INTERNATIONAL JOURNAL OF FINANCE AND ECONOMICS
Int. J. Fin. Econ. **7**: 247–260 (2002)
Published online in Wiley InterScience (www. interscience.wiley.com). DOI: 10.1002/ijfe.189

THE ECONOMICS OF EXCHANGE RATE VOLATILITY ASYMMETRY

MICHAEL McKENZIE*
Royal Melbourne Institute of Technology, Melbourne, Australia

ABSTRACT

One commonly observed feature of financial market volatility is the presence of asymmetry whereby shocks to the market do not generate equal responses. This phenomenon has been attributed to the leverage effect for stock markets. For exchange rates, asymmetry has also been documented with no economic reason apparent. In this paper, a hypothesis is proposed and tested which attributes the presence of asymmetric responses in exchange rate volatility to the intervention activity of the central bank. Using daily intervention data for the Reserve Bank of Australia, empirical evidence is presented in support of this hypothesis which suggests that intervention may do more harm than good in volatile markets. Copyright © 2002 John Wiley & Sons, Ltd.

JEL CODE: F31

KEY WORDS: ARCH; volatility asymmetry; exchange rate intervention

NON-TECHNICAL SUMMARY

One commonly observed feature of financial market volatility is the presence of asymmetry whereby shocks to the market do not generate equal responses. In what has come to be known as ‘sign bias’, negative shocks are found to elicit a greater response from the market compared to positive shocks of an equal magnitude. For stock markets, this asymmetry has been attributed to the leverage effect whereby an increase in stock price volatility associated with ‘bad news’ causes that firm’s stock price to decline and the firm’s debt to equity ratio to increase. As a result, the financial risk borne by the equity holders increases which lowers current prices thereby reinforcing the bad news which produced the price decrease in the first instance. However, an increase in stock price volatility associated with the arrival of ‘positive news’ to the market causes a decrease in that firm’s corporate leverage and reduces that firm’s corporate risk. Thus, the increased price risk of the firm caused by the ‘news’ is offset somewhat by reduced corporate risk and so produces a smaller volatility impact.

Asymmetry has also been documented for exchange rates with no economic reason apparent. In this paper, a hypothesis is proposed and tested which attributes the presence of asymmetric responses in exchange rate volatility to the active participation of the government in the foreign exchange market. Typically, when the currency falls by a large enough amount, the central bank steps in to sell its holdings of foreign reserves and stem the depreciation. This intervention may in itself create uncertainty in the market about the ‘true’ (long-run) value of the exchange rate. Alternatively, the intervention may be motivated by market uncertainty in which case the central bank is trying to give an ambiguous market direction. Irrespective as to the exact nature of the uncertainty, sales of foreign reserves in the event of an exchange rate depreciation (i.e. a negative shock) create uncertainty in the market such that the following periods volatility may also be expected to be high. In contrast, where the exchange rate appreciates (i.e. a positive

*Correspondence to: Michael McKenzie, School of Economics and Finance, Royal Melbourne Institute of Technology, GPO Box 2476 V Melbourne 3001, Australia, E-mail: michael.mckenzie@rmit.edu.au

shock) the central bank may choose to rebuild its foreign exchange reserves or else leave the market to its own devices. In either case the element of uncertainty surrounding positive net purchases by the central bank is absent compared to when the exchange rate is falling and the central bank is a net seller. Thus, shocks to the market of equal magnitude will generate different responses depending on whether they are associated with an exchange rate appreciation or depreciation.

Using daily foreign exchange market intervention data for the Reserve Bank of Australia, the empirical testing conducted in this paper finds support for the hypothesis. The practical implications of this finding for governments exchange rate policy are fairly straightforward. Any attempt by government to stabilize a falling currency adds to volatility in the market and is therefore best avoided. As such, intervention may do more harm than good in volatile markets.

1. INTRODUCTION

Since their introduction by Engle (1982), the ARCH family of models has extensively evolved so that they may better capture the dynamic characteristics of financial market data. One such innovation has been to formally incorporate the asymmetry of market responses to volatility shocks in that negative shocks have been found to generate a larger response than positive shocks of equal magnitude.[1] This characteristic is commonly referred to as sign asymmetry and a number of different conditional variance specifications have been proposed to account for this including the GJR-GARCH model, the EGARCH model and the TARCH model. Hentschel (1995) provides a concise taxonomy of not only these asymmetric models but many others from the ARCH family.

Whilst ARCH models themselves do not arise out of any economic theory,[2] the presence of sign asymmetry in stock market responses has been attributed to the leverage effect. Black (1976), Christie (1982) and Nelson (1991) have argued that an increase in stock price volatility associated with 'bad news' causes that firm's stock price to decline and the firm's debt to equity ratio to increase. As a result, the financial risk borne by the equity holders increases which lowers current prices thereby reinforcing the bad news which produced the price decrease in the first instance. However, an increase in stock price volatility associated with the arrival of 'positive news' to the market causes a decrease in that firm's corporate leverage and reduces that firm's corporate risk. Thus, the increased price risk of the firm caused by the 'news' is offset somewhat by reduced corporate risk and so produces a smaller volatility impact. Interested readers may refer to Bollerslev, Chou and Kroner (1992, p. 24) for a discussion of the leverage effect and the application of non-linear or asymmetric ARCH models to stock market data. More recent applications may be found in Campbell and Hentschel (1992), Engle and Ng (1993), Glosten, Jagannathan and Runkle (1993), Kearns and Pagan (1993), Rabemananjara and Zakoian (1993), Brailsford and Faff (1993), Bailsford (1995) and Henry (1998).

Whilst the leverage effect provides a plausible explanation for asymmetry in stock market data, no theoretical justification exists for the presence of asymmetry in other financial data such as exchange rates. Yet ARCH models which allow asymmetric responses have been successfully fitted to exchange rate data (see Hsieh, 1989; Kam, 1995; Byres and Peel, 1995; Tse and Tsui, 1997; Hu, Jiang and Tsoukalas, 1997; Kim, 1998, 1999). This paper attempts to redress this gap in the literature by proposing and testing one possible hypothesis which relates asymmetry in exchange rate volatility to central bank intervention in the market. The rest of this paper proceeds as follows. Section 2 details the hypothesis by which asymmetry in exchange rate volatility is related to central bank intervention in the foreign exchange market. The model by which this hypothesis is to be tested is discussed in Section 3. Section 4 presents details of the data including a brief commentary on the evolution of Australian Reserve Bank intervention policy. Section 5 presents and discusses the estimated results. Finally, Section 6 summarizes the paper and presents some conclusions based on the empirical results as well as suggesting some further avenues for research.

2. CENTRAL BANK INTERVENTION AND EXCHANGE RATE VOLATILITY ASYMMETRY

The central bank is government's monetary authority and it may choose to intervene in the foreign exchange market for a number of reasons including to smooth the market, prevent imported inflation, ensure international competitiveness, or reduce exchange rate volatility. Arguably the primary reason for central bank intervention, however, is to correct deviations of the market away from a level dictated by the fundamentals. Such intervention takes the form of the central bank directly trading in the foreign exchange market. Implicit in this type of behaviour is the assumption that the central bank is in a better position to respond to longer term influences than traders who respond to more immediate market place pressures. Osterberg and Humes (1993, 1995) provide evidence to suggest that foreign exchange traders do suffer information asymmetries and as such, central bank intervention on these grounds may be justified.

The active participation of the central bank in the foreign exchange market is hypothesized in this paper to explain the presence of volatility asymmetry. When the currency falls by a large enough amount, the central bank typically steps in to sell its holdings of foreign reserves and stem the depreciation. This intervention may in itself create uncertainty in the market about the 'true' (long-run) value of the exchange rate. The Chief Administrative Officer of the Reserve Bank of Australia (RBA) acknowledged this possibility in a speech to the Australian Society of Corporate Treasurers when referring to market testing role of the authority: 'It's not easy to sort out the forces at work in the market at any time—to separate out the "genuine" from the "speculative", or the manipulative, the plainly mischievous, the outworking of bouts of gloom and euphoria, the guessing and second guessing.... When the pressures are strong and the episodes are frequent and long-lasting, testing can sometimes involve large amounts.'[3] Alternatively, the intervention may be motivated by market uncertainty in which case the central bank is trying to give an ambiguous market direction. The RBA reserves a role itself in this area as it often uses intervention in an attempt 'to calm temporary agitation in the market, particularly if the source of the agitation lacks substance and seems likely to be short-lived.'[4] Irrespective as to the exact nature of the uncertainty, sales of foreign reserves in the event of an exchange rate depreciation (i.e. a negative shock) create uncertainty in the market such that the following periods volatility may also be expected to be high.

In contrast, where the exchange rate appreciates (i.e. a positive shock) the central bank may choose to rebuild its foreign exchange reserves or else leave the market to its own devices. The RBA again provides evidence of this sort of behaviour referring to a period in late 1986 when the exchange rate was appreciating and the RBA was a heavy net purchaser of foreign exchange, 'the objective was not to stop the rate going above a particular figure. [The] main purpose was to recoup the reserves we had used earlier in the year...'[5] In any event, the element of uncertainty surrounding positive net purchases by the central bank is absent compared to when the exchange rate is falling and the central bank is a net seller. Thus, shocks to the market of equal magnitude will generate different responses depending on whether they are associated with an exchange rate depreciation or appreciation.

One problem with testing any hypothesis involving central bank intervention in the foreign exchange market is that detailed timely information is scarce. Understandably, the central bank is hesitant to release exact details of such sensitive information. Historically, proxy variables have been constructed based on some change in the central banks holdings on international reserves. Such data is available usually at either a monthly frequency directly from the central bank itself or the International Monetary Fund's *International Financial Statistics* which also provides this information at a quarterly frequency. However, the use of such a proxy variable presents a number of problems. First, it is the daily activities of the central bank which is usually of most interest from an empirical standpoint. When you consider that the central bank typically intervenes on a tick basis, one could reasonably argue that even daily data does not sufficiently capture the intervention activity of the central bank. In this case, the use of quarterly data has a rather obvious potential to obscure important information. Second, changes in foreign reserves may not capture the actual level of net purchases undertaken by the central bank for the purposes of manipulating the exchange rate. Changes in international reserves may occur for a number of reasons including sales to the government, the re-valuation of reserves or the accrual of interest earned on foreign dollar holdings. In this case, the use of a proxy based on changes in international reserves again may obscure important relationships.

More recently, a limited amount of daily foreign exchange intervention data has been made available. For example, the US Treasury provides daily intervention information available at a one-year lag and the Bundesbank has provided a historical intervention database over the period 1982–1988.[6] The Australian government monetary authority, the Reserve Bank of Australia, also provides information on its foreign exchange market activities. This series provides daily information on the net market purchases of the central bank and is a composite of the bank's two main activities. These are the trading of foreign exchange to manipulate the market and the trading of foreign exchange to meet the needs of the government.[7] Thus, the series is not pure foreign exchange intervention data. To the extent that the government has discretion as to the timing of both types of transactions as well as the size of the former, Andrew and Broadbent (1994, p. 10) argue that it is appropriate to use an aggregate figure to calculate the total effect of the Reserve Bank's actions on the exchange rate.

This paper will use the daily data made available by the Australian government to test the impact of central bank intervention on volatility in the Australian foreign exchange market. This data has been previously analysed by a number of authors. Andrew and Broadbent (1994) tested whether the intervention activities of the RBA had exerted a stabilizing influence on the foreign exchange market. To the extent that stabilizing speculators make profits, the authors conclude that the central bank has achieved its goal as evidenced by its trading profit of AUD$3.4 billion over the period December 1983 to June 1994. Mansfield (1997) applied a series of Granger causality tests to establish that knowledge of daily market intervention by the RBA improves the prediction of returns to the Australian dollar. However, weekly returns information was found to influence the trading activity of the central bank. Murphy and Hopkins (1997) utilized a case study approach to examine movements in the Australian dollar over the period July to October 1993. The authors found that for the brief period under study, central bank intervention was a significant determinant of changes in the Australian exchange rate as were public announcements by the RBA.

3. MODEL

The hypothesized relationship between exchange rate volatility and intervention may be tested using a model which captures the impact of intervention in both the mean[8] and variance equation, i.e.:

$$R_t = a_0 + a_1 D_{0,t} + a_2 R_{t-1} + \varepsilon_t \qquad \varepsilon_t \sim N(0, h_t)$$

$$h_t = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \beta_1 h_{t-1} + \gamma_1 \varepsilon_{t-1}^2 D_{1,t-1} \qquad (+\gamma_2 \varepsilon_{t-1}^2 D_{2,t-1}) \tag{1}$$

where R_t are the exchange rate returns, D_0 is a dummy variable which takes on a value of 1 if a positive net purchase of foreign exchange is made by the central bank, -1 for a negative net purchase and zero otherwise. The hypothesized behaviour of the central bank suggests that $a_t > 0$ as foreign reserve sales ($D_0 = -1$) are assumed to be motivated by an exchange rate depreciation in which case a below-average return should be observed. By similar logic, foreign reserve purchases ($D_0 = 1$) should coincide with an exchange rate appreciation or an above-average return.

The conditional variance of the errors are assumed to follow a generalized form of the Threshold ARCH (GTARCH) model of Zakoian (1994). The term threshold is used as the response mechanism changes to include γ_1 when the error term crosses below the threshold of zero. The asymmetric nature of this TARCH model is best described using an approach introduced by Pagan and Schwert (1990) and is presented in Figure 1. Christened the 'news impact curve' by Engle and Ng (1993), the curve relates the impact of shocks to that markets volatility. From Figure 1, where $D_{1,t} = 0$, the standard GARCH model conditional variance is specified and the news impact curve is symmetric in ε_t, h_t space. However, a negative shock (i.e. $D_t = 1$) generates an asymmetric response from the market in that where $\gamma > 0$ ($\gamma < 0$), then this model produces a larger (smaller) response from the market compared to a cognate positive shock.[9]

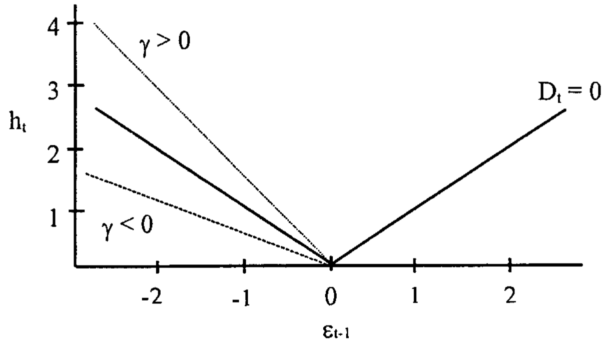

Figure 1. News impact curve of the TARCH model.

To capture the effect of intervention on volatility asymmetry, an additional dummy variable (D_2) may be included in the GTARCH model. In this modified conditional variance equation, D_2 takes on a value of unity if central bank intervention in the form of negative net purchases occurs and zero otherwise. The γ_2 term in equation (1) captures the potential impact of central bank intervention on the asymmetry of the conditional variance. Under the hypothesis to be tested, where the exchange rate depreciates (a negative shock), the central bank will sell foreign reserves (a negative net purchase) to stem a downward movement in the exchange rate. This intervention creates (or reflects) uncertainty in the market such that the following period's response is greater than for a cognate positive return. As such, where central bank intervention occurs (i.e. $D_2 = 1$), the conditional variance is $\gamma_2\varepsilon_{t-1}^2$ greater (smaller) where $\gamma_2 > 0$ ($\gamma_2 < 0$) compared to an equivalent positive shock.

This dummy variable augmented GTARCH model implicitly assumes government intervention to be exogenous. That is, while the model allows government interention to impact on volatility, the intervention decisions of government are assumed to be independent policy choices made without regard for volatility. The merit of such an assumption is unclear as while the exact process by which government makes intervention decisions is highly esoteric, on the balance of probabilities it is likely that volatility enters into the government decision-making function to some degree. Thus, the results presented in this paper must be interpreted in light of the possibility that some form of feedback loop may exist between volatility and government intervention.

4. DATA

Data for the daily net foreign exchange purchases by the Reserve Bank of Australia were available over the period 12 December 1983 to 31 December 1997 giving a total of 3560 observations. As the bulk of the RBA's intervention involves trading US dollars against the Australian dollar on a spot basis,[10] daily 4 pm rates for the USA/AUD were also sampled over the relevant period. The mean level of intervention by the RBA over the sample period was AUD\$5.45 million and the standard deviation was AUD\$76.7 million. Not surprisingly, the data is highly non-normal (Jarque–Bera = 1097936.0) and exhibits a high proportion of outliers (kurtosis = 88.20). Whilst the central bank made more positive net purchases than negative (1165 and 490 transactions respectively), there was a disproportionate number of large sales of foreign exchange (skewness = −5.96).

Figure 2 presents a combined plot of central bank net foreign exchange purchases and the USD/AUD exchange rate. The start of the sample period corresponds to the time of the floating of the Australian dollar on December 12, 1983. Prior to this time, Australia was a participant in the Bretton Woods regime until its collapse in 1973. In the interim, the exchange was pegged briefly to the US dollar and then to a Trade Weighted Index. At the time of the float, the RBA adopted a policy of 'testing and smoothing' (in which it would occasionally enter the market to test the strength and nature of market trends[11] or to

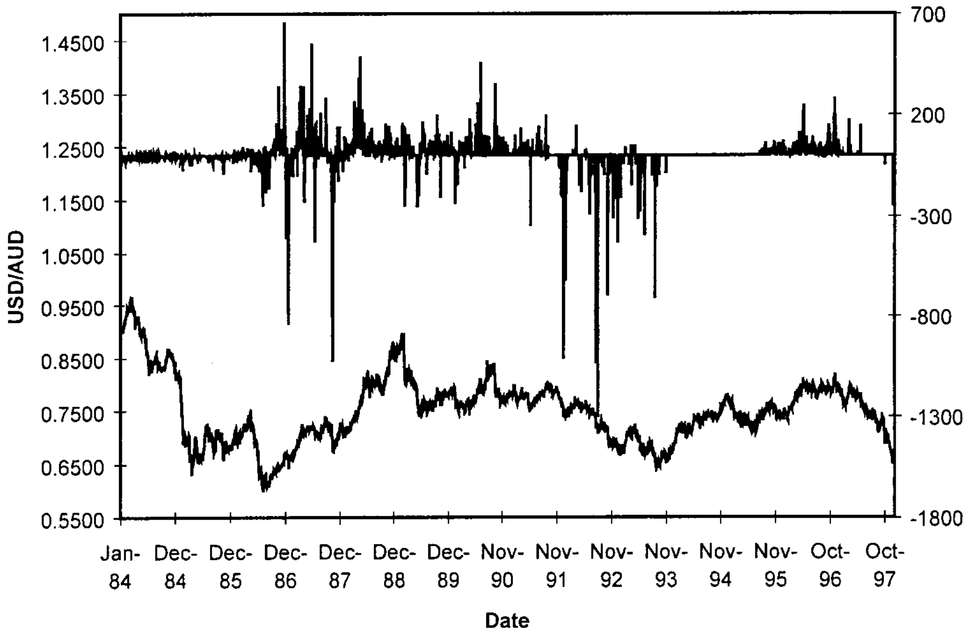

Figure 2. Daily intervention by the RBA and the USD/AUD exchange rate from December 1983 to December 1997.

smooth the path of large currency transactions. Although it would generally not intervene in the market, the RBA publicly reserved discretionary rights in this area. The intervention was aimed primarily at correcting for 'unjustified falls' in the exchange rate and would take the form of direct purchases of the Australian dollar. From Figure 2, the degree of intervention by the RBA in the initial period after the float would appear to support this policy statement. The level of net foreign exchange purchases in the first year of the float were generally quite small. To the end of 1984, the mean absolute daily transaction was AUD\$5.76 million and the maximum positive (negative) net daily purchase was AUD\$32 (AUD\$81) million. Further, the RBA intervened on average 56% of the time (i.e. of the total number of days in the month in which the markets were open, the RBA did not intervene in the market 44% of the time).

In February 1985 the AUD began a downward slide which resulted in a 24% depreciation against the USD by late April. The RBA announced they would take action to moderate the volatility of the dollar and sold down their foreign reserve holdings to the order to AUD\$319 million in February with a further sale of AUD\$343 million in April. At the time, this was an unprecedented level of intervention by the central bank in the exchange rate. The exchange rate appreciated over the next year, albeit with varying levels of 'help' by the central bank. However, the AUD again came under pressure in early May 1986. This renewed period of selling led to the AUD losing the gains of the previous year, falling from 0.7455 on May 12 to a record post-float low of 0.5980 by 1 August 1986. On 14 May 1986, the Federal Treasurer, Paul Keating, made an infamous comment in which he warned that Australia was in danger of becoming a 'banana republic' unless the burgeoning current account deficit stemming largely from the accumulation of foreign debt was controlled. Whilst the RBA issued no official statements of a change in intervention policy,[12] Figure 2 clearly indicates that the 'testing and smoothing' policy which it had adopted since the float was abandoned shortly after the Keating comment in favour of a more pro-active approach to managing the exchange rate. From July 1986 to the end of December 1993, the RBA traded an average of AUD\$40 million per day and intervened in the market an average of 55% of the time. The maximum positive (negative) daily purchase over this period was AUD\$661 million (AUD\$-1305) and there were 17 instances in which they traded every day the markets were open in a given month.

More recently, the RBA has been relatively quiet in terms of its market intervention activities. The dollar has traded continuously in a band of between 0.82 and 0.65 with little or no central bank intervention except an apparent effort to rebuild its foreign currency reserves undertaken in 1996. From 1994 to the end of the data sample period, the central bank intervened only 27% of the time on average and the mean absolute daily transaction was AUD$10.97 million with a maximum (minimum) daily transaction of AUD$285.7 million (AUD$-250.0 million). Of the 277 purchases made over this 1011-day period, 274 were positive net purchases of foreign exchange.

5. ESTIMATION RESULTS

Continuously compounded percentage returns to the USD/AUD exchange rate were estimated as $R_t = \log(p_t/p_{t-1})$ where p is the observed spot exchange rate at time t. The LM test for ARCH effects proposed by Engle (1982) provided evidence as to the presence of ARCH effects in this returns data. It is possible to model these ARCH effects using the standard GARCH model proposed by Bollerslev (1986). Panel A of Table 1 provides the result of this estimation procedure and the intervention dummy in the mean equation is significant and of the correct sign suggesting that above (below) average returns are observed when positive (negative) net foreign exchange purchases are transacted. Technically, the hypothesis on central bank behaviour suggests that sales and purchases coincide with positive and negative returns and not above or below average returns. Therefore, to provide additional insights to this hypothesis, Table 2 presents a summary of information regarding the occurrence of positive and negative intervention and the corresponding exchange rate return. Of the 1904 days on which no intervention occurred, the mean exchange rate was close to zero and a relatively even number of positive and negative returns were observed. When the central bank sold (purchased) reserves, however, the mean return was −0.420% (0.136%) and 71% (64%) of the observations occurred in negative (positive) return days. Taken together, this evidence of the relationship between intervention and returns and the significant positive a_1 coefficient in the mean equation provide support for the hypothesised behaviour of a central bank.

The variance equation of this model passes the standard tests of robustness in that both the ARCH(α) and GARCH(β) terms are positive and statistically significant. Further, the ARCH process is stationary as the sum of the ARCH and GARCH parameters is less than unity, i.e. $\Sigma(\alpha_i + \beta_i) < 1$ (where $i > 0$). The adequacy of this model needs to be considered and a number of different techniques exist for this purpose. The squared standardized residuals of this GARCH (1,1) model reveals an absence of significant autocorrelation which Bollerslev and Mikkelsen (1996) argue indicates the model has captured all the ARCH effects. An additional test of ARCH model adequacy is to consider whether the standardized residuals are iid$\sim$N(0,1). The mean standardized residual (−0.0062) is not significantly different from zero and the standard deviation is close to unity (1.0004). However, the residuals are still not *Gaussian* as evidenced by the highly significant Jarque–Bera statistic (1644.82). The kurtosis value of 6.14 indicates leptokurtosis and the standardized residuals are negatively skewed (−0.548).

When modelling volatility clustering as an ARCH process, skewness in the standardized residuals of the model is potentially suggestive as to the presence of volatility asymmetry to the extent that large negative changes tend to follow large negative changes whilst the same cannot be said for large positive values. One may formally test for asymmetry in the residuals of this GARCH model fitted to the daily exchange rate data. To this end, Engle and Ng (1993) suggest a sign bias test, a negative size bias test and a positive size bias test to be conducted jointly in an OLS regression equation of the following form:

$$z_t^2 = a + b_1(S_t^-) + b_2(S_t^-\varepsilon_{t-1}) + b_3(S_t^+\varepsilon_{t-1}) + v_t \qquad (2)$$

where z_t are the standardized residuals (i.e. $z_t = \varepsilon_t/\sqrt{h_t}$) and $S_t^-(S_t^+)$ is a dummy variable that takes on a value of unity if ε_{t-1} is negative (positive) and zero otherwise. The sign bias test relates to the statistical significance of b_1. Where the test statistic is insignificant, than positive and negative shocks do not have an appreciably different impact on volatility. The negative (positive) size bias test relates to the statistical test on $b_2(b_3)$. If $b_2(b_3)$ is found to be statistically non-zero, then it is likely that large and small negative (positive) innovations impact differently on volatility. The standard ARCH models require that b_1, b_2 and b_3 are jointly equal to zero which may be tested with the standard F-statistic. The sign bias test of Engle and

Table 1. ARCH model estimation results. This table presents the estimated parameters of the GTARCH model:

$$R_t = a_0 + a_1 D_{0,t} + a_2 R_{t-1} + \varepsilon_t \qquad \varepsilon_t \sim N(0, h_t)$$

$$h_t = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \beta_1 h_{t-1} + \gamma_1 \varepsilon_{t-1}^2 D_{1,t-1} (+\gamma_2 \varepsilon_{t-1}^2 D_{2,t-1} + \ldots)$$

which has been augmented with dummy variables (D_{2-4}) to test for the impact of central bank intervention over the period December 1983 to December 1997

	a_1	α_1	β_1	γ_i	$\gamma_2(D_2)$	$\gamma_3(D_3)$	$\gamma_4(D_4)$	$\Sigma(\alpha_1+\beta_1)$
Panel A								
GARCH	0.001	0.089	0.890	–	–	–	–	0.979
	(15.82)	(13.48)	(123.39)					
GTARCH	0.001	0.079	0.889	0.017	–	–	–	0.968
	(15.60)	(8.50)	(120.43)	(1.98)				
Panel B: D_2 take the value of unity if negative net purchases of foreign exchange are made by the central bank								
GARCH	0.001	0.089	0.886	–	1.200	–	–	0.975
	(15.31)	(13.46)	(119.37)		(3.70)			
GTARCH	0.001	0.081	0.885	0.014	1.170	–	–	0.966
	(15.19)	(8.59)	(117.18)	(1.44)	(3.58)			
Panel C: $D_3(D_4)$ take the value of unity if large (small) negative net purchases of foreign exchange are made by the central bank								
GARCH	0.001	0.094	0.875	–	–	2.970	0.148	0.969
	(15.43)	(13.38)	(108.70)			(5.13)	(0.28)	
GTARCH	0.001	0.087	0.875	0.012	–	2.910	0.148	0.962
	(15.30)	(8.75)	(107.66)	(1.21)		(5.03)	(0.284)	
Panel D: D_2 take the value of unity if positive net purchases of foreign exchange are made by the central bank								
GARCH	0.001	0.089	0.889	–	−0.092	–	–	0.978
	(15.77)	(13.31)	(118.99)		(0.72)			
GTARCH	0.001	0.079	0.888	0.018	−0.122	–	–	0.967
	(15.64)	(8.42)	(115.80)	(1.93)	(0.94)			
Panel E: $D_3(D_4)$ take the value of unity if large (small) positive net purchases of foreign exchange are made by the central bank								
GARCH	0.001	0.089	0.890	–	–	−0.041	−0.205	0.979
	(15.79)	(13.20)	(116.95)			(0.25)	(0.95)	
GTARCH	0.001	0.078	0.889	0.019	–	−0.051	−0.284	0.967
	(15.67)	(8.37)	(114.86)	(2.01)		(0.31)	(1.34)	

Note: Absolute values of t-statistics in parentheses.
D_2, D_3 and D_4 are specified as E-06.

Table 2. Exchange rate returns and nature of government intervention

	No intervention	Foreign reserve purchases	Foreign reserve sales
No. of observations	1904	1165	490
$R_t < 0$	912	417	349
$R_t > 0$	992	748	141
Mean R_t	0.00007	0.00136	−0.00420
Min R_t	−0.02744	−0.02889	−0.04560
Min R_t	0.03093	0.03081	0.02439

Note: This table presents a summary of the USD/AUD exchange rate returns (R_t) observed on days of no intervention and days on which the central bank purchased and sold foreign reserves.

Table 3. Engle and Ng sign bias test results

Sign bias test	Negative size bias test	Positive size bias test	Joint test
0.163	−5.868	−3.017	2.400
(0.126)	(0.620)	(0.831)	(0.065)

Note: *P*-values in parentheses.

Ng was applied to the residuals of the GARCH model fitted to the exchange rate returns and the estimated coefficient and associated probability are presented in Table 3. Examining these results, we can see that whilst none of the sign and size tests are individually significant, the joint test is significant suggesting the possible presence of asymmetry in the data.

To capture asymmetry in the market's response to volatility shocks, we may augment the GARCH conditional variance specification by including a dummy variable term such that the conditional variance takes on the form specified in equation (1). Panel A of Table 1 presents the estimated results for this GTARCH model. The ARCH and GARCH terms are again both positive, statistically significant and sum to be less than unity. Most importantly, the asymmetry term (γ_1) is significant and positive. This indicates a sign asymmetry in the data as negative shocks to the market elicit a larger response ($\alpha_1 + \gamma_1$) than an equivalent positive shock (α_1).

To investigate a possible cause of this asymmetry, the conditional variance equation may be modified to take account of the impact of central bank intervention. Panel B of Table 1 presents the results where equation (1) is estimated with the inclusion of a dummy variable capturing sales of foreign reserves by the central bank. The estimated parameters of this augmented GARCH model are similar to the standard model in terms of the alpha and beta coefficients. More importantly, the dummy variable associated with negative central bank net purchases is positive and statistically significant indicating that the conditional variance is greater in the period following central bank intervention. To the extent that central bank sales of foreign reserves accompany a fall in the exchange rate, this means that the response by the market to shocks is asymmetric. When the exchange rate falls, the market response is greater than if the exchange rate rises. As the standard GARCH model is nested in this government bank intervention augmented variant, it is possible to compare these two models using the standard likelihood ratio testing procedure. A comparison of the log likelihood estimates for these two models reveals a clear preference for the central bank intervention augmented variant at the 5% level.

We may re-estimate this model using a GTARCH specification which is presented in Panel B of Table 1. This robust model provides a most interesting result as the negative central bank net purchases dummy variable is again positive and significant. However, the Threshold term (D_1) which was previously significant in the standard GTARCH model is now insignificant. This result suggests that the asymmetry in the exchange rate sources from central bank sales of foreign exchange. A comparison of the central bank intervention augmented GTARCH model to the nested standard GTARCH model reveals a clear preference for the former at the 5% level. Thus, it would appear that the inclusion of a variable capturing central bank sales of international reserves is a worthwhile addition to the standard GTARCH and GARCH models.

The extent of the uncertainty in the market may be reflected in the degree of intervention by the central bank. If we believe this to be true, then asymmetry caused by central bank intervention would be related to the size of the sale of foreign exchange. As such, distinguishing the size of central bank intervention may provide some additional insights to the previous results. To this end, we may classify central bank sales of foreign exchange as either 'large' or 'small' where the delimeter is the mean absolute central bank foreign exchange transaction (AUD$26 million) over the sample period.[13] Thus, the conditional variance equation to be tested is either the standard GARCH or GTARCH model augmented with the inclusion of two additional dummy variables, D_3 (D_4), which take on a value of unity where the central bank makes a large (small) sale of foreign exchange and zero otherwise. The estimated models are presented in Panel C of Table 1 and the robust GARCH model produces a positive γ coefficient on both dummy variables, although only the dummy variable associated with large negative net purchases of the central bank was statistically significant. The GTARCH model estimated with the small and large sale of foreign exchange dummy variables is remarkably similar to the GARCH model and the threshold term is not significantly different from zero. Thus, it would appear that it is the sale of above-average sized parcels of foreign exchange by the central bank which would appear to cause asymmetry in foreign exchange volatility.

The impact of acquisitions of foreign exchange by the RBA on market volatility may also be tested by substituting a dummy variable for positive intervention into the conditional variance equation of the GARCH and GTARCH models. In this case, the impact of positive net foreign exchange purchases by the central bank ($D_2 = 1$) is captured by the γ_2 coefficient. Under the hypothesis to be tested, the estimated coefficient associated with this positive intervention dummy variable should be close to zero and statistically insignificant as positive net purchases are postulated not to be associated with market uncertainty. Panel D of Table 1 provides the estimated coefficients for this model and the α and β coefficients are positive and significant. Net positive foreign exchange purchases by the central bank is found not to have a statistically significant impact on volatility in the USD/AUD market. In the context of the GTARCH model, the threshold term is significant, indicating that the asymmetry in the market is not accounted for by this dummy variable. We may also distinguish between small and large positive purchases by including two dummy variables in the GARCH and GTARCH models and as shown in Panel E of Table 1, the results are unaltered. The net large and small positive foreign exchange purchase dummy variables were found not to have a statistically significant impact on volatility.

The policy implications of the findings discussed in this section suggest that the market watches and reacts to the sales of foreign reserves by government in a manner which is not found for purchases. As such, any attempts by government to settle and provide direction to the market which involve episodes of selling may ultimately prove futile and indeed even exacerbate market volatility.

5.1. Sub-period analysis

Based on the discussion contained in Section 4, we may distinguish three distinct sub-periods for analysis based on the nature of the intervention by the Reserve Bank of Australia. The first sub-period relates to the 'smoothing and testing' policy phase which runs from the time of the floating of the dollar to June, 1986. The second sub-period for analysis is defined as the 'active intervention' period of the central bank and corresponds to July 1986 to December 1993. The final sub-period for analysis ranges from January 1994 to the end of the data sample period in December 1997 and might be described as a 'reserve rebuilding' phase. In sub-period 3, the Australian dollar was generally appreciating and the RBA intervened little except to acquire foreign reserves.

In order to test each of these sub-periods, the GARCH and GTARCH models estimated in Section 5 were re-estimated in each discrete sub-period. The results are not presented to conserve space and may be compactly summarized as follows. In sub-period 1, the asymmetry term is significant and remains so with the inclusion of the negative net purchases dummy variable. The same result is evident when we distinguish between large and small negative net purchases, except that the large dummy variable is significant in the GARCH model. Given that the level of central bank intervention over this period amounted to little more than 'tinkering', these results are consistent with our expectations. Recall from the full period analysis, it was primarily the large negative net purchases, which were responsible for generating the asymmetry. The fact that the TARCH asymmetry term is significant over this period suggests that whilst the central bank intervention does help to explain exchange rate asymmetry it does not fully account for this phenomenon.

Sub-period 2 relates to the period of active intervention by the central bank and the results in this sub-period are largely consistent with the results discussed in Section 5 except that the asymmetry term in the standard GTARCH model was insignificant. It is possible to argue that a structural break exists in sub-period 2 at October 1991 as the central bank sold its foreign exchange reserves from that point on in an apparent attempt to stop the downward slide of the Australian dollar (the largest single day sale of AUD$-1.305 billion was made in this period and of the 130 transactions in this period of 559 observations, 115 were negative). As a test of robustness, the models were re-estimated first, in the period covering July 1986 to October 1991 and second, from October 1991 to the end of sub-period 2 in December 1993. For the July 1986 to October 1991 period, the results were generally consistent with those reported for the whole sub-period and for the October 1991 to December 1993 period, a lack of data prevented the models from reliably estimating.

In the final sub-period, recall there are virtually no sales by the central bank of foreign exchange and the Australian dollar generally appreciates. This final sub-period is also interesting as the LM test for ARCH effects is not significant (in contrast to the first two sub-periods) and the estimated ARCH models exhibit an insignificant α_1 term.[14] As one would expect with only three negative net purchase observations, the intervention dummy variables are highly insignificant, but more interestingly, the threshold term is also insignificant. Figure 3 presents a plot of the squared returns to the Australian dollar for the sample period, and casual observation provides no immediate reason to explain this result. Whilst there does appear to be less volatility clustering over this final sub-period compared to very early in the sample, arguably other periods exhibited even less volatility (1991-2, for example). It is possible that these results are reflection of the relatively small sample size (although 1011 observations well exceeds that minimum sample size of 500 suggested by McClain, Humphreys and Boscan (1996) as necessary for reliable ARCH model estimation). Alternatively, it would appear that in this third sub-period where by central bank is fairly inactive in the

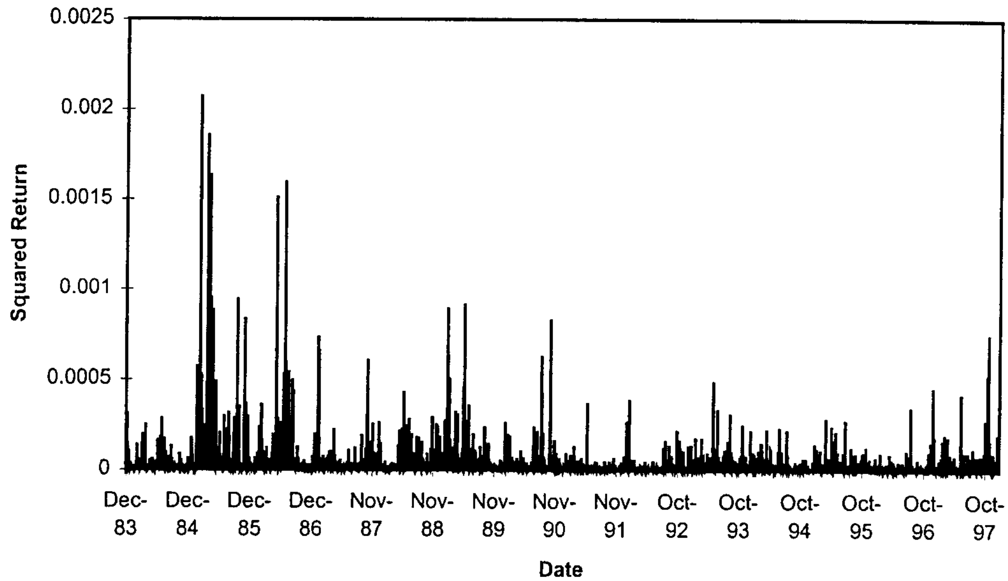

Figure 3. Squared returns to the Daily USD/AUD exchange rate from December 1983 to December 1997.

market, the market volatility not only loses the asymmetry element, but also the clustering feature. Whilst not suggesting that the central bank intervention is a factor in determining volatility clustering in exchange rate volatility (many freely floating exchange rates experience this phenomenon), it is an interesting result nonetheless.

6. CONCLUSIONS

Sign bias in financial market volatility refers to the presence of an asymmetry whereby negative shocks are found to elicit a greater response from the market compared to positive shocks of an equal magnitude. For stock markets, this asymmetry has been attributed to the leverage effect. Exchange rate data has also been found to exhibit evidence of asymmetric responses, however, with no reason offered. In this paper, a hypothesis is put forward which attributes the presence of asymmetric responses in exchange rate volatility to the intervention activity of the central bank. Specifically, the sale of foreign exchange by the central bank is hypothesized to cause sign asymmetry. Using daily central bank intervention data for Australia, empirical evidence is found which supports this hypothesis. Specifically, large sales of foreign reserves by the central bank was found to elicit a greater than normal response from the market compared to periods in which the central bank purchased foreign reserves. Thus, the policy implications of this work suggest that the market watches and reacts to the sales of foreign reserves by government such that any attempts to settle the market which involve episodes of selling may ultimately prove futile and indeed even exacerbate market volatility.

ACKNOWLEDGEMENTS

The author would like to thank Gerry Gannon, Heather Mitchell, Mardi Dungey, John Dokovic of The Reserve Bank of Australia, Robert Brooks and an anonymous referee.

NOTES

1. A second assumption of the standard ARCH model about the market's response to volatility shocks is that large and small innovations impact in a proportionately similar fashion on volatility. This 'size' assumption arises from the quadratic specification of the GARCH conditional variance equation. Empirical evidence suggests that large shocks have been found to produce a disproportionately larger response from the market when compared to small shocks. Unlike sign bias, size asymmetry is not thought to be confined to a particular class of asset and may thus be present in any speculative asset price series. As the focus of this paper is on explaining sign bias, the size bias assumption is not formally considered.
2. Although the literature has attempted to provide an economic rationale for ARCH effects, precise links have proved difficult to capture (see Ackert and Racine, 1997; Diebold and Lopez, 1995).
3. RBA Bulletin, December 1986, p. 4.
4. *Ibid.*
5. *Ibid.*
6. Frankel and Dominguez (1993) have used this US and German intervention information and found that intervention operations influence the risk premium. Further, official announcements on exchange rate policy and reports of intervention were also found to influence exchange rate expectations.
7. The Reserve Bank also engages in a third form of transaction which involves changing the foreign currency position of reserves. As this type of transaction does not involve the Australian dollar, their inclusion is not necessary.
8. The authors wish to thank an anonymous referee for the suggestion of formally testing the impact of intervention on the mean exchange rate. To capture the impact of intervention on the mean exchange rate, a number of different dummy variable specifications were tested. The results were qualitatively the same and so the -1, 0, $+1$ type dummy variable was chosen for inclusion in the final model as it allowed for the most compact mean equation specification.
9. This model only allows intervention to impact on the slope of the news impact curve over a limited range and it is technically possible to adopt other specifications which allow a much richer dynamic process in this regard. Unfortunately, due to programming limitations, the use of a more complicated model was not feasible.
10. RBA Bulletin, March 1988, p. 7
11. The market testing role of government is commonly referred to as 'leaning into the wind' and evidence of this type of behaviour for French foreign exchange intervention in the Franc–Deutschemark exchange rate may be found in Usman and Savvides (1994).

12. In 1986, the RBA issued a statement in which it mentioned that the exchange rate had been included on a checklist of monetary policy indicators. However, the RBA has indicated that it did not change its intervention policy nor had it attempted to establish any particular exchange rate on a number of occasions. See RBA Report and Financial Statements 30 June 1986, *RBA Bulletin* December 1986, p. 4, and *RBA Bulletin* March 1987 p. 3.
13. The mean negative (and positive in later analysis) transaction size was also used as an alternative to the mean absolute transaction size without significantly altering the results. To conserve space the results are not presented and are available upon request.
14. The absence of GARCH effects for long periods of time in financial data is not unprecedented as Diebold and Lopez (1995) studied the autocorrelation function of the squared returns of the S&P500 and concluded that 'there seems to be no GARCH effects in the 1980's'. (p. 459).

REFERENCES

Ackert LF, Racine MD. 1997. The economics of conditional heteroscedasticity: evidence from Canadian and US stock futures market. *Atlantic Economic Journal* **25**: 371–385.

Andrew R, Broadbent J. 1984. Reserve bank operations in the foreign exchange market: effectiveness and profitability. *Research Discussion Paper* 9406, International Department, Reserve Bank of Australia.

Black F. 1976. Studies of stock price volatility changes. *Proceedings of the 1976 Meetings of the Business and Economics Statistics Section*, American Statistical Association, 177–181.

Bollerslev T. 1986. Generalised autoregressive conditional heteroscedasticity. *Journal of Econometrics* **31**: 307–328.

Bollerslev T, Chou RY, Kroner KF. 1992. ARCH modelling in finance. *Journal of Econometrics* **52**: 5–59.

Bollerslev T, Mikkelsen H. 1996. Modelling and pricing long memory in stock market volatility. *Journal of Econometrics* **73**: 151–184.

Brailsford T. 1995. Market closures and time varying volatility in the Australian equity market. *Journal of Empirical Finance* **2**: 165–172.

Brailsford TJ, Faff RW. 1993. Modelling Australian stock market volatility. *Australian Journal of Management* **18**: 109–132.

Byers JD, Peel DA. 1995. Bilinear quadratic ARCH and volatility spillovers in inter-war exchange rates. *Applied Economics Letters* **2**: 215–219.

Campbell J, Hentschel L. 1992. No news is good news: an asymmetric model of changing volatility in stock returns. *Journal of Financial Economics* **31**: 281–318.

Christie A. 1982. The stochastic behaviour of common stock variances: value, leverage and interest rate effects. *Journal of Financial Economics* **10**: 407–432.

Diebold FX, Lopez JA. 1995. Modelling volatility dynamics. In *Macroeconometrics: Developments, tensions and prospects*, Hoover KD (ed.). Kluwer Academic Press: Boston.

Engle RF. 1982. Autoregressive conditional heteroscedasticity with estimates of the variance of United Kingdom inflation. *Econometrica* **50**: 987–1007.

Engle RF, Bollerslev T. 1986. Modelling the persistence of conditional variances. *Econometric Reviews* **5**: 1–50.

Engle RF, Ng V. 1993. Measuring and testing the impact of news on volatility. *Journal of Finance* **48**: 1749–1778.

Frankel JA, Dominguez KM. 1993. Foreign exchange intervention: an empirical assessment. In *On Exchange Rates*, Frankel JA (ed.) MIT Press: Boston, MA.

Gannon GL. 1996. Unconditional first and conditional second moment effects: Index portfolios and index futures: *Research in Finance Supplement to 1996*, Chen AH, Chan KC (eds.) 143–158.

Glosten LR, Jagannathan R, Runkle DE. 1993. On the relation between the expected value and the volatility of the nominal excess return on stocks. *Journal of Finance* **48**: 1779–1801.

Henry O. 1998. Modelling the asymmetry of stock market volatility. *Applied Financial Economics* **8**: 145–153.

Hentschel L. 1995. All in the family: nesting symmetric and asymmetric GARCH models. *Journal of Financial Economics* **39**: 71–104.

Hsieh DA. 1989. Modelling heteroscedasticity in daily foreign exchange rates. *Journal of Business and Economic Statistics* **7**: 307–317.

Hu MY, Jiang CX, Tsoukalas C. 1997. The European exchange rates before and after the establishment of the European Monetary System. *Journal of International Financial Markets, Institutions and Money* **7**: 235–254.

Kam SW. 1995. Heteroscedastic modelling of daily foreign exchange rates with non-normal assumption and day-of-the-week and holiday effects. Discussion Paper No. 186, University of Queensland.

Kearns P, Pagan AR. 1993. Australian stock market volatility: 1875–1987. *Economic Record* **69**: 163–178.

Kim SJ. 1998. Do Australian and US macroeconomic news announcements affect USD/AUD exchange rate. Some evidence from E-GARCH estimations *Journal of Multinational Financial Management* **8**: 233–248.

Kim SJ. 1999. Do macro-economic news announcements affect the volatility of foreign exchange rates? Some Evidence from Australia. Forthcoming in *Applied Economics*.

McClain KT, Humphreys HB, Boscan A. 1996. Measuring risk in the mining sector with ARCH models with important observations on sample size. *Journal of Empirical Finance* **3**: 369–391.

McKenzie MD, Brooks RD. 1998. *Research design issues in time series modelling of financial market volatility*. Series in Advance Corporate Finance, Volume 2, McGraw-Hill Publishing Company: Australia.

Mansfield P. 1997. The relationship between the trading activities of the Reserve Bank of Australia and movements in the value of the Australian dollar. *International Review of Financial Analysis* **6**: 49–61.

Murphy J, Hopkins S. 1997. Do interventions contain information? Evidence from the Australian foreign exchange market. *Australian Journal of Management* **22**: 199–218.

Nelson DB. 1990a. Stationarity and persistence in the GARCH (1,1) model. *Econometric Reviews* **6**: 318–334.

Nelson DB. 1990b. ARCH models as diffusion approximations. *Journal of Econometrics* **45**: 7–38.

Nelson DB. 1991. Conditional heteroscedasticity in asset returns: a new approach: *Econometrica* **59**: 347–370.
Osterberg WP, Humes RW. 1993. The inaccuracy of newspaper reports of US foreign exchange intervention: *Economic Review*. Federal Reserve Bank of Cleveland, Fourth Quarter, 25–33.
Osterberg WP, Humes RW. 1995. More on the differences between reported and actual US central bank foreign exchange intervention. Federal Reserve Bank of Cleveland Working Papers No. 9501.
Pagan AR, Schwert GW. 1990. Alternative models for conditional stock volatility. *Journal of Econometrics* **45**: 267–290.
Rabemananjara R, Zakoian JM. 1993. Threshold ARCH models and asymmetries in volatility. *Journal of Applied Econometrics* **8**: 31–49.
Reserve Bank of Australia. *Bulletin*. Various issues.
Tse YK, Tsui AKC. 1997. Conditional volatility in foreign exchange rates: evidence from the Malaysian Ringgit and Singapore Dollar. *Pacific-Basin Finance Journal* **5**: 345–356.
Usman AA, Savvides A. 1994. Foreign exchange market intervention and the French Franc–Deutschemark exchange rate. *Journal of International Financial Markets, Institutions and Money* **4**: 49–60.
Zakoian J-M. 1994. Threshold heteroskedastic models. *Journal of Economic Dynamics and Control* **18**: 931–995.

