Characterizing the Volatility of Wholesale Electricity Spot Prices in Australia

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Abstract

Understanding the volatility dynamics of electricity markets is important in evaluating the deregulation experience and in pricing electricity futures. This paper introduced an approach to portray the volatility of electricity price. We first introduced the Integrated Volatility (IV) and Quadratic Variation (QR) theory to define the volatility. Based on the theories, two non-parametric methods, i.e. Classical Realized Volatility (RV) and Realized Bi-power Volatility (RBV) were adopted to respectively measure the electricity price volatility with half-hour resolution in High-Frequency (HF) environment, using historical data from Victoria, Australia. By comparing the characterizing performance, the RBV method exhibited more superior effect. Next, the paper separated the total volatility into jump and continuous components based on Z jump test and the distinct dynamics of the Jump Volatility (JV) and Continuous Volatility (CV) were also analyzed.

Keywords: Electricity price volatility; realized volatility; electricity energy market

1. Introduction

The recent deregulation of the electricity utility industry has created wholesale market that exhibit levels of volatility unparalleled in traditional commodity market. The implication for evaluating electricity price volatility dynamics should be more profound than estimation of electricity price itself for investment and political decisions. For example, Bessembinder and Lemmon [1] asserted that future prices for electricity are a function of expected spot price and volatility. To this purpose, effective model for characterizing the electricity price volatility must be developed. Traditional methods that were employing parametric models e.g. Auto-Regressive Moving Average model (ARMA), Auto-Regressive Conditional Heteroskedasticity model (ARCH), Generalized ARCH model (GARCH), other GARCH-type models and Stochastic Volatility Models (SVM) usually utilize Low-Frequency (LF) daily or weekly data samples, which have difficulties completely reflecting the actual undulation of the electricity price. With the establishment of High-Frequency (HF) information environment, the measurement of volatility under HF situation has become the forward direction in this regard. Building on the influential work of Andersen and Bollerslev [2], many studies adopt the Realized Volatility (RV) measures often used for stock prices and interest rates to model the electricity spot price under HF situation. Other scholars modified and expanded the classical RV method to Realized Bi-power Volatility (RBV) method. Since the application of realized measures on the issue of electricity price volatility under HF situation is still in its infant period, this paper intends to implement this work to provide foundation for future work.

2. Methods

2.1 The integrated volatility and quadratic variation theory

The original theory of price volatility measurement in HF situation is Integrated Volatility (IV), which can be regarded as the continuous integration of instantaneous volatility rate in a very small time interval as Eq. (1).

\[ IV_t = \int_0^t \sigma^2(s) ds \]  

(1)

where \( \sigma(s) \) is the instantaneous volatility rate, \( t \) denotes the time period.

The basic idea of IV is that electricity price conforms to a continuous diffusion process, which can be expressed as:

\[ dp(t) = \mu(t) dt + \sigma(t) dW(t) + \kappa(t) dq(t) \]  

(2)

where \( p(t) \) denotes the spot price of electricity, with the assumption that the price process is governed by a continuous-time stochastic-volatility model with an additive jump component. \( \mu(t) \) and \( \sigma(t) \) are the drift and instantaneous volatility. \( W(t) \) is a standard Wiener process, and \( q(t) \) is a Poisson counting process, with \( dq(t)=1 \) if there is a jump at time \( t \) and zero otherwise. The time-varying intensity of the arrival process for the jumps is denoted by \( \lambda(t) \), while \( \kappa(t) \) represents the corresponding jump size at time \( t \) if \( dq(t)=1 \).

When the data are sampled at a sufficiently high frequency, it is reasonable to assume that the drift of Eq.

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(2) is negligible. Therefore, the Quadratic Variation (QV) of the cumulative return process is given by:

\[
QV_t = \int_0^t \sigma^2(s) ds + \sum_{t=1}^{\infty} k^2(s) \tag{3}
\]

The above provides a brief overview of quadratic (QV) theory.

Note that, in the absence of jumps, the summation term (the sum of the squared jumps) in Eq. (2) is zero, in which case the QV is simply the IV of the continuous sample path process, i.e. \( IV_t = \int_0^t \sigma^2(s) ds \).

2.2 The volatility measures of realized volatility and realized bi-power volatility

To provide the analytical solution of the IV, the sum of the squared intraday returns can be regarded as the estimate of the volatility of the day \( t \), which is named as the Realized Volatility (RV) calculated by Eq. (4):

\[
RV_t = \sum_{j=1}^{M} \tau_{ij}^2 \tag{4}
\]

where \( \tau_{ij} \) is the intraday return, which refers to the logarithmic return rate of electricity price series. This paper assumes that the availability of electricity prices samples over a period is \( T \) days and prices are sampled \( M \) times per day at equally-spaced intervals. Accordingly, the intraday returns for day \( t \) are:

\[
\tau_{ij} = \ln p_{ij} - \ln p_{ij-1}, j = 1, ..., M, t = 1, ..., T \tag{5}
\]

where \( i \) refers to the day, and \( j \) denotes the time node on day \( i \). \( p_{ij} \) is the electricity price at this time. \( p_{ij-1} \) is the price at the previous time.

Barndorff-Nielsen and Shephard (BNS) [3] show that, as the frequency of intraday sampling \( M \) increases: (i) when there are no jumps of the electricity price, the \( RV_t \) converges to the \( IV_t \). Here, \( RV_t \) is an unbiased estimator of \( IV_t \); (ii) when there exist jumps, the \( RV_t \) converges to \( QV_t \). To solve the interference of jumping discontinuities on volatility measurement in price fluctuations, which comes from the finite active Level-Dimension process expressed as the diffusion factor \( \kappa(t) dq(t) \) in Eq. (2), the Realized Bi-power Volatility (RBV) method was first proposed by BNS, defined as:

\[
RBV_t = \frac{1}{\mu_t^{(1-2/M)} \sum_{j=1}^{M} \tau_{ij}^2 |\tau_{ij-2}|} \tag{6}
\]

where \( \mu_t = E[Z] = \sqrt{2/\pi} \), and \( Z \) denotes a standard Normal random variable. Eq. (6) comprehensively considers the impact of jump discontinuities, which can better depict the electricity price volatility under the interference of market microstructure noise. In the case of large fluctuation range, the performance of RBV is more stable and effective.

2.3 The decomposition of realized volatility

As is mentioned, as the frequency of intraday sampling \( M \) increases, the \( RV_t \) converges to the \( QV_t \), while the \( RBV_t \) converges to \( IV_t \). Similarly, the difference \( RV_t - RBV_t \) converges to \( QV_t - IV_t \), thereby providing a consistent estimator of the discontinuous jump component of the total variation in return. Under the null hypothesis of no jumps, the difference between the RV and RBV is asymptotically zero. However, in any given finite sample, \( RV_t - RBV_t \) may differ from zero due to sampling variation. Accordingly, a test statistic is employed to identify the presence of a significant jump on day \( t \). Huang and Tauchen [4] suggest the following test statistic:

\[
Z_t = \frac{(RTQ_t - RBV_t)}{RV_t} \tag{7}
\]

where

\[
RTQ_t = \mu_t^{-3} \frac{M^2}{M-4} \sum_{j=1}^{M} \frac{1}{|\tau_{ij-4}|}^{4/3} |\tau_{ij-2}|^{4/3} |\tau_{ij}|^{4/3} \tag{8}
\]

The ratio in the numerator of Eq. (7) measures the contribution (if any) of jumps to the total within-day variance of the process. Under the asymptotic distribution theory developed by BNS, \( Z_t \) converges to a standard Normal variable as \( M \to \infty \). The Z test statistic is calculated on each day \( t \), and a jump is identified if \( Z_t \) exceeds the critical value \( \Phi_{1-\alpha} \) of the standard Normal distribution. For a chosen level of significance \( \alpha \), the day \( t \) jump component of volatility \( JV_t \) is identified by:

\[
JV_t = I_{(Z_t > \Phi_{1-\alpha})}(RV_t - RBV_t) \tag{9}
\]

Viewing \( RV_t \) as the total realized variation and \( JV_t \) as the jump component of realized variation, all that remains is to estimate the continuous component of the total variation which is named continuous volatility (CV) as:

\[
CV_t = RV_t - JV_t \tag{10}
\]

3. Results

Australia is one of the few countries in the world that have completed the reform of the electricity market. The market openness and maturity of Victoria state are also rare in the world. This paper utilizes electricity spot prices from the power markets operating in Victoria state. The sample consists of continuously recorded 30-minute spot prices from Dec. 8th, 1998 to May 31, 2019.

The following Fig. 1-4 show the electricity price series and electricity price return series using data in 2010.

![Fig.1 Electricity price \( p_{ij} \) in 2010 with extreme noise.](image)

![Fig.2 Electricity price \( p_{ij} \) in 2010 getting rid of extreme noise.](image)
Fig. 3 Electricity price return $r_{i,j}$ in 2010 with extreme noise.

Fig. 4 Electricity price return in 2010 getting rid of extreme noise.

Since the fluctuation of electricity price value are large, the logarithmic return rate of electricity price is employed to reduce the fluctuation value and eliminate the non-stationarity of some certain processes. The return rate of price has the characteristics of stability, ergodicity and better statistics nature, and is a suitable index to measure volatility.

Actually, the time series analysis model generally requires the random variable be second-order moment stationary. While the price sequence is usually generalized Wiener process, where the second-order moments of this process are not stable and many models are not applicable, so we need to log-transform it into a stable sequence.

### 3.1 Result of realized volatility and realized bi-power volatility

The two kinds of volatility RV and RBV calculated using data from 08/12/1998-31/05/2019 were shown as Fig. 5 and Fig. 6.

Comparing Fig 5 and 6, from a holistic perspective, the volatile trend and overall characteristics of electricity price volatility described by the RBV method are similar to those obtained by RV methods.

But there are also discrepancies, the volatile amplitude of RBV is significantly smaller than that of RV. This is because there are several jump discontinuities in the electricity price process, which are related to market microstructure such as discontinuous trading and inquiry-quotation difference, while the RV method is based on the efficient market hypothesis that electricity price follows a continuous process.

In fact, the electricity price fluctuation is closely related to normal operation (investors’ experience habits) and abnormal operation (irrational trading behavior). The lack of historical information, frequent short-term transactions, trading quotations deviating from normal values that result in bid-ask spreads, will lead to discontinuous changes and noise in future electricity prices. The RBV has the capability in response to this noise and shows its advantage in electricity price measurement, which is proved in the case. Comparatively, the RBV is the effective IV estimator, especially when there are obvious jumps during the changing process of the return.

To measure the effect of the above methods more accurately, the descriptive statistics of RV and RBV are compared and analyzed in Table 1.

<table>
<thead>
<tr>
<th>Volatility</th>
<th>Average</th>
<th>Standard deviation</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>RV</td>
<td>2.2841</td>
<td>6.0706</td>
<td>11.4572</td>
<td>232.2834</td>
</tr>
<tr>
<td>RBV</td>
<td>1.7962</td>
<td>4.1361</td>
<td>9.7574</td>
<td>157.6405</td>
</tr>
</tbody>
</table>

It is observed that the skewness and kurtosis of RBV are both much smaller than RV, indicating the volatility calculated using RBV is closer to normal distribution, which shows the superiority of RBV to characterize the volatility than RV.

### 3.2 Analysis of jump component and continuous component of realized volatility

This section checks the jump test statistics $Z_t$ and decompose the RV into jump component and continuous component, which is given in Fig. 7 and Fig. 8.
The jump volatility (JV) of electricity price

Fig. 7 The jump volatility (JV) of electricity price

Also, the ‘jump or not’ and jump magnitude was calculated. The descriptive statistics of these variables are given then, as given in Table 2.

Table 2 Basic statistics analysis of the various volatility variables (Continuous volatility, jump volatility, ‘jump or not’, jump magnitude)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Jump volatility</th>
<th>Continuous volatility</th>
<th>'jump or not'</th>
<th>Jump magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of samples</td>
<td>7479</td>
<td>7479</td>
<td>7479</td>
<td>2095</td>
</tr>
<tr>
<td>Average</td>
<td>0.4555</td>
<td>1.8285</td>
<td>0.2801</td>
<td>1.6261</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>3.1096</td>
<td>4.1789</td>
<td>0.4490</td>
<td>5.7120</td>
</tr>
<tr>
<td>Skewness</td>
<td>19.6241</td>
<td>9.4518</td>
<td>0.9795</td>
<td>10.6919</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>648.1116</td>
<td>148.6810</td>
<td>-1.0408</td>
<td>192.6141</td>
</tr>
</tbody>
</table>

From Table 2, it can be seen that (1) the average of JV and CV is 0.4555 and 1.8285, respectively, which indicates that the CV is obviously small to the JV. And it is the continuous component that mainly constitute the RV of every trading day. (2) The skewness of JV and CV is 19.6241 and 9.4518, while the kurtosis of JV and CV is 648.1116 and 148.6810, separately, revealing that these two sequences exist right-skewed and spike phenomenon. (3) The jump times is 2095, accounting for about 28.01% of the total samples, which exhibits the frequency of RV jumping is relatively high, which may be caused by various reasons, e.g. the introduction of renewable energy generation, the fluctuation of the consumed electricity (demand), etc. (4) The average of jump magnitude is relatively small in comparison to that of RV. Also, the jump magnitude shows right-skewed and spike phenomenon.

4. Conclusion

Characterizing volatility of electricity spot price has significant implications for evaluating the transaction income and risk and in assessing the deregulation experience. This paper proposed approaches, i.e. Realized Volatility (RV) and Realized Bi-power Volatility (RBV) to estimate electricity price fluctuation. To this purpose, this paper introduced intraday return to provide a feasible analytical solution for the integrated volatility. The inclusion of intraday return simplified the calculation of volatility. Results show that RBV has better performance for characterizing electricity price than RV. Based on the calculated RV and RBV, the RV was further decomposed as continuous and jump component. The descriptive statistical characteristics of the various variables offers more understanding about the volatility.

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Reference