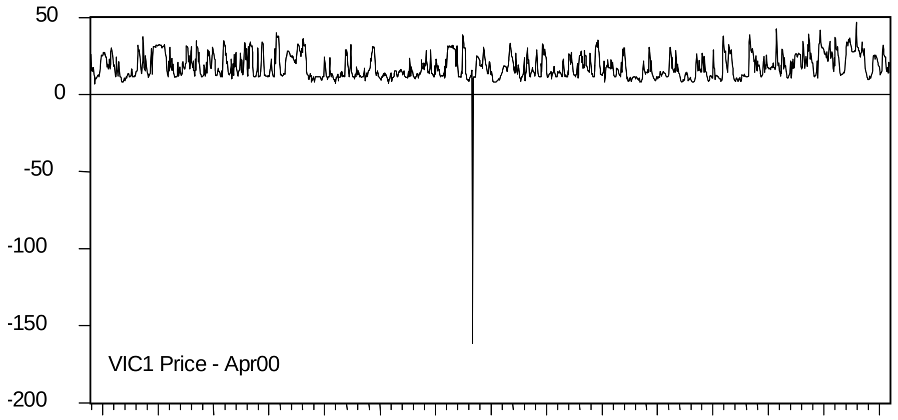


Figure 2: Plot of VIC1 price for the period 28/8/00 to 31/8/00, illustrating the occurrence of extreme spikes in the price series.

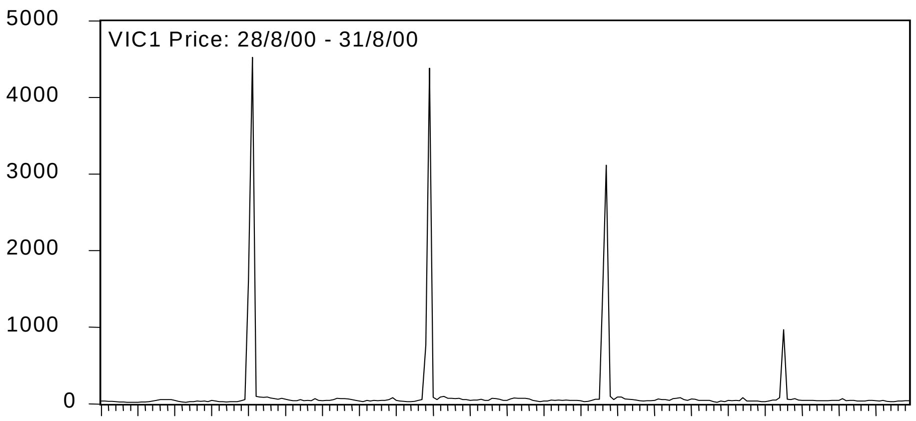


Figure 3: Plot of VIC1 Price and Returns for the 10-day period 16/8/2000 to 26/8/2000. Price is in A$/MWh and returns are percentage returns.

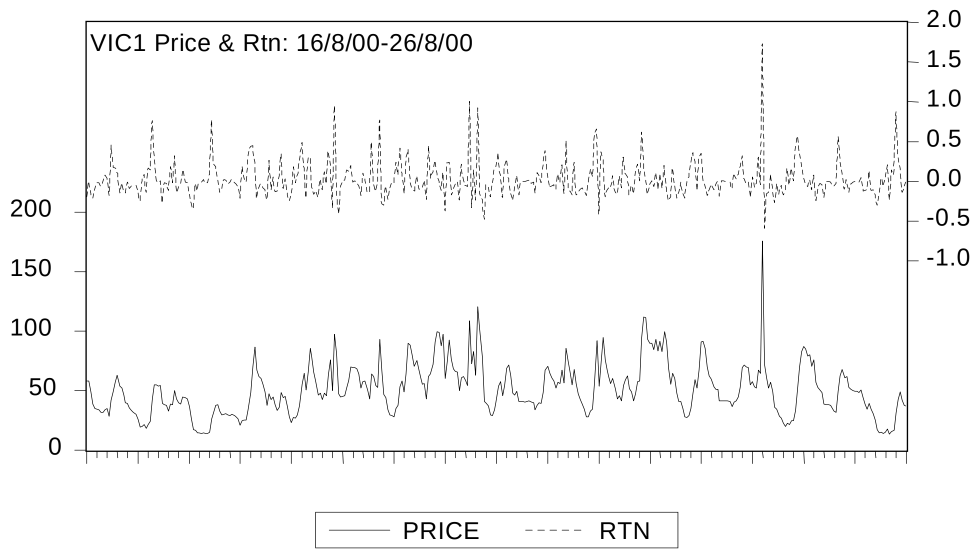
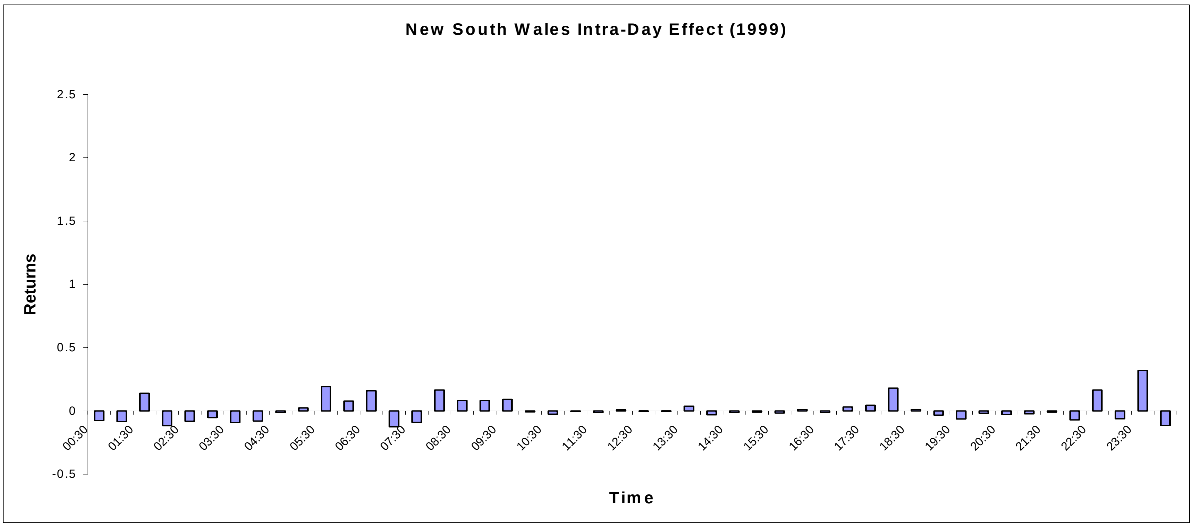
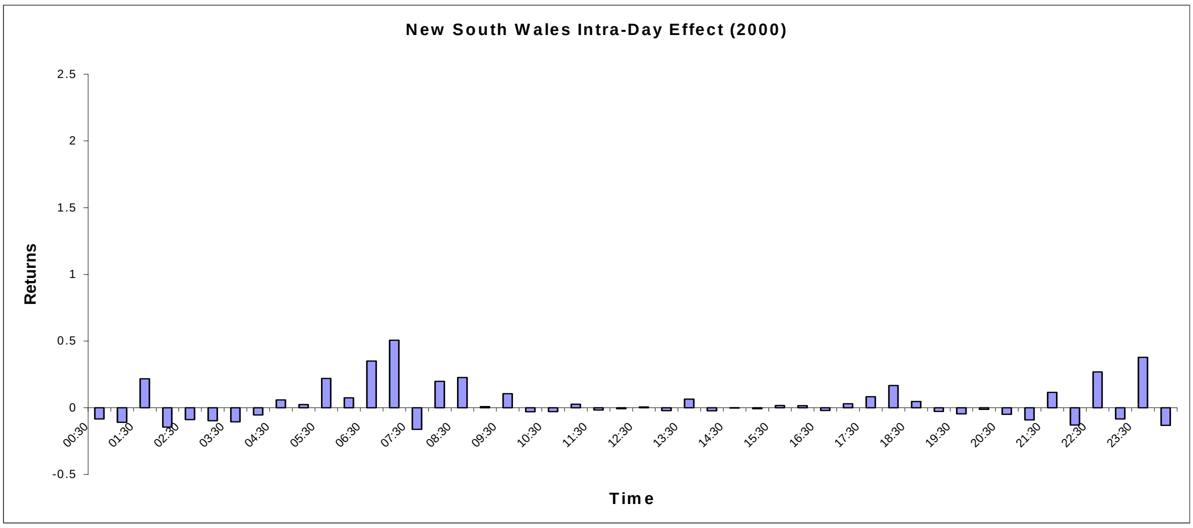
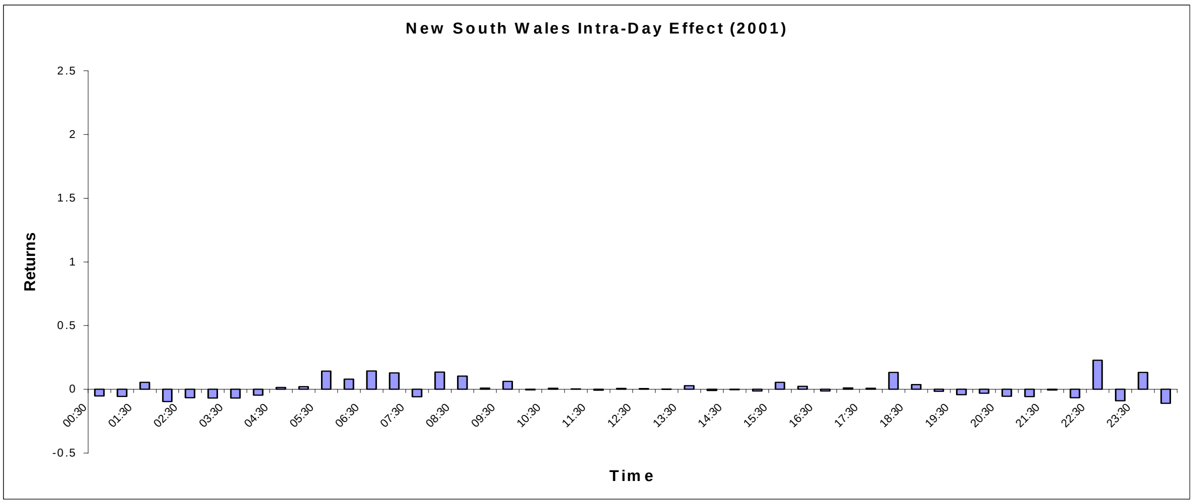
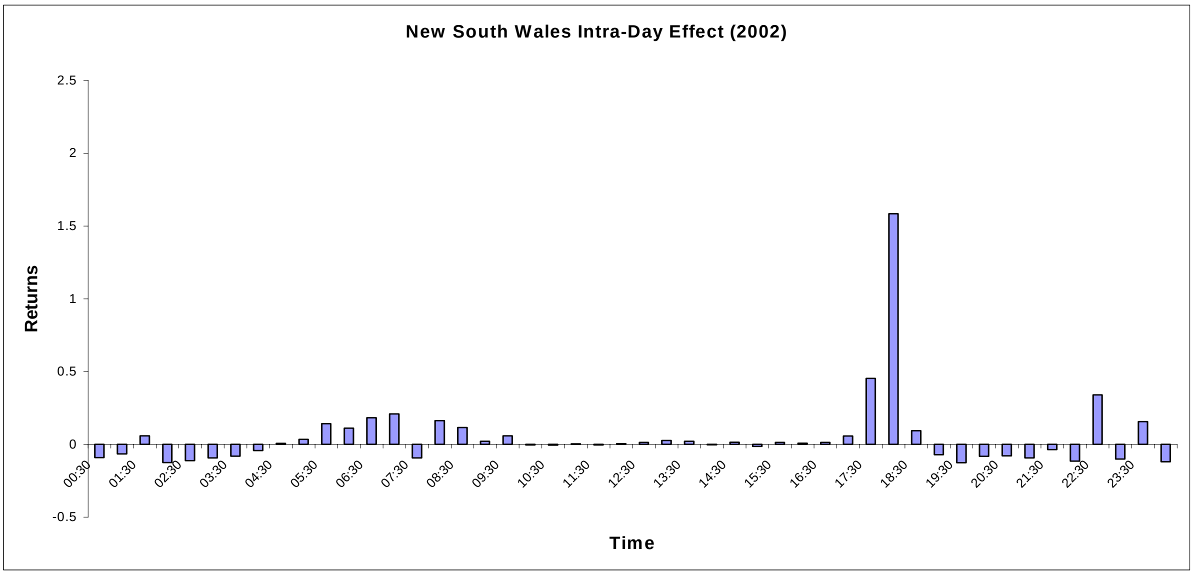


Figure 4: Half-Hourly returns for NSW1 for the years 1999-2005, illustrating the transient nature of the observed 6:00pm effect








New South Wales Intra-Day Effect (2002)
Returns
Time
2.5
2
1.5
1
0.5
0
-0.5
00:30
01:30
02:30
03:30
04:30
05:30
06:30
07:30
08:30
09:30
10:30
11:30
12:30
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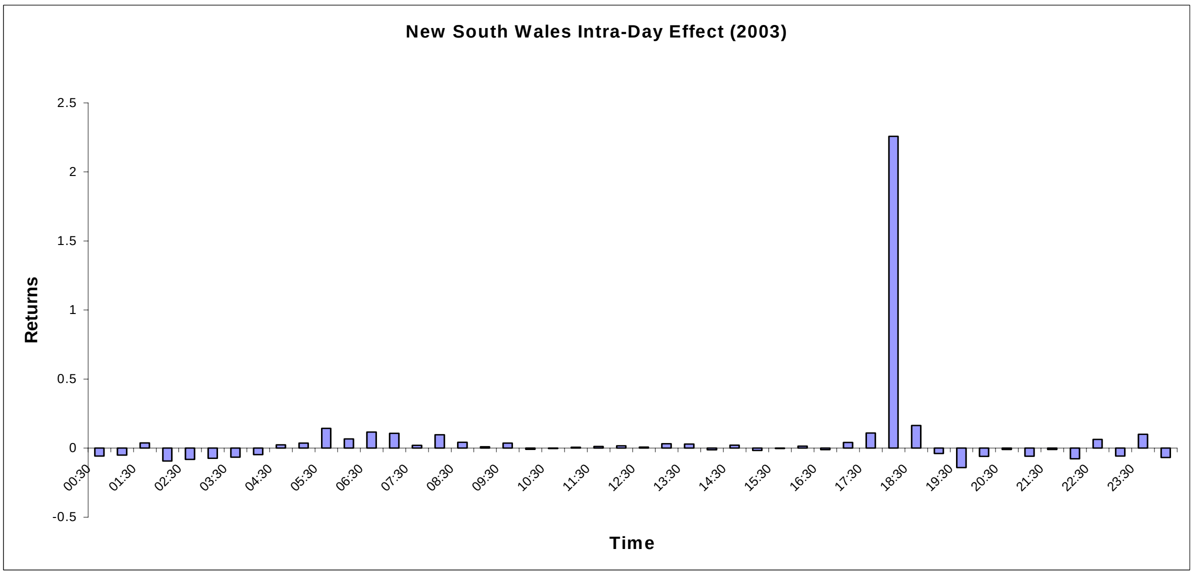
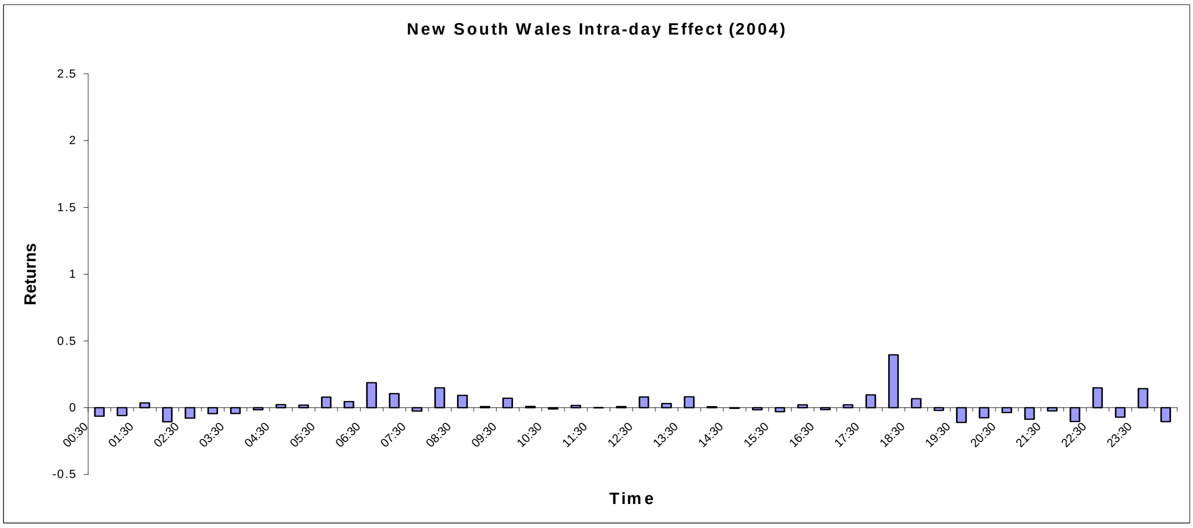
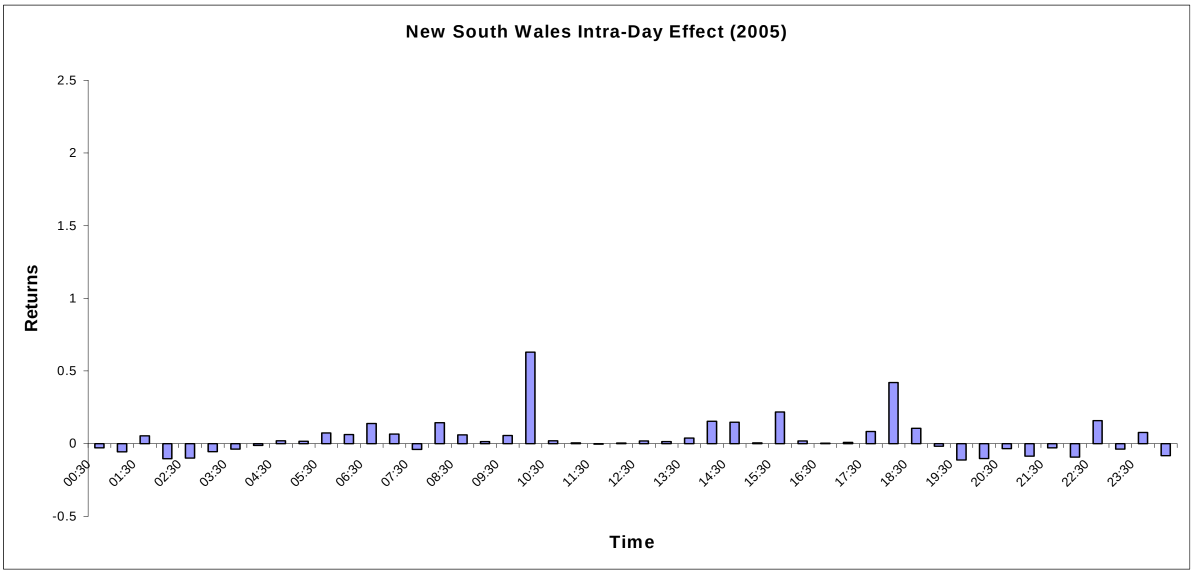
21:30
22:30
23:30


New South Wales Intra-Day Effect (2003)
Returns
Time
2.5
2
1.5
1
0.5
0
-0.5
00:30
01:30
02:30
03:30
04:30
05:30
06:30
07:30
08:30
09:30
10:30
11:30
12:30
13:30
14:30
15:30
16:30
17:30
18:30
19:30
20:30
21:30
22:30
23:30


New South Wales Intra-day Effect (2004)
Returns
Time
2.5
2
1.5
1
0.5
0
-0.5
00:30
01:30
02:30
03:30
04:30
05:30
06:30
07:30
08:30
09:30
10:30
11:30
12:30
13:30
14:30
15:30
16:30
17:30
18:30
19:30
20:30
21:30
22:30
23:30


New South Wales Intra-Day Effect (2005)
Returns
2.5
2
1.5
1
0.5
0
-0.5
00:30
01:30
02:30
03:30
04:30
05:30
06:30
07:30
08:30
09:30
10:30
11:30
12:30
13:30
14:30
15:30
16:30
17:30
18:30
19:30
20:30
21:30
22:30
23:30
Time