THE EFFECT OF MACROECONOMIC ANNOUNCEMENTS AND RESERVE BANK INTERVENTION ON THE JUMP AND CONTINUOUS COMPONENT OF FOREIGN EXCHANGE REALISED VOLATILITY: THE CASE OF AUSTRALIA AND UNITED STATE

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Abstract

The paper investigates the effects of the Australia and U.S. macroeconomic announcements and Reserve Bank of Australia intervention on the jump and continuous component of USD/AUD exchange rate volatility during 1999-2002. Using the realised volatility and bipower variation, we disintegrate exchange rate volatility into 2 majors components: the continuous component and the jump components. The result indicates that there is the sign asymmetric effect by the Reserve Bank of Australia intervention on USD/AUD volatility. Only the buy of the Australian dollar is associated with an increase in both jump and continuous component of USD/AUD volatility. The result of macroeconomic announcement shows that most of the Australian announcement increase jump and continuous component of the exchange rate volatility while only few of U.S. macroeconomic announcement affect the USD/AUD exchange rate volatility. I also find that the degree of unanticipation of the announcement affects the size of the jump and continuous component. Finally, there are evidence of asymmetric effect between a good news and bad news from macroeconomic announcement on the jump and continuous component, however it is unclear which directions result in higher volatility.

Keywords: Bipower variation; Continuous component; Exchange rate intervention; Jump component; Macroeconomic announcement; Realised volatility
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1) Introduction

In this chapter, we analyse the effect of Reserve Bank of Australia intervention and Australain and U.S. Macroeconomic announcement on the USD/AUD exchange rate volatility during Jan-1999 until Dec-2002 using the "realised volatility" technique.

There are numbers of econometric models that have been introduced to estimate the volatility of the asset price e.g., GARCH model, stochastic volatility model and implied volatility. Each approach has their own advantage and at the same time, being criticised on their distinct weaknesses.

Follow Andersen, Bollerslev, Diebold and Labys (2001) (henceforth ABDL) we use the realised volatility as a measure of daily exchange rate volatility. The realised volatility uses the high frequency intra-day data to calculate the daily asset return volatility. The advantage of the realised volatility is that it is model free estimate. Also it only contains with small measurement error which ABDL(2001) states that for practical purposes this realised volatility can be treated as observed[1]. Moreover, Barndorff-Nielsen & Shephard (2004) (henceforth BNS) offer a "bipower variation" which also utilises the use of high frequency intra-day data and have similar property as the realised volatility as an alternative way to calculate volatility. BNS(2004) also suggests that by the use of realised volatility and bipower variation they are able to disintegrate the volatility into two major components: the jump component and the continuous component. Under the content of realised volatility, the continuous component of volatility could be recognised as a bound of exchange rate volatility movement while the extra movement of volatility that goes beyond the bound of continuous component is recognised as the jump component. This disintegration of volatility allows a greater depth in the exchange rate volatility analysis.

The effect of foreign exchange intervention on exchange rate volatility has been studied for a long time in various approaches. Most literatures find that intervention typically increases exchange rate volatility[2]. The most frequent used approaches include GARCH model and implied volatility. This chapter use the

[1] Author also show on how good is the realised volatility and bipwer variation as a volatility measurement in the appendix.

[2] The useful articles on the effect of intervention on exchange rate volatility include Baillie and Osterberg (1997), Bonser-Neal and Tanner (1996), Dominguez (1998), Dominguez (2006), Humpage (2003) and Kim, Kortian and Sheen (2000)

realised volatility and bipower variation approach to examine the effect of the Reserve Bank of Australia (RBA) intervention on USD/AUD exchange rate volatility in term of continuous and jump component of volatility.

Generally, the continuous component of exchange rate volatility reflects the amount of market activity. If the Reserve Bank intervention affects the exchange rate market, the continuous component of the exchange rate volatility should increase due to an increase in market activity and uncertainty. The jump component of exchange rate volatility reflects the large volatility movement that exceed to average daily movement of volatility. It is possible that this large volatility movement reflect the reaction of market agent during the time that intervention news hit the market. Normally, the Reserve Bank intervention operation is not publicly announced, at least during the time of intervention. However, there are evidences that some market agents are able to detect the intervention activity by the Reserve Bank (Dominuguez 2003a). Therefore the jump could possibly reflect the reaction of some big trader in the foreign exchange market.

After the availability of high frequency intra-day exchange rate data, the effect of macroeconomic announcement on exchange rate volatility has been a subject to many studies since early 1990s,. The early studies use different type of econometric model, including the GARCH and EGARCH models (Kim 1999), to investigate the effect of macroeconomic announcement on exchange rate volatility. In this chapter, the realised volatility and bipower variation are used as the volatility measurement. The disintegration of volatility into the jump and continuous component allow deeper analysis on the effect of macroeconomic announcement on exchange rate volatility. Since the macroeconomic announcement is publicly available, it is possible that there would be a jump of exchange rate volatility during the moment that macroeconomic announcement is released, while the continuous component would represent the market activity before and after the moment of announcement.

The effects of macroeconomic announcement and intervention on exchange rate volatility are analysed by two main approaches. First approach uses the summary statistic of the jump and continuous component (which derives from the realised volatility and bipower variation) to find the effect of the announcement and intervention on the exchange rate volatility. Second approach uses the econometric regression to investigate the effect of the announcement and intervention on exchange rate volatility. Many literatures suggest the possibility that the effect of macroeconomic announcement and intervention on exchange rate volatility could be asymmetric(Andersen, Bollerslev, Diebold and Vega 2003). Hence the asymmetric effect of the announcement and intervention is also investigated in both approaches.

Finally, we evaluate how well the realised volatility and bipower variation are as a measure of volatility. The popular GARCH model is used to estimate the exchange rate volatility model. The realised volatility, bipower variation and the tradtional ex-post volatility measure, “daily square return” are used to compare the performance in tracking the GARCH model.

The paper is structured as follows. Section 2 mentions the literature review of the effect of macroeconomic announcement and intervention on exchange rate volatility as well as the extraction of jump and continuous component. Section 3 shows the theoretical framework of realised volatility, bipower variation and the extraction methodology of the jump and continuous component of volatility. Section 4 reports the result of the summary statistic of the jump and continuous component. Section 5 reports the result of the regression analysis of realised volatility on macroeconomic announcement and Reserve Bank intervention. Section 6 evaluates performance of the realised volatility and bipower variation in explaining the exchange rate volatility model. Section 7 concludes.

2) Literature review

2.1) Extraction of jump component and continuous component

The extraction procedure of the jump component from the continuous process is the combined technique between the realised volatility and realised bipower variation. Therefore, it is good idea to review the background of these two techniques.

The realisations of applying high frequency data to improve the measure of asset price volatility have long been mentioned. Among others, Merton (1980) and French, Schwert, and Stambaugh (1987) used the data on the daily measurement basis to estimate the monthly standard deviation and suggest that by sampling the data process more frequently, it improves the accuracy of the standard deviation. Recently, Andersen and Bolleslev (1998a) illustrate the benefit of using intra-day high frequency data in daily volatility estimation. They state that the ex-post squared return volatility (measured on daily basis) which is used as the proxy of the ex-post volatility contains large measurement error and perform poorly when it is used to model and forecast volatility. Instead, Andersen and Bolleslev (1998a) impose a new technique which calculates the daily volatility by cumulating the intra-day square return. They find that the daily volatility that are calculated from the intra-day high frequency data reduce large proportion of the measurement errors in the volatility model. Moreover, they show that the predictive power of the volatility model significantly improve when the ex-post volatility is computed from the cumulative square return of the high frequency data.

Following the work of Andersen and Bolleslev (1998a), ABDL (2001) introduce the concept of realised volatility. ABDL(2001) states that realised volatility is the technique that uses the intra-day high frequency asset price data to construct the model-free estimates of daily asset price volatility with the assumption that there is no jump in the stochastic model. Note that this assumption is critical for the realised volatility in order to converge to the integrated volatility. The realised volatility is approximately free of measurement error under general conditions, hence the volatility that derive from realised volatility can be treated as an observation instead of latent variable.

ABDL (2001) uses 5-minute DM/USD and Yen/USD exchange rate returns to compute the realised volatility for the duration of 10 years. They find that the distribution of realised daily variance, standard deviation and covariances are skewed to the right and leptokurtic. Interestingly, they find that the distribution of logarithmic standard deviation and correlations are approximately normal. The volatility of the realised volatility is found to be highly persistent. The realised volatility does not have an evidence of unit root and appear to be fractionally integrated with a very slowly mean-reverting process. These results of ABDL(2001) are empirically confirmed by ABDL (2003) who models and forecasts realised volatility using 30-minute interval exchange rate data involving DM/USD, Yen/USD and Yen/DM.

The bipower variation is introduced by Barndorff-Nielsen & Shephard (2004). It is the alternative way to construct the model free estimator of daily integrated variance in stochastic volatility models using the intra-day high frequency data. The most important characteristic of the bipower variation is that this estimator is robust to the presence of the jump which implies that theoretically bipower variation can efficiently estimate the integrated volatility even when there are jumps in the series. This robustness of jump is what separate the realised volatility by ABDL(2001) from bipower variation by BNS(2004). BNS(2004) uses the fact that the realised volatility are different from bipower variation to extract the jump component from the asset pricing volatility. In short, BNS(2004) states that since realised volatility is not robust in the presence of jump while bipower is, the difference between these two estimators should equivalent to the jump component.

2.2) Macroeconomic announcements, conditional volatility and jumps

The way that macroeconomic announcement affect exchange rate is in line with the definition of the jump component where Huang (1985) defines the continuous component in stochastic volatility process by using the concept of information structure and equilibrium asset prices such that "a continuous information structure is one on which no events can take us by surprise" (Huang (1985), P.60) and Johannes (2004) uses Huang(1985) argument and states that "jumps are precisely the events that take market participants by surprise"(Johanne (2004), P.229) thus, jump component is the market reaction to the surprise information and possibly cause the discontinuity in the volatility model. So if the macroeconomic announcement surprises the market, it should affect the exchange rate volatility via the form of the jump component while the most likely moment that the macroeconomic announcement would surprise the market is during the short interval after the information of macroeconomic announcement is released.

Many empirical study the effect of announcements on volatility in financial markets, such as the exchange rate, bonds, and stock markets[3]. For example, Andersen and Bollerslev (1998b) use the 5-minute interval data from DM/USD between the period of Oct 1992-Sep 1993 to investigate the effect of US and Germany macroeconomic announcements on the volatility of DM/USD foreign exchange market. They found that the macroeconomic announcements have large impact on the exchange rate volatility. When news hit the market, there are evidences of significant instantaneous jumps in volatility. They also found that the impact of the arrival of announcements is short lived and the impact of announcements on volatility at the daily level is small.

BNS(2006) investigate the effect of news on exchange rate volatility by separate the jump and continuous component of DM/USD and Yen/USD exchange

[3]Among others, the work on bond market includes Balduzzi, Elton and Green(2001), Li and Engle (1998), Fleming and Remolona (1997) and Jones, Lamont and Lumsdaine (1998), work on stock market includes Bomfim (2003), Boyd, Jagannathan and Hu(2005) and Schwert (1989)

rate volatility. Their result suggests that there are statistical evidences which support the existence of the jumps in the exchange rate series. Interestingly, they illustrate two different days that contain similarly large value of realised volatility. The first set of observation contains a significant large jumps in the realised volatility series while another set of observation contain no significant jump component in the realised volatility. They found that there was a major unexpected US macroeconomic announcement on the first observation that contains the significant jumps, while there was a political unsettlement news on the day that contain large volatility variation but no significant jumps in the second observation. They confirm their finding by grouping the days that have large realised variance and large jump component and found that most of those days are relevant to the release of U.S. macroeconomic announcements. At the end, they conclude that news is quickly absorbed into the market, while the effect is short lived.

2.3) Intervention, conditional volatility and jumps

Beine, Lahay, Laurent, Neely and Palm (2006) investigate the effect of Federal Reserve Bank (FED), Bundesbank (BNN) and Bank of Japan (BOJ) intervention on a jump component and continuous component of exchange rate (USD/YEN and USD/DEM) volatility using realised volatility and bipower variation. The data of USD/YEN and USD/DEM are 5-minute interval exchange rate data between 1987-2004. The result suggests that although the jump component is not more likely to occur on the day of intervention, when it occurs the size of the jump component is larger than the average. The evidence from the causality test tends to suggest that the intervention cause the jump component. The result from the AFIMA model shows that the intervention increases the continuous component in the exchange rate volatility.

Dominguez (2003a) use the high frequency intra-day exchange rate data and U.S. Central Bank intervention data to investigate the microstructure of foreign exchange market following the central bank intervention. Since most of the U.S. Central Bank intervention is reported by Reuters, it allows the effect of intervention to be measured within the day of intervention and therefore we get a more precise effect of intervention in the exchange rate market. After the time of intervention is identified, the pre and post event window which contain the period of 2 hours are created to measure the volatility of the exchange rate before and after the intervention.

The result found a strong evidence that the volatility surrounds intervention periods is substantially higher than the period of no-intervention and the impact generally persists to the end of the trading day. Dominguez (2003) suggests that the state of the market is important on the efficacy of the intervention. The result suggests that the effect of intervention is large when the Central Bank intervene in the time of high trading volume, in the time after the macroeconomic announcement release and during the time that other central bank are in the market. Interestingly, there is also some evidence that the exchange rate is substantially volatile before the intervention is publicly released which suggests that there are some traders who are aware of intervention operation before the operation is publicly released.

Dominguez(2006) use the reported time of US. and Germany Central Bank intervention by Reuter to investigates the effect of macroeconomic announcement and intervention on the mean and variance level of exchange rates using the event study method. The MA(1)-FIGARCH(1,d,1) model investigates the intra-day effect of intervention using a tick by tick exchange rate data while the AFIMA model find the effect of daily exchange rate volatility using realised volatility. The result suggests that the interventions, announcement, macro controls and seasonal effect together explain about 25% of intra-day DM/USD volatility. The intra-day result finds that coordinated interventions have a greater impact on exchange rate volatility than the unilateral intervention. The interventions that are timed close to macroeconomic announcement have larger effects on volatility than interventions that are not timed close to macroeconomic announcements. Dominguez (2006) use the realised volatility by Andersen and Bollerslev (1998) to investigate the daily effect of intervention on exchange rate volatility and find that the intervention influence exchange rate volatility. The average size of the realised volatility on the day of intervention is generally greater than the day of no intervention. The AFIMA model suggests that intervention significantly increase volatility on the day of intervention but there is little evidence that the effect of intervention extend beyond the day of intervention.

Beine and Laurent (2003) use an ARFIMA-FIGARCH model to capture the daily exchange rates and their outliers for four major currencies against the U.S. dollar during 1980-1996. The Bernoulli-normal mixture distribution is used to account for the outliers. They found that large numbers of outliers are related to the central bank interventions in the foreign exchange markets. The time-varying jump probability model is introduced to improve the estimation of intervention on exchange rate. The results indicate that the interventions significantly influence the jump probability. Hence there is the evidence to support that central bank interventions are associated with the jumps that occur in exchange rate series. Beine and Laurent (2003) also test whether the impact of exchange rates depends on the direction of the interventions and found that there is the asymmetric effect of central bank interventions such that the buying of U.S. dollar exhibits higher jump probability than the selling of U.S. dollar.

Kim, Kortian and Sheen (2000) apply the EGARCH(1,1) model to investigate the effectiveness of the intervention of the Reserve Bank of Australia during Dec 1983-Dec 1997. They found that the volatility of the USD/AUD exchange rate significantly increase on the day of intervention, but the presence of the RBA in the market overtime is able to calm the market volatility.

3) Theoretical Framework[4]

3.1) Extracting the continuous and jump component

The continuous time jump diffusion process is defined as

$$dp(t) = \mu(t)dt + \sigma(t)dW(t) + \kappa(t)dq(t), \quad 0 \le t \le T, \tag{1}$$

where $p(t)$ is a logarithmic asset price at time *t*, $\mu(t)$ is a continuous and locally bounded variation process, $\sigma(t)$ is a strictly positive stochastic volatility process with a sample path that is right continuous and has well defined left limits, $W(t)$ is a standard Brownian motion, and $q(t)$ is a counting process with time varying intensity $\lambda(t)$ where $P[dq(t)=1] = \lambda(t)dt$ and $\kappa(t) = p(t) - p(t-)$ referred to the size of the jumps in the (logarithmic) price process.

The associated one period return is

$$r(t) = p(t) - p(0) = \int_0^t \mu(\tau)d\tau + \int_0^t \sigma(\tau)dW(\tau) + \sum_{0 \le \tau \le t} \kappa(\tau) \tag{2}$$

The quadratic variation for the cumulative process $r(t)$ may be defined,

$$[r,r]_t = \int_0^t \sigma^2(s)ds + \sum_{0<s\le t} \kappa^2 , \tag{3}$$

where the integral term represents the integrated volatility of the continuous sample path component, the summation term represents the square jump component that

[4] This theoretical framework follows Andersen, Bollerslev and Diebold (2005a), Andersen, Bollerslev and Diebold (2005b) and Beine, Lahaye, Laurent, Neely and Palm (2006)

occurred between time *0* and time *t*. In a special case of stochastic volatility diffusion where no jump is assumed, the quadratic variation equals the integrated volatility of the continuous sample path component.

Following the quadratic variation equation above, ABDL (2001) define the daily realised volatility by the summation of the corresponding $\frac{1}{\Delta}$ high frequency intra-daily square returns,

$$RV_{t+1}(\Delta) \equiv \sum_{j=1}^{1/\Delta} r_{t+j\cdot\Delta,\Delta}^{2} \ , \qquad (4)$$

where $r_{t,\Delta}$ is denoted to the discretely sampled Δ-period returns and defined as $r_{t,\Delta} \equiv p(t) - p(t-\Delta)$, j is the order of the intra day returns and $\frac{1}{\Delta}$ is assumed to be an integer (where in this application of 5-minute interval data, $\frac{1}{\Delta}$ = 288). Following the work by ABDL(2001) and BNS(2004), by the use of quadratic variation theory it shows that,

$$RV_{t+1}(\Delta) \xrightarrow{p} \int_{t-1}^{t} \sigma^2(s)ds + \sum_{t<s\le t+1} \kappa^2 \qquad (5)$$

the realised volatility that is presented in equation (4) converges uniformly in probability to the increment of the quadratic variation process, which is the combination between the integrated variance of the instantaneous returns of the continuous component and the jump component, as the sampling frequency of the returns increases ($\Delta \to 0$).

Equation (5) clearly illustrates the limit of the realised volatility presented in equation (4). Although it can, in theory, accurately determine the dynamic of the returns volatility, it needs to assume that there are no jumps. This, on the other hand, implies that realised volatility does not distinguish between the diffusion and jump component.

By the use of the asymptotic result, BNS(2004) are able to consistently estimate the integrated volatility even in the presence of jump components. This method is defined as realised bipower variation.

$$BV_{t+1}(\Delta) \equiv \mu_1^{-2} \sum_{j=2}^{1/\Delta} \left| r_{t+j\cdot\Delta,\Delta} \right| \left| r_{t+(j-1)\cdot\Delta,\Delta} \right| , \qquad (6)$$

where

$$\mu_a = E(|Z|^a), \quad Z \sim N(0,1), \quad a > 0$$

and $\mu_1 \equiv \sqrt{(2/\pi)}$ is the mean of the mean of the absolute value of a standard normally distributed random variable. BNS(2004,2006) shows that

$$BV_{t+1}(\Delta) \xrightarrow{p} \int_t^{t+1} \sigma^2(s)ds \tag{7}$$

Moreover, BNS(2004) suggest that the differrence between the result of the realised volatility and realised bipower variation should converge to the outcome that is equivalent to the jump component.

$$RV_{t+1}(\Delta) - BV_{t+1}(\Delta) \xrightarrow{p} \sum_{t<s\leq t+1} \kappa^2(s)\,. \tag{8}$$

There is nothing to ensure that the jump component in equation (8) will not be negative, I follow the suggestion of BNS(2004) by truncating the measurement of the jump component to have a minimum value of zero,

$$J_{t+1}(\Delta) \;\; \equiv \max[RV_{t+1}(\Delta) - BV_{t+1}(\Delta), 0]\,. \tag{9}$$

where $J_{t+1}(\Delta)$ is the jump component which is the result of differencing realised volatility and realised bipower variation in equation (8).

3.2) Significance of the jump component

The result of the non-negativity transaction jump component in equation (8) is consisted with large number of non-zero and small size jump components. BNS(2005) suggest that it is possible that these jumps do not contain any significant economic implication and could be omitted from the sample in order to improve the efficiency of the result. BNS(2005,2006) provides a theoretical framework that account for those small jump. They use the theory of asymptotic distribution and found that when there is no jump and for $\Delta \rightarrow 0$, under sufficient regularity, frictionless market conditions, they have

$$\Delta^{-1/2} \frac{RV_{t+1}(\Delta) - BV_{t+1}(\Delta)}{\left[(\mu_1^{-4} + 2\mu_1^{-2} - 5)\int_t^{t+1} \sigma^4(s)ds\right]^{1/2}} \rightarrow N(0,1)\,, \tag{10}$$

Therefore the jumps that appear after the standardisation of the jump component by equation (10) may be interpreted as the “significance jump components”. Here, the integrated quarticity ($\int_t^{t+1} \sigma^4(s)ds$) from equation (10) is needed to be estimated and

BNS(2005) suggests that the realised tripower quarticity measure (TQ) can consistently estimate the integrated quarticity.

$$TQ_{t+1}(\Delta) \equiv \Delta^{-1}\mu_{4/3}^{-3}\sum_{j=3}^{1/\Delta}\left|r_{t+j\cdot\Delta,\Delta}\right|^{4/3}\left|r_{t+(j-1)\cdot\Delta,\Delta}\right|^{4/3}\left|r_{t+(j-2)\cdot\Delta,\Delta}\right|^{4/3} \quad , \tag{11}$$

where $\mu_{4/3} \equiv 2^{2/3}\Gamma(7/6)\Gamma(1/2)^{-1}$, thus we have, for $\Delta \to 0$,

$$TQ_{t+1}(\Delta) \to \int_t^{t+1}\sigma^4(s)ds \ . \tag{12}$$

By using the result of equation (11) into equation (10), we acquire,

$$W_{t+1}(\Delta) \equiv \Delta^{-1/2}\frac{RV_{t+1}(\Delta) - BV_{t+1}(\Delta)}{\left[(\mu_1^{-4} + 2\mu_1^{-2} - 5)TQ_{t+1}(\Delta)\right]^{1/2}} \tag{13}$$

where the “significant jump components” are determined by comparing $W_{t+1}(\Delta)$ with the test statistics with the null hypothesis of no jump.

Huang and Tauchen (2005) suggests that the $W_{t+1}(\Delta)$ statistic defined in (13) tends to over reject the null hypothesis for a large critical values. Instead Huang and Tauchen (2005) find that the statistic,

$$Z_{t+1}(\Delta) \equiv \Delta^{-1/2}\frac{\left[RV_{t+1}(\Delta) - BV_{t+1}(\Delta)\right]RV_{t+1}(\Delta)^{-1}}{\left[(\mu_1^{-4} + 2\mu_1^{-2} - 5)\max\left\{1, TQ_{t+1}(\Delta)BV_{t+1}(\Delta)^{-2}\right\}\right]^{1/2}} , \tag{14}$$

corrects the size of distortion and is well approximated by a standard normal distribution.

Hence we identify the significant jump components by comparing the $Z_{t+1}(\Delta)$ against some critical value, Φ_α,

$$J_{t+1,\alpha}(\Delta) \equiv I[Z_{t+1}(\Delta) > \Phi_\alpha]\cdot[RV_{t+1}(\Delta) - BV_{t+1}(\Delta)] \tag{15}$$

where α is the level of the significance. Following Andersen, Bollerslev and Diebold (2005a), to ensure that the jump component and continuous component are added up to realised volatility, we estimate the continuous component to be equal to,

$$C_{t+1,\alpha}(\Delta) \equiv I[Z_{t+1}(\Delta) \le \Phi_\alpha]\cdot RV_{t+1}(\Delta) + I[Z_{t+1}(\Delta) > \Phi_\alpha]\cdot BV_{t+1}(\Delta) \tag{16}$$

Lastly, Andersen, Bollerslev and Diebold (2005a) and Huang and Tauchen (2005) investigate on the problem of market microstructure noise component which create the serial correlation among the returns. This serial correlation generates a bias in the realised bipower variation and tripower quarticity measure. Andersen, Bollerslev and Diebold (2005a) and Huang and Tauchen (2005) use the staggered realised bipower variation and tripower quarticity measure to overcome the problem of first order autocorrelation, that is

$$BV_{1,t+1}(\Delta) \equiv \mu_1^{-2}(1-2\Delta)^{-1}\sum_{j=3}^{1/\Delta}\left|r_{t+j\cdot\Delta,\Delta}\right|\left|r_{t+(j-2)\cdot\Delta,\Delta}\right|, \tag{16}$$

$$TQ_{t+1}(\Delta) \equiv \Delta^{-1}\mu_{4/3}^{-3}(1-4\Delta)^{-1}\sum_{j=3}^{1/\Delta}\left|r_{t+j\cdot\Delta,\Delta}\right|^{4/3}\left|r_{t+(j-1)\cdot\Delta,\Delta}\right|^{4/3}\left|r_{t+(j-2)\cdot\Delta,\Delta}\right|^{4/3}. \tag{17}$$

4) Data Description

4.1) Exchange rate data

Our intra-day exchange rate data cover four years period, from 1st January 1999 through 31st December 2002. The initial data were received as a 5 minute continuous time of AUS/USD bid and ask quotations. The currency is interpreted as an increase in AUS/USD is associated with the appreciation of the Australian dollar. We then converted the series of bid and ask quotations into log bid and log ask. Next, we average the series of log bid and ask to get the average log price of an exchange rate. Finally we correct some anomalies and outliner[5] then converted the average log price into to a continuous returns by taking the difference between the 5 minute average log price.

The data is recorded in Greenwich Mean Time (GMT) time zone, the benefit of having data recorded in GMT is that we can always convert the time of announcement into the GMT time which is convenient and less confusing when we are dealing with more than one country. It is also well know that the foreign exchange market activities are low during weekends period, hence we excluded the Saturday and Sunday data from the sample by excluding data from Saturday 12:00am. (GMT time) until Sunday 7:55pm. GMT(time). Note that we need to be careful about the time period that we decide to exclude from the sample period since the New York's time is much behind relative to GMT time while the Australian time is much ahead relative to the GMT time. For example, Friday 5:00pm. of New York's time during the month of November is equivalent to Friday 10:00pm. GMT time, while on

[5] The outliner and anomalies include that during 1 Jan 99 until 31 Dec 00 the average quotation at 12:00am. is very different from the quotation at 11:55pm. and 12:05 am. We conclude that this difference is not the actual value of the exchange rate at the current time but it represents the problem with the exchange rate recording program by sources. We solve this problem by defining the value of quotation at 12:00am. as the average quotation between 11:55pm. and 12:05am. Another anomalies include that during some trading day the quotation is unchanged for some period of time (eg. 2 hours or about 24 observations) and it is very unlikely that during that period there is no exchange rate movement at all. We solve this problem by after acquiring the return series, we omitted the observations that have a sequence of zero more than 2 hours.

Monday 9:00am. Camberra's time during the month of November is equivalent to Sunday 10:00pm. GMT time.

4.2) The macroeconomic announcement data

The macroeconomic announcement data are taken from the Bloomberg real time macroeconomic announcement data and Bloomberg macroeconomic survey data. The Bloomberg real time data records the time and figure of the economic announcements that are released from the Australian government and US government. The Bloomberg survey data presents the forecasted figure of the major economic variables. The data is taken from about 10-30 practitioner and academics from both Australia and US. The median of the survey value is used to be the forecasted value. The forecasted data are also tested for unbiasedness and efficiency. The results of the tests imply that the surprise component of announcement is noise (unbiased test) and the surprise component cannot be explained by the past information of announcement (efficiency test).

The macroeconomic announcement that is used in this report include gross domestic product (GDP), consumer price index (CPI), producer price index (PPI), retail trade, current account deficit (CAD), unemployment rate (Unem) and consumer confidence index (Confi). Note that due to the lack of information, the survey data on Australian PPI and consumer confidence index are not available.

The Bloomberg real time data always come with date and time, it is important to correctly identify the time zone of the data. Normally the time (of announcement) that presents in the real time data is the time that associates with the local time (where the computer is set to), eg. If one uses Bloomberg services in Australia, the time of the US announcement will be presented in Australian time. After we correctly identify the time of the announcement, we then convert all time of announcement to GMT time which we also need to bear in mind the daylight saving effect.

5) Result

5.1) Reaslised volatility, bipower variations and jumps descriptive statistics

Figure 1 plots the daily price and daily return over the whole sample for the USD/AUD. The plot of realised volatility, bipower variation and jumps are shown in Figure 2. The plot of realised volatility and bi-power variation clearly exhibit a high degree of serial correlation, which are confirmed by the result of the Ljung-Box test from Table 1.

Table 1

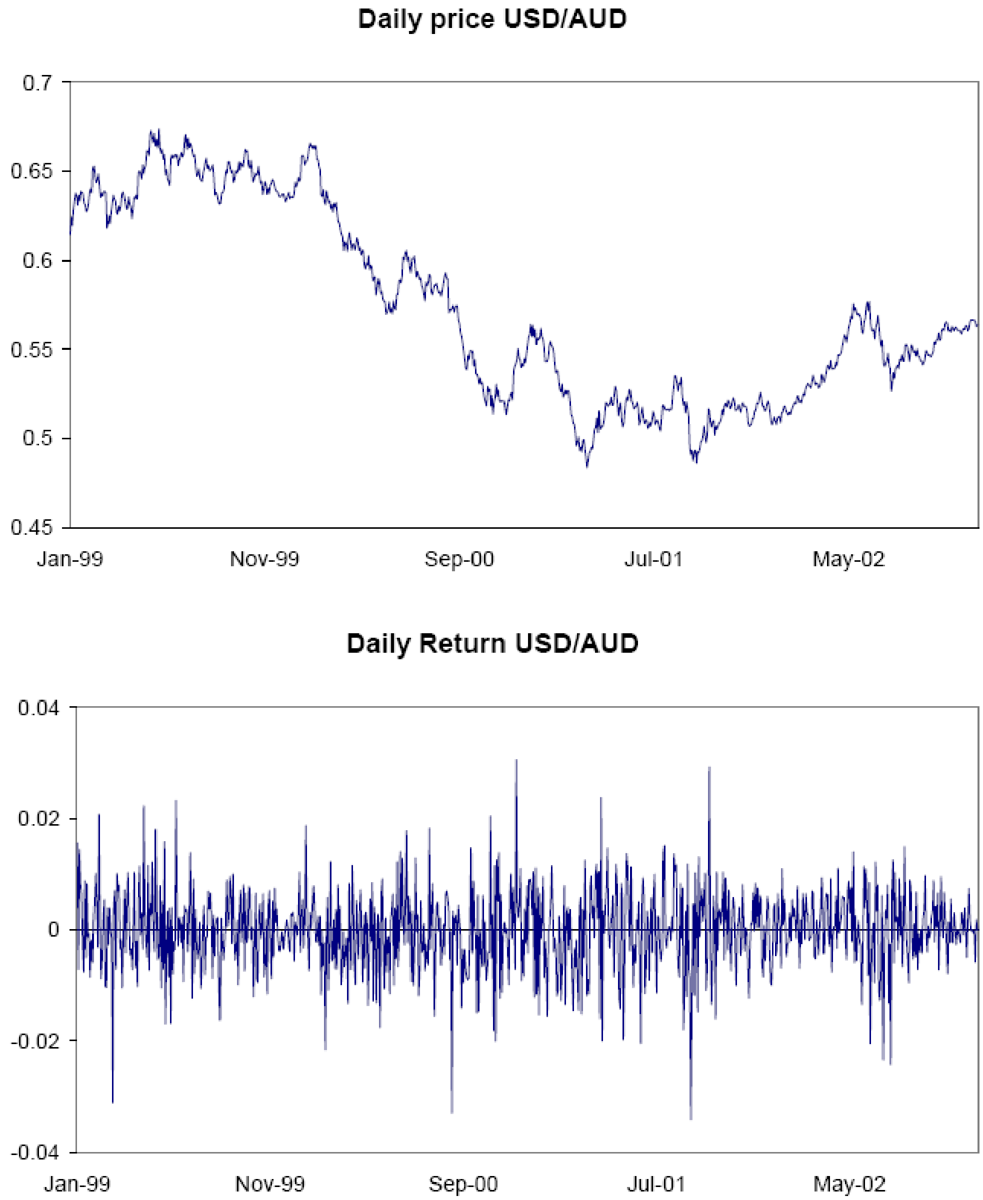
Summary statistic of realised volatility, bipower variations and jumps

	Mean	St. Dev.	Skewness	Kurtosis	Q(10)	Q(40)
RV	0.528	0.328	2.606	16.112	1565	3231
$RV^{1/2}$	0.699	0.198	1.120	5.606	2323	5232
$\ln(RV)$	-0.790	0.541	0.166	3.077	2913	7002
BV	0.426	0.272	2.802	19.284	1220	2297
$BV^{1/2}$	0.627	0.181	1.156	5.838	1840	3798
$\ln(BV)$	-1.012	0.552	0.187	3.042	2282	5051
$Jump$	0.103	0.103	3.334	22.257	748	1729
$Jump^{1/2}$	0.291	0.135	1.038	5.612	938	2332
$\ln(Jump)$	-2.622	0.893	-0.495	4.634	1050	2771

The results of the Ljung-Box test indicate strong serial correlation in the daily realised volatility, bipower variation and jumps. Note that although the jump exhibits a strong serial correlation, the magnitude of its Ljung-Box test is relatively smaller than the realised volatility and bipower variation series. This finding is similar to the result of Andersen, Bollerslev and Diebold (2005a), which indicates that the jump component which is the discontinuity series is less dependent on its lag than the continuous series such as realised volatility and bi-power variation.

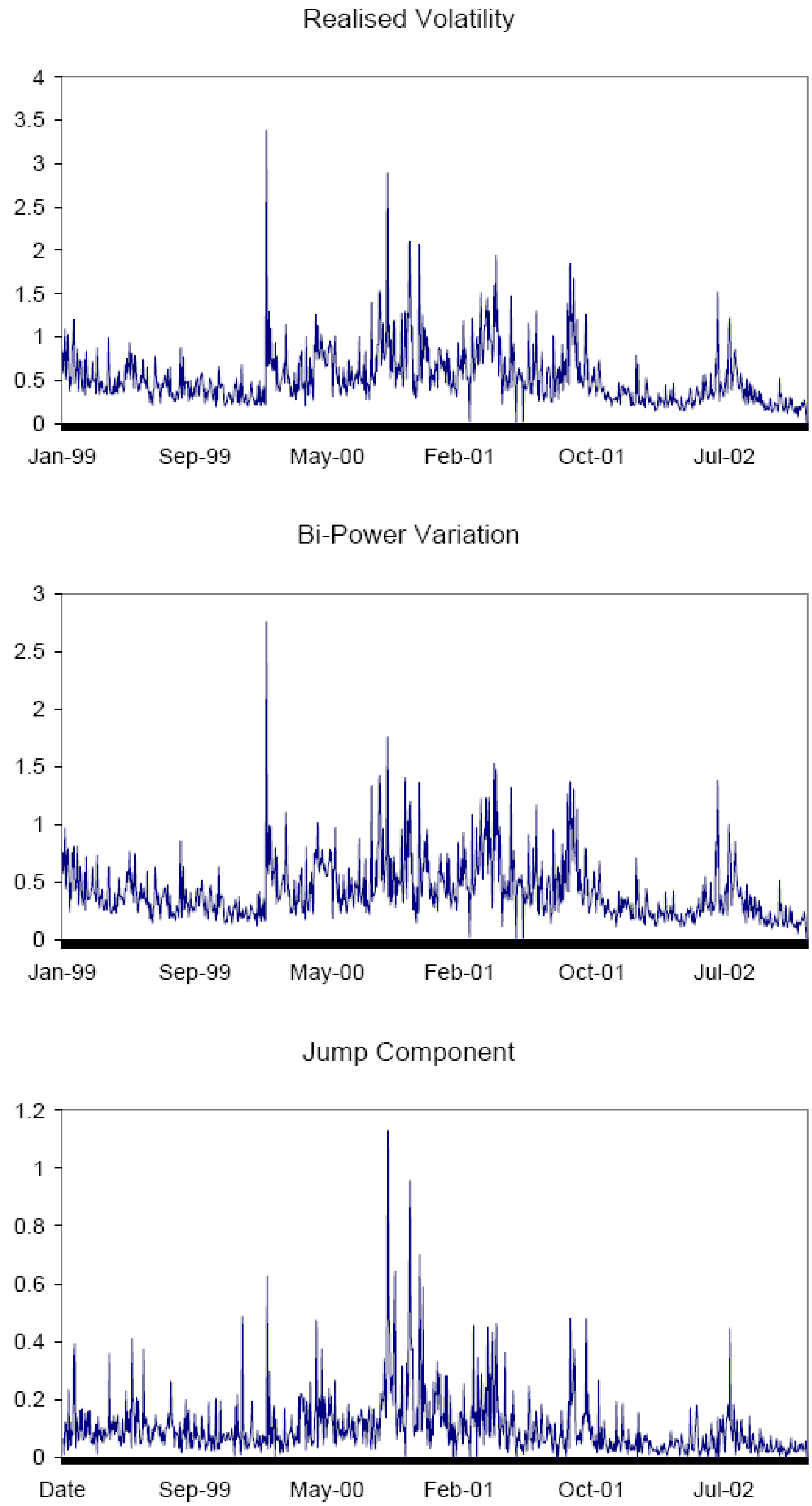
The mean of the realised volatility is higher than the mean of the bipower variation and the difference between them is roughly equal to the mean of the jumps. This result reflects the outcome of the jumps extraction procedure such that the realised volatility is the combination between the bipower variations (continuous component) and the jumps. The size of the jumps is much smaller than the size of realised volatility and bipower variation. The proportion between the size of the jump component against realised volatility and bipower variations are only 0.19 and 0.24, respectively. This illustrates some characteristic of this exchange rate volatility series such that the majority of the volatility movements belong to a continuous component and about 20% of the volatility movements belong to the jumps.

Figure 1: Daily prices and daily return of USD/AUD



Note: Daily price is recorded at 17:00 Australian time

Figure 2: Realised volatility, Bi-Power Variation and Jumps component



The series of realised volatility and bi-power variation are not normally distributed with the positive skewness and high degree of kurtosis. However the standard deviation form of realised volatility and bi-power variation ($RV^{1/2}$ and $BV^{1/2}$) and the logarithmic form of realised volatility and bi-power variation ($\ln(RV)$ and $\ln(BV)$) are more likely to be normally distributed, with much lower degree of skewness and kurtosis. This finding are similar to what Anderson, Bollerslev and Diebold (2005) found in the realised volatility of DM/USD series and what Beine, Lahaye, Laurent, Neely and Palm (henceforth BLLNP) (2006) found in the realised volatility of JPY/USD series

The summary statistic of significant jump component is presented in Table 2. The significance of the jump is separated into 4 different levels including α =0.95, 0.99, 0.999 and 0.9999. In each level of significance, there are four types of observations:

- “Jump (whole sample)” variable shows the summary statistic of the jump component for both, significant and insignificant jump components.
- “Jump (non zero sample)” variable only presents the summary statistic of the significant jump component.
- “Continuous component (whole sample)” presents the summary statistic of the continuous component for both, significant and insignificant jumps.
- “Continuous component (non zero jump sample)” presents the continuous component on the day that only contains the significant jumps.

The “prop.” column represents the proportion between the number of significant jumps and the number of whole sample. The prop. number shows the number of significant jump over the whole sample. Not surprisingly, the result suggests that the prop. numbers are decreasing as the levels of significance increase. The highest proportion is 0.919 when α is equal to 0.95, while the lowest proportion is 0.539 when α is equal to 0.9999. The mean of the significant jumps are decreasing when α increases, however when we take out the non-significant jump out from the sample, the level of the mean behave differently such that, the higher the significance level the higher the level of the mean.

This implies that the high level of α will drop the small or insignificant jumps and keep the large and significant jumps. This result shows that the separating process of the small insignificant jump from the jump component series is successful.

Table 2

The summary statistic of jump component and continuous component

	Prop.*	Mean	St. Dev.	Skewness	Kurtosis	Q(10)	Q(40)
$\alpha = 0.95$							
Jump (Whole sample)		0.098	0.103	3.235	22.144	690	1633
Jump (Non zero sample)**	0.919	0.106	0.103	3.335	22.787	619	1401
Continuous component (Whole sample)		0.430	0.280	3.108	23.641	1140	2091
Continuous component (Non zero jump sample)		0.418	0.246	1.698	6.952	1231	2413
$\alpha = 0.99$							
Jump (Whole sample)		0.092	0.103	3.129	21.658	536	1255
Jump (Non zero sample)	0.839	0.109	0.103	3.292	22.771	453	1040
Continuous component (Whole sample)		0.436	0.288	3.058	22.321	1129	2091
Continuous component (Non zero jump sample) ⊗		0.413	0.243	1.724	7.203	938	1730
$\alpha = 0.999$							
Jump (Whole sample)		0.080	0.104	3.123	21.518	407	869
Jump (Non zero sample)	0.681	0.117	0.107	3.288	22.482	331	681
Continuous component (Whole sample)		0.448	0.293	2.912	20.583	1130	2157
Continuous component (Non zero jump sample)		0.411	0.243	1.758	7.389	471	853
$\alpha = 0.9999$							
Jump (Whole sample)		0.067	0.100	2.590	13.672	219	573
Jump (Non zero sample)	0.539	0.124	0.107	2.392	12.426	175	448
Continuous component (Whole sample)		0.461	0.304	3.074	21.790	1096	2132
Continuous component (Non zero jump sample)		0.406	0.238	1.508	5.626	246	496

*Prop. represents the proportion between the number of non zero observation of jump component over the whole observation of jump component (which is always 955 observations).
** The non zero sample represents the sample of the significant jump component only.
⊕ This represents the sample of the continuous component that occur on that day that contain the significant jump component.

The level of skewness and kurtosis of the jumps still indicate that the distributions of these significant jumps are not normal. The results of Ljung-Box test tell that all of the significant jump components are serially correlated, while the value of the Ljung-Box test are lower as the level of significance gets larger.

5.*2) Continuous components, jump components and central bank interventions*

Table 3 presents summary statistic of the jumps and continuous components that occur on the day of RBA intervention. Note that Table 3 only presents the summary statistic when $\alpha = 0.999$ [6]. Table 3 contains 4 different intervention schemes;

- The time when there is an intervention
- The time when there is no intervention
- The time when there is an intervention by selling the AUD
- The time when there is an intervention by purchasing the AUD.

This representation allows us to compare the characteristic of the continuous and jumps between the day of intervention and the day of no intervention.

One way to access the effect of intervention on the jump component is to analyse the number of significant jump components occur between the time of intervention and the time of no intervention. Table 3 under the "Prop." column shows the proportion between the numbers of significant jump over the whole period. The highest Prop. number occurs when there is an intervention by purchasing AUD while the lowest Prop. number occurs when there is an intervention by selling AUD which is slightly lower than the Prop. number of the day of no intervention. The result implies that the proportion of significant jumps is higher when RBA intervene by purchasing AUD compared to the day of no intervention. On the other hand, the proportion of significant jumps is lower on the day RBA intervene by selling AUD compared to the day of no intervention.

Another way to assess the effect of intervention on exchange rate volatility is by considering the size of the jump and continuous components during the day of intervention and the day of no intervention. The difference in the size of the jumps and continuous component between the day of intervention and the day of no intervention would imply how intervention is associated with the change in exchange rate volatility. The mean of the size of the jumps and continuous components are presented in Table3.

[6] The summary statistic for others α are provided in appendix. The level of $\alpha = 0.999$ is used for the analysis since we feel that the level of significance is not too strong (which may drop some important medium size jumps) and not too weak (which may include some insignificant jumps)

Table 3

Summary statistic of jumps and continuous component during the time of intervention

	Whole sample		Significant jump only*		
$\alpha = 0.999$	Obs.	Mean	Obs.	Prop.	Mean
Jumps					
Intervention	202	0.077	132	0.653	0.117
No intervention	753	0.081	518	0.688	0.117
Sale of AUD	168	0.050	106	0.631	0.079
Purchase of AUD	34	0.210	26	0.764	0.274
Continuous component					
Intervention	202	0.434	132	-	0.405
No intervention	753	0.452	518	-	0.412
Sale of AUD	168	0.351	106	-	0.308
Purchase of AUD	34	0.843	26	-	0.804

* The sample of "Significant jump only" only includes the day that contains significant jumps.

The jumps (based on the column of "significant jump only") on the day of no intervention is equal to the jumps on the day of intervention. Although this set of result suggests that intervention does not affect the size of the jump component, the analysis on the direction of the intervention seems to suggest a different conclusion. The jump component from the sale of AUD is lower than the jump component on the day of no intervention. On the other hand, the jump component from the purchase of AUD is substantially higher than the jump component on the day of no intervention. This implies that intervention by purchasing AUD is associated with the large jump in the foreign exchange rate volatility, while there is no evidence to support that the sale of the AUD is associated with a large jump in the foreign exchange rate volatility.

The means of the continuous component (based on the column of "significant jump only") are provided in Table 3. The pattern of the result is similar to the result of the jump component. Without allowing for the direction of the intervention, the continuous component on the day of intervention is slightly lower than the continuous component on the day of no intervention. However, if the direction of the intervention is accounted for, the continuous component on the day of purchase (sale) of AUD is larger (smaller) than the mean of a day when there is no intervention. This implies that the purchase (sale) of AUD is associated with an increase (decrease) in the continuous component of volatility.

The results clearly show that intervention is associated with a change in the jump and continuous components in the foreign exchange market volatility. Interestingly, there is an evidence of a sign asymmetric of intervention. The purchase (sale) of AUD is associated with a larger (smaller) numbers of significant jumps, a larger (smaller) size of the jump and a larger (smaller) size of the continuous component than the day of no intervention. Following the results above, it implies that the intervention by purchasing AUD is associated with the day that experience high foreign exchange rate volatility while the intervention by selling AUD is associated with the day that experience low foreign exchange rate volatility.

Table 4

The distribution of the frequency of intervention

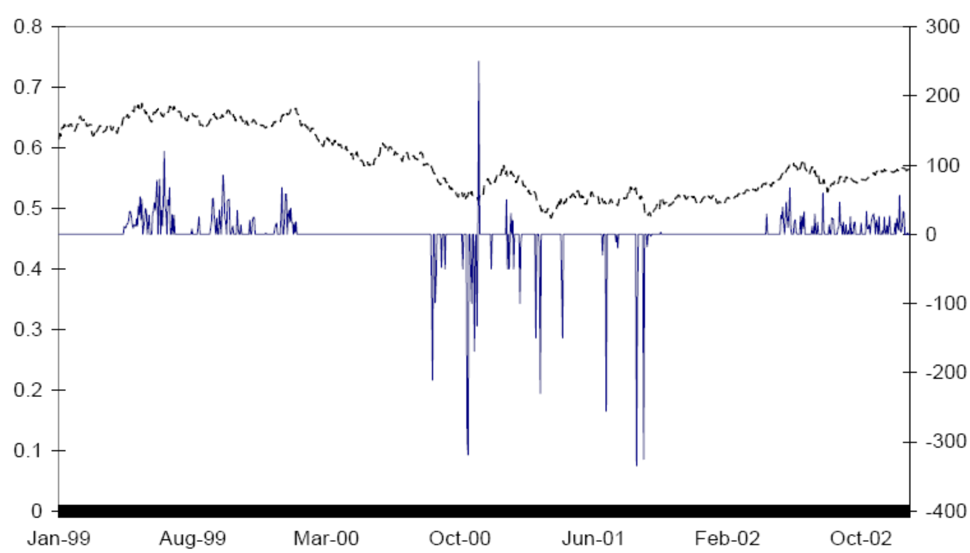
	Purchase of AUD	Sale of AUD
Between AUD 1-50 millions	16*	149
	(0.471)**	(0.887)
Between AUD 51-100 millions	7	17
	(0.206)	(0.101)
Between AUD 101-150 millions	3	1
	(0.088)	(0.006)
Between AUD 151-200 millions	1	1
	(0.029)	(0.006)
Greater than AUD 200 millions	5	1
	(0.206)	(0.006)
Total	32	169

*The number represents the frequency of intervention in the dollar range.
** This number represents the proportion of total

5.2.1 Asymmetric effect of exchange rate volatility and the size of intervention

One possibility that explain the sign asymmetric effect of intervention is the distribution of the size of intervention between the purchase and sale operations. Table 4 presents the distribution of the amount of the RBA daily intervention between purchase and sale operations. The Table 4 shows that the size of intervention is asymmetric between the sale of AUD and purchase of AUD. The distribution suggests that about 89 % of the time, the size of intervention when the RBA sold AUD were less than 50 million dollars, while 10% of the time when RBA sold the AUD was between 50 to 100 million dollars and only 1% of the time when RBA sold AUD that the interventions were over 100 million dollars. Meanwhile, the interventions by purchasing AUD have different distribution over the size of intervention. The purchases that were under 50 million dollars were only accounted for 47% of the time when RBA purchased AUD, while almost 21% of the time when RBA purchased AUD were between 50 to 100 million dollars and nearly 27% of the time when RBA purchased AUD that were over 100 million dollars. In fact almost 15% of the time when RBA purchased AUD that the size of intervention by purchasing exceeded 200 million dollars. Figure 3 illustrates the plot of amount of intervention between purchase and sale of AUD and it also shows an obvious different between the size of intervention. RBA have different intervention strategy when it comes to the time of selling or purchasing AUD[7].

Figure 3: RBA Intervention and the plot of USD/AUD



[7] A possible explanation for the RBA asymmetric intervention strategy is that Australia is an inflation targeting country. The depreciation of AUD raises the price of import. The higher price of import will increase the domestic price which inturn will increase the pressure on inflation. On the other hand, although the appreciation of the AUD will hurt the exporter but does not put pressure on inflation. This means that the RBA would be more concerned about the depreciation of the AUD and will intervene heavily to prevent the excessive depreciation.

Also RBA might have asymmetric intervention behaviour when it comes to the time of high inflation and low inflation. RBA would be more worry for the factor that increases the inflation than the factor that decreases the inflation. On the time of high inflation, RBA would be concerned on depreciation of the AUD since the depreciation increase inflation pressure. On the mean time when it come to the time of low inflation (relative to the target level), the appreciation of AUD could cause the inflation to be even lower, however the RBA might not be worry about the consequence of the appreciating currency as much as the time of currency depreciating and therefore would not intervene as heavily as the time of high inflation and currency depreciating.

Table 5

The summary statistic between the purchase and sale of AUD

	Jumps		Continuous component	
	Obs	Mean	Obs	Mean
Aggregate intervention				
Intervention between AUD 1-50 millions	106	0.102	106	0.349
Intervention greater than AUD 50 millions	25	0.187	25	0.637
Difference of two means test (when standard deviation is assumed to be different)		-1.96*		-3.28*
Difference of two means test (pooled standard deviation)		-2.61*		-4.427*
Direction analysis				
Sale of AUD				
Between AUD 1-50 millions	92	0.079	92	0.294
Greater than AUD 50 millions	13	0.083	13	0.382
Difference of two means test (when standard deviation is assumed to be different)		-0.229		-1.818*
Difference of two means test (pooled standard deviation)		-0.182		-2.011*
Purchase of AUD				
Between AUD 1-50 millions	14	0.251	14	0.710
Greater than AUD 50 millions	12	0.301	12	0.912
Difference of two means test (when standard deviation is assumed to be different)		-0.465		-1.118
Difference of two means test (pooled standard deviation)		-0.462		-1.113

* The test is significant at 5% level.

Note that only the significant jumps at $\alpha = 0.999$ are used in this table.

At this stage, it seems that the difference in size of intervention between purchase and sale operation explain the sign asymmetric effect of intervention. Hence, it is interesting to investigate how significant is the size of intervention on the exchange rate volatility. In order to investigate on the effect of the size of intervention on exchange rate volatility, we divide the sample into two sub-samples: Interventions that are more than 50 AUD million dollars and intervention that are less than 50 AUD million dollars[8]. We analyse the different in size of intervention on the aggregate intervention and on the direction of intervention (purchase of AUD and sale of AUD). The mean value of the jump and continuous components between these two

[8] The average size of intervention is 63 million dollar. Hence we think 50 million dollar figure is reasonable amount to differentiate a large and small intervention.

sub-samples are reported in Table 5 and the "difference of two means test"[9] is used to statistically test the difference between the mean of the jump and continuous component.

The result from the aggregate intervention suggests that large intervention significantly associates with larger jump and continuous component in volatility series than the small amount intervention. The difference of two means test rejects the null hypothesis of no difference at 5% level for both the mean of jump and continuous components.

The result from the direction analysis suggest a weak evidence to support the positive relationship between the size of intervention and the size of exchange rate volatility since there is only one test that significantly rejects the null hypothesis of no difference in mean which is the test on the continuous component during the time of sale of AUD.

5.2.2 Asymmetric effect on exchange rate volatility and market expectation

Another possible factor that could explain the sign asymmetric of intervention is the market expectation toward the RBA intervention. If the size of intervention reflects the magnitude of concern by RBA on the current situation of exchange rate market. Under the implicit assumption that the RBA have superior information relative to other market participants, market participants would interpret the RBA intervention as a signal of the current market situation. The large intervention would signal a large concern on the current market situation to the market participant and this signal could increase the uncertainty in the market and inturn increase the volatility.

Moreover, the market participant, overtime, realise that RBA have asymmetric intervention strategy and learn that RBA are more concern on preventing the excessive depreciation of AUD relative to the excessive appreciation of AUD. The market participants learn that the time of the intervention by purchasing AUD is associated with larger concern from the RBA than the time of selling the AUD. Hence, market participants have the expectation that the time of intervention by purchasing AUD signals a larger uncertainty to the exchange rate market than the time of intervention by selling AUD.

[9] The test is illustrated in Appendix.

In this case, it is not so much the different in the amount of intervention from the RBA asymmetric intervention strategy that effect the exchange rate volatility, but it is the market expectation, which is interpreted by the market participants, toward the RBA asymmetric intervention strategy that affect the exchange rate volatility.

In summary, the Reserve Bank intervention is associated with an increase in exchange rate volatility. There is an evidence of sign asymmetric effect of intervention. Only the purchase of AUD that is associated with an increase in exchange rate volatility. The asymmetric intervention strategy is one possible explanation for the sign asymmetric effect of intervention, however the test from Table 5 shows a weak relationship between the size of intervention and the size of exchange rate volatility. Table 5 also shows that regardless the amount of intervention, the purchase of AUD is always associated with a larger exchange rate volatility than the sale of AUD. Hence it might be the market expectation toward each direction of intervention that explain the sign asymmetric effect of intervention.

5.3) Jump components and macroeconomic announcement

Table 6 and 7 reports the mean of the jumps and continuous component and the proportion number (prop.) on the day of Australian and US. macroeconomic announcements .

Table 6 reports the result of the Australian announcement on USD/AUD exchange rate volatility. Note that the following analysis focuses on the summary statistic under the “significant jump only” column. It appears that the prop. value on the days that there are announcements about the Australian GDP and retail trade are higher than the prop. value on the day of no announcement while the remaining Australian announcements have lower prop. value than the day of no announcement.

The sizes of the jumps during the day of Australian announcements are generally slightly smaller than the jumps during the day of no announcement, with the exception of the announcement about Australian unemployment.

Table 6

The jump and continuous component summary statistic on the day of Australian macroeconomic announcement

	Whole sample			Significant jump only				
Australian	Obs	Mean of Jump	Mean of Continuous	Obs	Prop.	Mean of Jump	Mean of Continuous	Mean of Total volatility
GDP	11	0.078	0.534	8	0.727	0.107	0.386	0.494
Retail trade	40	0.081	0.554	31	0.775	0.105	0.494	0.599
Unemployment	31	0.075	0.504	19	0.613	0.123	0.457	0.580
Current account deficit	10	0.038	0.519	5	0.500	0.076	0.374	0.450
CPI	13	0.071	0.797	8	0.615	0.115	0.483	0.598
No announcement	667	0.082	0.434	465	0.697	0.118	0.403	0.521
A greater than 1 Unanticipated announcement								
GDP	3	0.117	0.726	2	0.667	0.176	0.509	0.685
Retail trade	10	0.073	0.631	6	0.600	0.121	0.628	0.749
Unemployment	20	0.088	0.462	13	0.650	0.136	0.468	0.603
Current account deficit	2	0.078	0.687	1	0.500	0.157	0.593	0.749
CPI	4	0.012	0.846	1	0.250	0.048	0.702	0.750

The sample under “whole sample” include the significant jump and insignificant jump in calculation while the sample under “significant jump only” only include the sample that have significant jump component. The “Jump” column represent the mean level of the size of the jump component in realised volatility, the “continuous” column represents the mean level of the size of the continuous component in realised volatility. The “Prop.” column represents the proportion between the number of significant jump over the whole observations. “Total volatility” column represent the mean level of the sum of the jump and the continuous component which ultimately equal to the realised volatility. The unanticipated announcement section describe the summary statistic of the announcement that has the standardised news greater than 1.

The results on the continuous component and total volatility on Australian announcements are mix. The continuous component and total volatility on the day of GDP and current account deficit announcements are lower than the day of no announcement. The continuous component and total volatility on the day of retail trade, unemployment and CPI announcements are higher than the day of no announcement. Nevertheless, the margins between these differences are small.

The overall results of the Australian announcements on the exchange rate volatility do not provide a strong evidence to support the relationship between the macroeconomic announcement and a movement in exchange rate volatility.

Although the above analysis uses the unanticipated announcement to find the effect of announcement on foreign exchange rate volatility, there is no differentiation between the degree of unanticipation of the announcement in the sample. It might be possible that the predicted value of announcement is different from the actual value of the announcement but the degree of unanticipation is not enough to surprise the market. This means that the degree of unanticipation of the announcement is an important factor that could determine the effect of announcement on the exchange rate volatility. In order to investigate whether a degree of unanticipation is associated with foreign exchange rate volatility, we compute the summary statistic of the unanticipated announcements that have a degree of unanticipation greater than 1[10]. The result of this "greater than 1 unanticipated announcement" is presented in the lower part of Table 6[11].

The result of a "greater than 1 unanticipated announcement" shows that although the prop. value have not changed by much, the size of the jump and continuous component have increased dramatically. The jump for all announcements, except CPI announcement, increase by a substantial amount. Moreover the jump during the day of Australian unanticipated announcements (except CPI) is much larger than the jumps during the days of no announcement. The continuous components also experience similar results. The size of the continuous components during the day of all Australian announcements increase significantly and become much larger than the size of the continuous components during the day of no announcement.

Interestingly, although size of the jumps during the day of unanticipated Australian CPI announcement is very small, its continuous component is relatively large. This may reflect the fact that market takes time to digest the unanticipated information of the CPI announcement, and most of the market reaction appears in the continuous component.

The results suggest that there is evidence to support the view that macroeconomic announcement is associated with an increase in foreign exchange rate volatility, both in the jumps and continuous components. The degree of unanticipation of the announcement also plays a pivotal role on the market reaction. The degree of unanticipation has to be sufficiently high to surprise the market.

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[10] The degree of unanticipation of 1 implies that the surprise component is equal to one standard deviation of $(A_{kt} - E_{kt})$, where A_{kt} is the actual value of the announcement *k* at time *t*, E_{kt} is the forecasted value of the announcement *k* at time *t*.

[11] Author realises the numbers of observations in each announcement are small when I account for a "greater than 1 unanticipated announcement", however it is the summary statistic of realised volatility that is analysed here.

Similar analysis is done for the case of announcements about U.S. variables and the result is presented in Table 7. In general, the result of the jump and continuous components of U.S. announcements are mix. The U.S. unemployment, consumer confidence and PPI announcements have a larger jump component compared to the day of no announcement. GDP, unemployment and PPI announcements have larger continuous components compared to the day of no announcement. The prop. value of all announcements are either relative close or smaller than the day of no announcement.

Table 7

Summary Statistic for the jumps and continuous components during U.S. macroeconomic announcements

	Whole sample			significant jump only				
US.	Obs	Mean of Jump	Mean of Continuous	Obs	Prop.	Mean of Jump	Mean of Continuous	Mean of Total volatility
GDP	44	0.064	0.552	26	0.591	0.108	0.460	0.568
Retail trade	12	0.026	0.332	5	0.417	0.062	0.299	0.361
Unemployment	33	0.100	0.477	22	0.667	0.150	0.435	0.584
CAD	16	0.029	0.481	8	0.500	0.057	0.287	0.344
CPI	29	0.077	0.431	20	0.690	0.112	0.371	0.484
Consumer confidence	43	0.079	0.434	25	0.581	0.136	0.400	0.536
PPI	38	0.080	0.423	23	0.605	0.132	0.413	0.545
No announcement	667	0.082	0.434	465	0.697	0.118	0.403	0.521
A greater than 1 Unanticipated announcement								
GDP	13	0.057	0.682	5	0.385	0.147	0.491	0.638
Retail trade	5	0.039	0.355	3	0.600	0.066	0.376	0.442
Unemployment	13	0.080	0.431	10	0.769	0.104	0.346	0.450
CAD	7	0.035	0.360	4	0.571	0.060	0.299	0.359
CPI	9	0.064	0.393	6	0.667	0.096	0.314	0.410
Consumer confidence	10	0.108	0.418	7	0.700	0.155	0.477	0.632
PPI	14	0.121	0.417	10	0.714	0.170	0.479	0.649

The sample under "whole sample" include the significant jump and insignificant jump in calculation while the sample under "significant jump only" only include the sample that have significant jump component. The "Jump" column represent the mean level of the size of the jump component in realised volatility, the "continuous" column represents the mean level of the size of the continuous component in realised volatility. The "Prop." column represents the proportion between the number of significant jump over the whole observations. "Total volatility" column represent the mean level of the sum of the jump and the continuous component which ultimately equal to the realised volatility. The unanticipated announcement section describe the summary statistic of the announcement that has the standardised news greater than 1.

The results for the case of a “greater than 1 unanticipated announcement” is also mixed. The announcements of U.S. GDP, consumer confidence and PPI have larger jumps and continuous components compared to the day of no announcement while the other announcements do not. These results imply that there is evidence to support the view that the USD/AUD foreign exchange rate volatility react to some but not all U.S. announcements as well as that the market will only react when the degree of unanticipation in the announcements is high.

It is interesting to compare the size of the jump and continuous components for the case of Australian announcements and U.S. announcements. For the same types of macroeconomic announcement, the sizes of the jumps and continuous components during the day of Australian announcement are relatively larger than the size of the jumps and continuous component during the day of U.S. announcement. The differences become larger for the case of a “greater than 1 unanticipated announcements”. These results imply that USD/AUD foreign exchange market tends to put more weight on the Australian macroeconomic announcements than to the US macroeconomic announcement.

6) Regression analysis of realised volatility on macroeconomic announcement and Reserve Bank intervention

So far, we have analysed the effect of intervention and macroeconomic announcement on volatility using the summary statistic of the jumps and continuous component from the realised volatility. In this section, we apply regression analysis to determine the relationship between the realised volatility, the macroeconomic announcements and Reserve Bank interventions. The summary statistic result in Table 1 suggests that the logarithm of the realised volatility is normally distributed, therefore the OLS regression is used to analyse the relationship between three types of volatility (realised volatility, continuous component and jump component[12]), the standardised surprise component of macroeconomic announcements and the Reserve Bank interventions.

[12] Although the logarithm series of jump component is not normally distributed . It is worth to see the relationship between the jump component, macroeconomic announcement and intervention. Beside, if the logarithm of realised volatility and bipower variation are normally distributed, the jump component which is the different between two normally distributed series should theoretically be normally distributed.

Before we move further into the detail of the model, we should define the term "standardized announcement" (S_{kt}) since. We follow Balduzzi, Elton and Green (2001) by imposing standaridised announcement in order to ease the problem of the units of measurement which are different across economic variables. The standardized news is calculated by

$$S_{kt} = \frac{A_{kt} - E_{kt}}{\hat{\sigma}_k}$$

where A_{kt} is the actual value of the announcement *k* at time t , E_{kt} is the forecasted value of the announcement *k* at time *t* (which is the Bloomberg median survey data), $\hat{\sigma}_k$ is the sample standard deviation of $A_{kt} - E_{kt}$ (or the surprise component of announcement *k*). Therefore, one unit increases in S_{kt} implies that an announcement is greater than expected by one standard deviation.

The regression equation are

$$rv_{t+1} = \beta_0 + \sum_{j=1}^{J} d_j + \sum_{k=1}^{K} \beta_k S_{k,t} + \alpha_1 INT_t + \varepsilon_t \qquad (18)$$

$$bv_{t+1} = \beta_0 + \sum_{j=1}^{J} d_j + \sum_{k=1}^{K} \beta_k S_{k,t} + \alpha_1 INT_t + \varepsilon_t \qquad (19)$$

$$jump_{t+1} = \beta_0 + \sum_{j=1}^{J} d_j + \sum_{k=1}^{K} \beta_k S_{k,t} + \alpha_1 INT_t + \varepsilon_t \qquad (20)$$

where rv_{t+1} is the logarithm of the realised volatility, bv_{t+1} is the logarithm of the bipower variation which represent the continuous component, $jump_{t+1}$ is the logarithm of the jump component, d_j presents the day of the week dummies with J =4 , $S_{k,t}$ is the absolute value of the standardized surprised component of announcement *k* at time t , k is the different type of announcements where we have *k*= 12. INT_t is the absolute amount of intervention at time t .

Note that the absolute term of the standardised surprise component ($S_{k,t}$) and absolute term of intervention (INT_t) are used in the regression because the nominal value of the standardised surprised component and intervention could give a misleading interpretation on the effect of realised volatility (Further discussion on this matter refers to appendix). If the coefficient of the absolute standardised surprise component (β_k) is positive (negative), it implies that regardless of the direction of the announcement, when there is an announcement it is associated with an increase (a decrease) in realised volatility. If the coefficient of the absolute intervention (α_1) is positive (negative), it implies that regardless of the direction of the intervention, when there is an intervention it is associated with an increase (a decrease) in realised volatility.

The second regression analysis is to investigate the effect between the direction of the announcements and intervention on exchange rate volatility. The model is as follow:

$$rv_{t+1} = \lambda_0 + \sum_{j=1}^{J} d_t + \sum_{k=1}^{K} \lambda_{kj} P_{k,t-j} + \sum_{k=1}^{K} \delta_{kj} N_{k,t-j} + \phi_1 SINT_t + \phi_2 PINT_t + \varepsilon_t \quad (21)$$

$$bv_{t+1} = \lambda_0 + \sum_{j=1}^{J} d_t + \sum_{k=1}^{K} \lambda_{kj} P_{k,t-j} + \sum_{k=1}^{K} \delta_{kj} N_{k,t-j} + \phi_1 SINT_t + \phi_2 PINT_t + \varepsilon_t \quad (22)$$

$$jump_{t+1} = \lambda_0 + \sum_{j=1}^{J} d_t + \sum_{k=1}^{K} \lambda_{kj} P_{k,t-j} + \sum_{k=1}^{K} \delta_{kj} N_{k,t-j} + \phi_1 SINT_t + \phi_2 PINT_t + \varepsilon_t \quad (23)$$

where rv_{t+1} is the logarithm of the realised volatility, bv_{t+1} is the logarithm of the bipower variation which represent the continuous component, $jump_{t+1}$ is the logarithm of the jump component, d_j presents the day of the week dummies with J =4 , $P_{k,t}$ is the greater than expected standardized surprised component of variable *k* at time *t*, $N_{k,t}$ is the less than expected standardized surprise component of variable *k* at time *t* , *k* is the number of announcements where we have *K*=12. $SINT_t$ is the amount of intervention associated with selling AUD at time t and $PINT_t$ is the amount of intervention associated with purchasing AUD at time t . All independent variables in the regression are in absolute term.

The result of the equation (18-20), is presented in Table 8-10, respectively.

Table 8

The effect of macroeconomic announcement and intervention on realised volatility

	Case of Australian announcement		Case of U.S. announcement	
Monday	-0.932*	(0.059)		
Tuesday	-0.901**	(0.060)		
Wednesday	-0.776	(0.062)		
Thursday	-0.748	(0.060)		
Friday	-0.790*	(0.046)		
GDP	0.226*	(0.116)	0.060	(0.073)
Retail trade	0.241*	(0.047)	-0.119	(0.219)
Unemployment	0.057	(0.088)	-0.006	(0.086)
Current account deficit	0.183*	(0.076)	-0.172	(0.127)
CPI	0.261	(0.173)	-0.039	(0.082)
Consumer confidence	-	-	0.050	(0.089)
PPI	-	-	-0.021	(0.108)
Intervention	0.003*	(0.001)	-	-

Note that to prevent multicollinearlity problem, Friday dummy is dropped for the day of the week effect. Therefore the constant term represent the change in realised volatility on Friday.
* shows that the coefficient is significant at 5% level.
** shows that the coefficient is significant at 10% level.

Table 9

The effect of macroeconomic announcement and intervention on continuous component

	Case of Australian announcement		Case of U.S. announcement	
Monday	-1.188*	(0.060)		
Tuesday	-1.108	(0.059)		
Wednesday	-0.990	(0.061)		
Thursday	-0.957	(0.060)		
Friday	-1.034	(0.046)		
GDP	0.218*	(0.106)	0.105	(0.069)
Retail trade	0.263*	(0.058)	-0.057	(0.207)
Unemployment	0.059	(0.081)	-0.003	(0.085)
Current account deficit	0.220*	(0.074)	-0.152	(0.130)
CPI	0.341	(0.183)	-0.030	(0.081)
Consumer confidence	-	-	0.037	(0.088)
PPI	-	-	-0.038	(0.097)
Intervention	0.003*	(0.001)		

* shows that the coefficient is significant at 5% level.
** shows that the coefficient is significant at 10% level.

Table 10

The effect of macroeconomic announcement and intervention on jump component

	Case of Australian announcement		Case of U.S. announcement	
Monday	-2.644	(0.098)		
Tuesday	-2.788*	(0.098)		
Wednesday	-2.643	(0.104)		
Thursday	-2.678	(0.106)		
Friday	-2.515	0.075)		
GDP	0.359	(0.217)	-0.036	(0.152)
Retail trade	0.147**	(0.084)	-0.345	(0.293)
Unemployment	0.061	(0.184)	-0.033	(0.162)
Current account deficit	0.059	(0.189)	-0.101	(0.142)
CPI	-0.068	(0.228)	-0.217	(0.223)
Consumer confidence	-	-	0.148	(0.129)
PPI	-	-	0.080	(0.177)
Intervention	0.003*	(0.001)		

* shows that the coefficient is significant at 5% level.
** shows that the coefficient is significant at 10% level.

The result of the day of the week effect for the realised volatility and bipower variation (continuous component) series indicate that the volatility on Monday is abnormally lower than the other days in the week, while the result of the jump component series indicates that the volatility on Tuesday is abnormally lower than the other days in the week.

The result from the realised volatility analysis suggests that the announcement about Australian GDP, retail trade and current account significantly associated with an increase in the exchange rate volatility, while announcement about Australian unemployment, Australian CPI and all U.S. variables noted above are not significant. The largest impact of the announcement on exchange rate volatility occurs with the Australian retail trade, Australian GDP, and Australian current account, respectively. These results show that the intervention significantly increases foreign exchange market volatility. The result from the continuous component is similar to the result from the realised volatility, while the result from the jump component shows that none of the announcement, except Australian retail trade announcement, is significantly associated with an increase in the jump component of the exchange rate volatility.

Table 11

The effect of macroeconomic announcement and intervention on realised volatility

	Greater than expected announcement		Less than expected announcement	
Monday	-0.920*	(0.058)		
Tuesday	-0.867	(0.059)		
Wednesday	-0.744	(0.061)		
Thursday	-0.735	(0.058)		
Friday	-0.775*	(0.046)		
Australian				
GDP	0.076	(0.138)	0.424*	(0.157)
Retail trade	0.151*	(0.061)	0.357*	(0.074)
Unemployment	0.161	(0.152)	0.026	(0.101)
Current account deficit	0.309*	(0.046)	-0.182	(0.165)
CPI	-0.157	(0.211)	0.489*	(0.249)
US.				
GDP	0.062	(0.097)	0.055	(0.056)
Retail trade	-0.484*	(0.134)	0.072	(0.180)
Unemployment	-0.019	(0.143)	-0.035	(0.095)
CAD	-0.221	(0.195)	-0.080	(0.071)
CPI	-0.032	(0.122)	-0.001	(0.109)
Consumer confidence	0.073	(0.102)	0.046	(0.136)
PPI	-0.012	(0.204)	-0.075	(0.109)
Intervention	-0.002	(0.003)	0.004*	(0.001)

One unit increases in the standardized news of a current account deficit means the deficit is lower than expected.
* shows that the coefficient is significant at 5% level.
** shows that the coefficient is significant at 10% level.

Table 12

The effect of macroeconomic announcement and intervention on continuous component

	Greater than expected announcement		Less than expected announcement	
Monday	-1.176*	(0.059)		
Tuesday	-1.074	(0.059)		
Wednesday	-0.958	(0.060)		
Thursday	-0.943	(0.059)		
Friday	-1.02*	(0.046)		
Australian				
GDP	0.064	(0.109)	0.435*	(0.161)
Retail trade	0.167*	(0.074)	0.396*	(0.080)
Unemployment	0.166	(0.149)	0.029	(0.087)
Current account deficit	0.322*	(0.063)	-0.064	(0.157)
CPI	-0.098	(0.205)	0.586*	(0.259)
US.				
GDP	0.125	(0.091)	0.059	(0.037)
Retail trade	-0.408*	(0.138)	0.125	(0.156)
Unemployment	-0.054	(0.146)	-0.008	(0.096)
CAD	-0.225	(0.195)	-0.035	(0.084)
CPI	-0.003	(0.116)	-0.014	(0.108)
Consumer confidence	0.063	(0.107)	0.028	(0.127)
PPI	-0.008	(0.188)	-0.104	(0.094)
Intervention	-0.002	(0.002)	0.004*	(0.001)

One unit increases in the standardized news of a current account deficit means the deficit is lower than expected.
* shows that the coefficient is significant at 5% level.
** shows that the coefficient is significant at 10% level.

Table 13

The effect of macroeconomic announcement and intervention on jump component

	Greater than expected announcement		Less than expected announcement	
Monday	-2.636	(0.161)		
Tuesday	-2.758*	(0.009)		
Wednesday	-2.617	(0.263)		
Thursday	-2.670	(0.102)		
Friday	-2.50*	(-32.97)		
Australian				
GDP	0.239	(0.328)	0.527*	(0.204)
Retail trade	0.101	(0.120)	0.183	(0.131)
Unemployment	0.222	(0.244)	0.011	(0.256)
Current account deficit	0.308**	(0.163)	-0.663**	(0.373)
CPI	-0.333	(0.248)	0.106	(0.487)
US.				
GDP	-0.154	(0.178)	0.210	(0.217)
Retail trade	-0.689*	(0.141)	-0.158	(0.337)
Unemployment	0.069	(0.223)	-0.139	(0.187)
CAD	-0.048	(0.207)	-0.110	(0.112)
CPI	-0.111	(0.171)	-0.290	(0.433)
Consumer confidence	0.109	(0.159)	0.215	(0.191)
PPI	0.034	(0.329)	0.066	(0.165)
Intervention	-0.002	(0.004)	0.005*	(0.001)

One unit increases in the standardized news of a current account deficit means the deficit is lower than expected.
* shows that the coefficient is significant at 5% level.
** shows that the coefficient is significant at 10% level.

The result of the equation (21)-(23), is presented in Table 11-13, respectively. The result from the realised volatility shows that there is an asymmetric effect between a greater than expected and lower than expected macroeconomic announcement. A lower than expected announcement about the Australian GDP and CPI are significantly associated with an increase in exchange rate volatility, while their greater than expected announcements are not significant. A greater than expected announcement about the Australian current account deficit significantly increases foreign exchange market volatility while a lower than expected announcement does not significantly affect foreign exchange volatility. The announcement about the Australian retail trade is significant in both direction of announcement, however its lower than expected announcement has a larger effect on volatility than its greater than expected announcement. The result from the continuous component is similar to the realised volatility while the result from the jump component is slightly different. The announcement about the Australian retail trade becomes insignificant.

None of U.S. announcement is significant, except the U.S. retail trade announcement. Interestingly, the result of the U.S. retail trade suggests that a greater than expected US. retail trade announcement decreases exchange rate volatility. It is possible that the information from the U.S. announcement about the retail trade during the sample period reduce an uncertainty in the market.

The result of Reserve Bank intervention suggests that only the purchase of AUD significantly increase exchange rate volatility. This finding is similar to the result from the summary statistic section.

Overall, there is evidence that the macroeconomic announcements are significantly associated with an increase in exchange rate volatility, with one exception of U.S. retail trade announcement where the announcement is associated with a decrease in exchange rate volatility. Most of announcements that are significant belong to the Australian announcements. There are evidences of sign asymmetric effect of the announcement on exchange rate. Hence, good and bad news alters the size of the impact of the announcement on exchange rate volatility. It is unclear, however which direction has larger impact on exchange rate volatility. For example, the result of announcement about Australian GDP and retail trade suggest that a lower than expected announcement (which is equivalent to a bad news about the economy) has a larger impact on exchange rate volatility than a greater than expected GDP announcement (which represents a good news about the economy). On the other hand, the greater than expected Australian current account deficit (which represents good news about the economy) has a larger impact on exchange rate volatility than the lower than expected announcement about the Australian current account deficit.

7) Conclusion

This chapter extracts the jump and continuous component of exchange rate volatility using realised volatility and the bipower variation. The jump and continuous components, are then used to investigate the behaviour of exchange rate volatility on day of U.S. and Australian macroeconomic announcement and Australian Reserve Bank intervention.

The summary statistic of continuous and jump components show that the effect of intervention on exchange rate volatility is asymmetric. Only the intervention by purchasing AUD is associated with an increase in exchange rate volatility. In order to explain this asymmetric result of intervention, the distribution of intervention shows that RBA have different intervention strategy where the size of intervention by purchasing AUD is relatively larger than the size of intervention by selling AUD.

The size of intervention could explain the asymmetric result of intervention, however the test on the relationship between the size of intervention and exchange rate volatility does not provide a strong support. The result suggests that regardless of the size of intervention the intervention by purchasing AUD always associate with a larger exchange rate volatility. It is possible that the market participant learn that RBA would intervene more heavily when the Australian dollar is depreciating and therefore have some expectation toward RBA intervention strategy which result in the asymmetric effect of intervention on exchange rate volatility.

The summary statistic analysis on Australian and U.S. macroeconomic announcement show that the most of the Australian announcements are associated with an increase in exchange rate volatility, in both jumps and continuous components while there are only few of the U.S. announcements that are associated with a change in exchange rate volatility. We find that the degree of unanticipation of the announcement affects the magnitude of the volatility movement in the foreign exchange market. The announcement with a high degree of unanticipation is associated with large increase in the exchange rate volatility.

The regression analysis confirms the finding of the summary statistic analysis section. Only the intervention by purchasing AUD significantly associates with an increase in exchange rate volatility. Most of the significant announcements are the Australian announcements. We also find that there is some evidence to suggest that the effects of “greater than expected” and “less than expected” announcements are asymmetric. This implies that good news and bad news affect exchange rate volatility differently. It is still unclear however, which direction gives a larger impact on exchange rate volatility.

Appendix A: The absolute value in equation 18

The absolute term of the standardised surprise component ($S_{k,t}$) and absolute term of intervention (INT_t) are used in the regression because the nominal value of the standardised surprised component and intervention could give a misleading interpretation on the effect of realised volatility. Table 14 shows that there are 4 possible interpretations when the nominal value of standardised surprised components are used in equation (18).

Table 14

The sign of the coefficient (β_k) for the case of nominal value of standardised surprise component when there is an announcement

	The sign of Coefficient (β_k) if the announcement increase rv_{t+1}	*The sign of Coefficient (β_k) if the announcement decrease rv_{t+1}*
Greater than expected announcement	Positive	Negative
Less than expected announcement	Negative	Positive

- A greater than expected announcement ($S_{k,t}$ >0) is associated with an increase in realised volatility. In this case, the coefficient of β_k is positive
- A greater than expected announcement ($S_{k,t}$ >0) is associated with a decrease in realised volatility. In this case, the coefficient of β_k is negative
- A lesser than expected announcement ($S_{k,t}$ <0) is associated with an increase in realised volatility. In this case, the coefficient of β_k is negative.
- A lesser than expected announcement ($S_{k,t}$ <0) is associated with a decrease in realised volatility. In this case, the coefficient of β_k is positive.

However by the nature of volatility, the effect of announcement on realised volatility could behave differently from these four interpretations. It is possible that a greater than expected announcement is associated with an increase in realised volatility. At the same time a lesser than expected announcement is also associated with an increase in realised volatility.

The above possibility could happen if the information from a greater than expected announcement increases an uncertainty in the market, at the same time the information from the lesser than expected announcement also increase an uncertainty in the market. In this case the coefficient that is estimated from the nominal value of the surprised component cannot explain this relationship between the announcement and realised volatility, hence the absolute value of the surprised component is required.

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