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Is foreign exchange intervention by central banks bad news for debt markets?: A case of Reserve Bank of Australia's interventions 1986 – 2003

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Abstract

We investigate the effects of the Reserve Bank of Australia's foreign exchange interventions on the USD/AUD market and 90-day and 10-year interest rate futures markets for the period July 1986 to December 2003. Using recently released revised and updated intervention data, we investigate contemporaneous and disaggregated intervention influences and find significant evidence for i) intervention effectiveness in moderating the contemporaneous exchange rate movements especially if interventions were cumulative and large, ii) exchange rate volatility reducing effect with a day's lag, iii) undesirable interest rate movements following interventions in some periods compromising monetary policy effectiveness, and iv) a volatility reducing effect of cumulative interventions in the 90-day rate, and a volatility increasing effect of large interventions in both the 90-day and 10-year rate futures. These findings are a unique and significant contribution to the prevailing literature as they demonstrate that the RBA's interventions matter not only for the foreign exchange market but also for the debt markets.

JEL: F31, G14, E44

Keywords: Foreign exchange intervention, GARCH, USD/AUD, interest rate futures

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1. Introduction

Central bank intervention in the foreign exchange market has been based on a belief that central banks' participation in the market was indeed successful in achieving the twin aim of influencing the direction of exchange rate and calming volatility. The extant literature on interventions reports a common finding of a higher foreign exchange volatility and undesirable exchange rate movements being associated with intervention on the days of intervention. Various researchers who examined the operations of major central banks (the Federal Reserve, the Bundesbank, and the Bank of Japan) to have arrived at this conclusion include: *inter alia* Bein (2004), Bonser-Neal and Tanner (1996), Baillie and Osterberg (1997a, 1997b), Chang and Taylor (1998), Dominguez (1998), Frenkel et al (2005). Similarly, the Reserve Bank of Australia's (RBA) intervention operations have been reported to be either ineffective in influencing the trend of the exchange rate or at the very worst to exacerbate second moment disturbances (Edison et al., 2003, Rogers and Siklos, 2003, McKenzie, 2004).

The most important factor that is common in these studies is the issue of simultaneity between the interventions and the first and second moments of contemporaneous exchange rate changes. Much of the empirical work has often assumed that the decision to intervene is made exogenous of market conditions. However, such an assumption is a rather extreme one considering that central monetary authorities have explicitly declared they intervene to calm disorderly markets (Dominguez and Frankel, 1994 and 1996, Baillie and Osterberg, 1997a, Dominguez, 1998, Frenkel et al, 2004, Kim and Sheen, 2002). As a consequence, models that do not take into account this endogeneity will likely indicate a positive correlation between conditional volatility and intervention and lead one to the erroneous conclusion that higher volatility is a consequence of intervention, rather than a rationale for it.

There are essentially two approaches in handling the simultaneity issue, modeling approach and data approach. The former aims to address the simultaneity by devising

econometric models that avoid the endogeneity of intervention variables when modeling the intervention effects on exchange rates. This might be accomplished by utilizing instrument variables that are highly correlated with interventions but not correlated with exchange rate movements. If such instruments can be found, one might carry out an instrumental variable estimation of the first and second moments of exchange rate changes on the days of intervention. Alternatively, exchange rate changes and interventions can be jointly modelled as a part of systems estimation. However, parametric representation of such a system is very difficult, if not impossible, because of the non-standard nature of the distribution of the intervention variable. The intervention variable has three distinct types of observations, positive and negative values and zeroes, and so it would be appropriate to treat the intervention variable to have been generated from a mixture of three distributions rather than one continuous distribution. This makes it very difficult to jointly model intervention with exchange rate changes, which have a continuous distribution¹. Kearns and Rigobon (2005) makes a contribution in this regard. They estimated a simulated GMM model of the mean equations of intervention reaction function and exchange rate changes. The development of an equivalent variance equation framework would also be warranted.

On the other hand, the data oriented approach aims to circumvent simultaneity mostly by examining the lagged effects of intervention, so that the decision to intervene is pre-determined. However, lagged interventions usually lack explanatory power (Baillie and Osterberg, 1997a, Lewis, 1995b). Another data approach is to use ultra-high frequency (UHF) data of 5 or 10-minute quotes, particularly for the USD, the Yen and the Deutschmark. Identifying the precise time-stamp of intervention trades is vital in these studies, yet such data

¹ Kim and Sheen (2002) modified the friction model initially proposed by Almekinders and Eijffinger (1996) and effectively addressed this mixture of distributions in the intervention variable, albeit with a partial equilibrium framework, in investigating the reaction function of the RBA intervention.

are not released by intervention authorities². The focus here is on employing a rough proxy of intervention, e.g. time stamps of Reuters newswire reports (Dominguez, 2003), requiring arbitrary assumptions regarding the time lag between intervention transaction and news reports. The assumed lag varies substantially, between 10 minutes and 2 hours, introducing greater ambiguity into investigation results. Further, Fischer (2003) finds the Reuters news reports are in fact highly “deficient in capturing the timing of intervention rounds” (p.2) leading him to directly challenge the findings of the UHF literature. Thus, the UHF studies are found to be impotent to distil the *ex post* volatility effects of intervention as there is an over-disaggregation of returns. This fact is highlighted by the conclusions of the UHF studies themselves. Peiers (1997), Chang and Taylor (1998), and Dominguez (2003) all find that volatility precedes their intervention proxies, but still conclude that this volatility is caused by intervention, due to order flow learning. Kim et al. (2000), however, deal with the simultaneity problem by modelling various disaggregated characteristics of interventions, and find evidence to indicate that sustained and above-average size interventions by the RBA were successful in stabilising volatility in the USD/AUD market.

The literature so far considers only the direct impact of interventions on their targets; the first and second moments of exchange rate movements. Beine (2004) is one notable exception. He reports not only an elevated volatility in the Yen/USD and the Euro/USD exchange rates on the days of US FED interventions, but also in their covariance. Another is Fatum and Huchison (1999) who report insignificant response of the US federal fund futures rates but interventions raised their volatility. They concluded that interventions added to the noise in the market. In a similar vein, recent evidence suggests that interventions may be used to achieve monetary policy objectives (see Kim and Sheen, 2005, and Vitale, 2003) providing a natural information linkage between foreign exchange and short-term debt markets. In

² A recent notable exception is the release of Swiss National Bank transaction data (see Fischer and Zurlinden, 2004, Payne and Vitale, 2003). No such data is yet available from the RBA.

general, there is a potential for interventions to have significant impacts on other segments of the financial markets due to their system wide information releasing effects. For instance, both the first and second moment influences on the exchange rate would have important implications for international portfolio investors leading to a possible significant impact on the stock market. In addition, the equilibrium relationships between foreign exchange and short-term debt markets via interest rate parity conditions suggest potential information spill-over to debt markets. The literature is rather silent on this issue of indirect effects of interventions on other financial market segments.

In this paper, we have a dual aim of i) investigating the effectiveness of the Reserve Bank of Australia (RBA)'s interventions over 1986-2003 using recently released revised data on intervention activities that are free from various errors plagued the previously released data set, and ii) to investigate the nature of indirect effects of interventions on short- and long-term futures interest rates and see if there is a potential conflict between sterilized interventions and monetary policy effectiveness³. To address the simultaneity issue we improve on the modelling strategy of Kim et al. (2000) and investigate both the contemporaneous (overall and disaggregated) and lagged influences of the RBA interventions in these markets. The important results of our investigations are as follows. Firstly, there are significant simultaneity effects of the interventions in both the first and second moments of the contemporaneous daily exchange rate changes which is consistent with the literature. Secondly, there are a number of offsetting influences which represent intervention effectiveness. Lagged interventions partially reversed this contemporaneous effect in both the first and second moments. In addition, large interventions and those that were a part of a continued campaign over a number of days had the desired effect of reducing the current exchange rate trends on intervention days. Without these interventions, the trends would have been more pronounced.

³ We also looked at the stock market for the possible indirect effects of the interventions. The results, however, do not point to significant intervention effects. For the sake of brevity we chose not to report these results.

Thus, the RBA's interventions were mostly successful in moderating the first and second moment trends in the currency. Thirdly, we show significant indirect effects of interventions in the interest rate futures markets. The contemporaneous effect of the RBA purchasing the Australian Dollars (AUD) was to raise both the short-and long-term interest rate futures and also their volatilities. Considering the stated aim of the interventions over the relevant periods was to relieve downward pressures on the AUD in the midst of monetary easing, the interest rate raising effect of the interventions undermined the then current monetary policy stance. However, lagged and continued interventions had mild corrective influences, whereas large interventions tended to cause more volatility in the 90-day futures. In the case of the 10-year rate, the volatility was significantly higher on the days of continued and large intervention.

We provide significant contributions to the intervention literature by offering important detailed insights into the direct and indirect influences of the RBA's intervention activities. The results of the paper have important implications for the policy makers (the RBA), foreign exchange market participants, and foreign investors in the Australian financial markets at large. The remainder of this paper is structured as follows. We discuss the data employed in this paper in the next section. Section 3 provides detailed discussions on the empirical methodologies employed, and the estimation results for the foreign exchange market and the 90-day and 10-year interest rate future markets are discussed in sections 4 and 5, respectively. Conclusions are presented in section 6.

2. Data descriptions

2.1 RBA's Intervention Data

The RBA's intervention data is measured as daily net market purchases of foreign currency - almost always the US Dollar (USD) - by the RBA in terms of millions of AUD. A positive value would represent a purchase of the USD (i.e. sale of the AUD), a negative value a sale of the USD (i.e. purchase of the AUD). These daily recordings of net market purchases are a

composite of the RBA's intervention activities and the trading of foreign exchange to meet the needs of the government. The degree of intervention, however, can be inferred from the transaction data. To the extent that the RBA has discretion over when it can enter the market to replenish its foreign currency reserves after having used them to trade on behalf of the government, as well as the size of any foreign exchange intervention, it is appropriate to use an aggregate figure to calculate the total effect of the Reserve Bank's actions on the exchange rate (Rankin, 1998). Further, Neely (1998) found that the inclusion of client transactions did not significantly alter the statistical properties of intervention data in the US.

The RBA has recently released revised data on the net market purchases which is corrected for various errors that plagued the old dataset. The errors are intervention amounts recorded on settlement dates instead of on the days of intervention, and incorrect inclusion of the RBA's transactions with other central banks in the dataset. The differences between the two datasets are considerable. For the period Dec 1983 to June 2003, there were a total of 1955 interventions, out of which 507 were incorrectly recorded. The recording errors ranged from the minimum of 0.1 (0.1) and the maximum of 241 (196.5) million over-reporting of the intervention purchase (sale) of the USD. This casts doubt over previous studies that utilized the 'flawed' net market purchase data. To the best of our knowledge this is the first paper to utilize the 'purified' intervention data and it is available up to the end of 2003.

Since the floating of the AUD in December 1983, there have been five distinct periods of intervention activities characterised by the differing approaches adopted by the RBA (See Rankin, 1998). Table 1 provides summary statistics for the RBA's intervention operations over these different phases.

Period I (December 1983-June 1986): The RBA used interventions as a means of "smoothing and testing of the market" during this period. It allowed the exchange rate to be

influenced mostly by market forces. Although interventions were relatively frequent (49% of business days), they were also relatively small averaging only AUD13.8 million.

Period II (July 1986-September 1991): This period marked the commencement of the RBA taking a much more active role in the foreign exchange market. Very large swings in the exchange rate at the beginning of this period prompted the RBA to intervene in greater magnitudes (averaging AUD64 million) and on a more regular basis (66% of business days). Some episodes where the RBA believed the exchange rate had overshot included February 1989 where it was valued in the vicinity of USD0.90, and October 1990 where it sharply appreciated in response to the commencement of the conflict in Iraq. The period had been dominated by selling of the AUD, however a particularly large defence (AUD1025 million) was undertaken around the time of the October 1987 stock-market crash.

Period III (October 1991- November 1993): During this period the RBA initiated a substantial easing of monetary policy to assist economic recovery in the midst of the recession Australia was experiencing. The currency as a result came under significant selling pressures and almost all of the interventions by the RBA involved purchases of the AUD. The RBA also sought to maximise the signalling impact of its interventions through careful management of their size and timing. The average size of interventions again increased to AUD138 million but decreased in frequency to 23% of business days.

Period IV (December 1993-June 1995): The RBA during this time did not undertake any interventions and represented its longest absence from the foreign exchange market in the post float era.

Period V (July 1995-Present): The RBA initially entered the market in order to retire the swap positions which it had built up during Period III. Since the main objective during the initial stages of this period was to manage the Bank's portfolio of swaps rather than to influence the exchange rate, transactions were generally smaller. The RBA, however,

undertook particularly large interventions during 1997 and 1998 in response to the Asian financial crisis, to counteract the destabilising actions of certain hedge funds, and to calm the turbulence that followed the Russian moratorium on foreign debt. Overall, the period has been dominated by selling of the AUD but noticeable purchases were made during 2000-2001 in order to support a rapidly depreciating AUD, which at the time was trading below USD0.50.

Becker and Sinclair (2004) outline that there are broadly three ways the RBA carries out its intervention activities. i) Low key intervention where it uses agent banks so market as a whole is unaware of intervention. ii) Active participation in the broker market segment where its presence is immediately known to active players in the interbank market and their clients. iii) Direct dealing in the market maker segment where information spread is slower.

The second and the third types of interventions would be known to the market contemporaneously, and this will enhance the potential intervention effect. However, the low key intervention is not directly observable in the market. The low key intervention is used when the RBA wishes to replenish reserves depleted from previous interventions. Alternatively, 'secret intervention' designed to stimulate heterogeneity in the market aiming to break bandwagon effects can also take this form. The RBA might, on occasion, be unwilling and unable to turn the tide in exchange rate movements. Instead, it may choose to increase residual volatility in the market so as to encourage market participants to think that the trend is broken thus achieving the aim of breaking the bandwagon effect. In these cases, the RBA acts as a price taker and is not trying directly to push the exchange rate one way or another.

We focus our attention from the second period onwards as the RBA was not explicitly seeking to influence the exchange rate preferring to leave it to be determined primarily by market forces in Period I. Kearns and Rigobbon (2005) made a similar decision. Figure 1 shows the net market purchases along with the USD/AUD exchange rate since Period II. In

general, the intervention activities mirror the movements of the exchange rate. The patches of intervention sales (purchases) of the USD are associated with downward (upward) trends in the AUD. This seems to be consistent with the view that the RBA's interventions were to lean against the wind (Kim and Sheen, 2002).

2.2 *Foreign Exchange and Debt Market Data*

Although it is a normal practice for central banks to intervene during their respective business operating hours (see Neely, 2001, and Dominguez, 1998, 2003), Rankin (1998) states that “The RBA can deal with banks in any market around the world, 24 hours a day.” Becker and Sinclair (2004) confirms this “The RBA has the capacity to deal in Australian dollars around the world, 24 hours a day. (p4)”. However, the RBA does not disclose the relative frequency of daytime vs. overnight intervention activities. Thus, in the absence of such information, one is left to conjecture that the RBA was as likely to intervene during the overnight period (in European and North American markets) as during the daytime period (in the Sydney market). Since the intervention data at day t is an aggregate over transactions in both the Sydney and foreign (overnight) markets, the suitable holding period over which to measure the contemporaneous impact of the RBA's intervention on calendar day t is from the opening exchange rate observed on day t to the next day's opening in the Sydney's foreign exchange market. However, except for Kearns and Rigobon (2005), previous studies of the RBA interventions used 4pm Sydney close rate and calculated the daily return horizon over the close at day t and $t-1$. These include Kim et. al (2000), Edison et. al. (2003), McKenzie (2004). Thus, daily exchange rate changes so created are misaligned with the intervention data that include the interventions conducted not only in the Sydney market but also in the overnight ones in the foreign markets that open after the Sydney market's close at 4pm AEST. The results reported in these papers thus may not be an accurate depiction of the intervention effectiveness. We use 9am Sydney opening exchange rate sourced from Bloomberg to

generate the proper the measure of daily exchange rate returns that would enclose the daily aggregate net market purchase at t : $R_t = \ln(ER_{t+1}^{Open} / ER_t^{Open}) \times 100$, where ER^{Open} is the 9am observation of the USD/AUD exchange rate for the period 1 July 1986 up to 31 December 2003, yielding 4568 daily observations.

Similarly, the appropriate horizons over which to investigate the potential intervention impacts on the interest rate futures markets is from opening rate at t to the next day's opening. As only the closing rates are generally available for the spot market rates, we use the opening rate of the 90-day banking bill and 10-year government bond futures traded on the Sydney Futures Exchange ($\Delta IR_t = (IR_{t+1}^{Open} - IR_t^{Open})$), where IR is interest rate implied from the futures price (i.e. $100 - \text{futures price}$). These price data are obtained from datastream for the same period as the exchange rate.

Table 2 reports the summary statistics of the daily exchange and interest rate changes. In all cases, the average is quite close to zero, however significant skewness and excess kurtosis is observed. Also, there is evidence for the existence of significant serial correlation in the returns and conditional variance of the series. These results are evidence for significant time varying conditional heteroskedasticity. In addition, the Engle-and Ng (1993)'s sign bias tests show significant asymmetric volatility responses to unanticipated positive and negative shocks in all periods for the exchange rate and in some periods for the interest rate futures. In summary, the exchange rate and interest rate futures market series generally exhibit significant skewness, leptokurtosis, heteroskedasticity and leverage effects which are typical of high frequency returns data. An appropriate empirical model needs to be adopted to address these observed statistical properties.

3. Econometric modelling of the RBA's interventions

A GARCH family of volatility models have been proven to be useful in modelling observed statistical characteristics of daily financial returns series, and a parsimonious GARCH (1,1)

model has shown to outperform more profligate ones. In addition, there is an added attraction in an Exponential version of GARCH as this allows one to model not only an asymmetric behaviour of volatility but also negative coefficients in the volatility equation. The latter is particularly useful in the current study as a negative coefficient for the intervention variable indicates volatility reducing effects of intervention activities. In this paper, we model the RBA's interventions in a novel way that addresses the simultaneity issue discussed above. In addition, we model daily periodicity via daily dummies and a holiday dummy in the model. The resulting EGARCH(1,1) model we employ is shown in (1) and (2) below:

$$R_t = \alpha_c + \sum_{i=MON}^{THU} \alpha_i \cdot D_{i,t} + \alpha_{HOL} \cdot D_{HOL,t} + \varepsilon_t + \alpha_{MA} \cdot \varepsilon_{t-1} + (\alpha_{INTV} + \alpha_{CINTV} \cdot CIDUM_t + \alpha_{SINTV} \cdot SIDUM_t) \cdot Intv_t + \alpha_{INTV1} \cdot Intv_{t-1} \quad (1)$$

$$\varepsilon_t = z_t \sqrt{h_t}, \quad \varepsilon_t \sim t(0, h_t, d), \quad z_t \sim iid(0,1)$$

$$\ln h_t = \beta_c + \beta_h \ln h_{t-1} + \beta_{\varepsilon 1} \frac{\varepsilon_{t-1}}{\sqrt{h_{t-1}}} + \beta_{\varepsilon 2} \left(\frac{|\varepsilon_{t-1}|}{\sqrt{h_{t-1}}} - \sqrt{\frac{2}{\pi}} \right) + \sum_{i=MON}^{THU} \beta_{i,t} D_{i,t} + \beta_{HOL} D_{HOL,t} + (\beta_{INTV} + \beta_{CINTV} \cdot CIDUM_t + \beta_{SINTV} \cdot SIDUM_t) \cdot |Intv_t| + \beta_{INTV1} \cdot |Intv_{t-1}| \quad (2)$$

Where:

- $D_{i,t}$ = Daily dummy that takes the value of one for i (=Mon, Tue, Wed, Thu) and zero otherwise.
- $D_{HOL,t}$ = Holiday dummy that takes the value of one for the day immediately after public holidays.
- $RBAIntv_t$ = RBA intervention proxied by net market purchases of foreign currency (USD), measured in AUD millions.
- $CIDUM_t$ = Cumulative Intervention dummy variable that takes the value of one if intervention at day t is preceded by intervention in the same direction at $t-1$ and $t-2$.
- $SIDUM_t$ = Intervention size dummy variable that takes the value of one if the absolute amount of intervention at day t is greater than the relevant period average daily net market purchase, and zero otherwise.
- R_t = Continuously compounding daily returns (log changes time 100) of the USD/AUD exchange rate (ΔS_t), Absolute change in the 90-day (ΔIR_t^{90D}) and the 10-year interest rate futures (ΔIR_t^{10Y}).
- h_t = Conditional variance of the exchange rate or the interest rate changes.

Variables we focus on in equations (1) and (2) are the intervention variables. We examine not only the contemporaneous interventions but also address specific characteristics of interventions to isolate those types of transactions that have desirable effects. Together with one-day lag of intervention, these characteristics would provide important insights into

the disaggregated impacts of interventions that are masked by the contemporaneous effects of simultaneity reported in the literature.

Due to simultaneity, we expect the contemporaneous intervention variable, $Intv_t$, to have a positive coefficient in both the conditional mean and variance equations. This indicates that an intervention purchase of the USD (i.e. sale of the AUD) is associated with an appreciation of the AUD and higher volatility on the day of intervention. This in itself is insufficient evidence for intervention ineffectiveness. In fact, without the intervention the exchange rate trend and the volatility on the day would have been more pronounced. Therefore, an important issue is whether it is possible to isolate those characteristics of interventions that may have moderated the perverse contemporaneous effect. In this regard, we improve on the novel idea first introduced in Kim et. al (2000) and separately model these components for their disaggregated effects.

We first consider those interventions that are of sufficient size to be noticeable by the market. The success of an intervention may be predicated on its size for a number of reasons. A particularly large intervention would be more successful in trend reducing due to its enhanced visibility in the market. Larger interventions may provide a clearer signal of the RBA's intention to correct the overshoot exchange rate since they would be more noticeable and easier to distinguish from the RBA's portfolio rebalancing activities and other noise that may obscure the intervention signal. The clarity and strength of the information thus conveyed should therefore provide a more powerful benchmark from which the market could refer to, facilitating a greater homogenisation of opinions. On the other hand, it is not inconceivable that larger interventions could fuel volatility due to the greater information and inventory weight they carry. This may lead to a more visible microstructural disturbance as agents engage in a greater amount of trading activity to assimilate the larger amount of information conveyed (see Lyons, 2001). However, the literature on this issue appears to be

mixed⁴. Considering that the size of daily interventions have varied from as low as AUD 1 million to AUD 1,256m, determining the impact that the size of an intervention has on the exchange rate is an important policy consideration that should be explored.

We model large interventions by utilizing a slope dummy variable for the intervention variable, $SIDUM_t$, that takes the value of one for interventions greater than the average intervention for the time period examined, and zero otherwise. Accordingly, the definition of an average intervention will differ according to each time period. To the extent that large interventions matter, we expect some potency of intervention on these days. If so, we expect the size dummy coefficients, α_{SINTV} and β_{SINTV} , to be negative suggesting that the positive contemporaneous effect would be partially offset. That is, the RBA would be able to reduce the market momentum and moderate speculative surges thus achieving a contemporaneous calming effect on volatility. The net effect on large intervention days is, then, measured as the sum of α_{SINTV} and α_{INTV} in the conditional mean equation and the sum of β_{SINTV} and β_{INTV} in the conditional variance equation. Whether these contemporaneous effects are completely reversed by large interventions (i.e. negative net effects) is an empirical question.

We also distinguish interventions that are a part of a wave of interventions over a number of days. The market may perceive the RBA's signal as more credible if it sees a series of interventions rather than a one-off transaction⁵. We model this aspect of intervention with a cumulative intervention dummy, $CIDUM_t$, that takes the value of one for days of intervention that are preceded by at least 2 previous days of intervention in the same direction, and zero otherwise. As in the large intervention case, we expect the cumulative interventions to have a moderating role. That is, we expect the cumulative intervention coefficient to be

⁴ Galati and Melick (2002) find that the size of intervention had little bearing or effect on the first and second moments. Kim et al. (2000), however, find mild evidence that larger RBA interventions are associated with higher levels of volatility in some periods.

⁵ Beine et al. (2004) finds some support for the effectiveness of sequential and coordinated interventions in the DEM/USD market in bringing the volatility back to the pre-intervention level.

negative in both the conditional mean and the variance equations. The net effects of intervention on the days of cumulative interventions are then measured as the sum of α_{CINTV} and α_{INTV} in the mean equation and as the sum of β_{CINTV} and β_{INTV} in the variance equation.

By modelling the differing responses of the exchange rate, according to the different features of interventions, we provide a much more comprehensive picture of the intervention effectiveness. Large interventions have the potential to either homogenise opinions or exacerbate second moment disturbances by virtue of their larger information and inventory weight. Cumulative interventions have the potential to strengthen information signals.

Finally, we also consider a one day lag of intervention in the model. This will pick up the effects of interventions that should be free from endogeneity. As such, we expect the coefficient for the lagged intervention to be negative in both the mean and variance equations. We use one-day intervention lag in the face of various studies utilizing ultra high frequency exchange rate data because intervention is not carried out in isolation in one transaction within the day of intervention. Rather, central banks spread intervention over a number of transactions within the day and also over a number of days. This is done so as to maximize the visibility of the central bank's presence in the market thus reinforcing the signalling effect of intervention. This is one of the reasons why ultra high frequency studies such as Payne and Vitale (2003) is of limited use in ascertaining intervention effectiveness over a continued intervention campaign. Instead, intervention effectiveness should be measured over the series of intervention transactions considered to be a part of a campaign rather than investigating them in isolation. Our approach to modelling this aspect of intervention is to investigate the lagged effects in addition to the disaggregated effect of continued interventions.

4. RBA's intervention effects in the foreign exchange market

The estimation results of the equations (1) and (2) for the foreign exchange market for all the sample periods in Table 3.

4.1. Conditional Mean Results

The coefficient for the contemporaneous intervention effect is positive and significant as per prior expectations in all cases. For the whole sample, a one billion (million) purchase of USD is associated with a 4.18% (0.00418%) appreciation of the AUD during the whole sample. This pattern is repeated in all periods with similar magnitudes. This confirms the simultaneity between exchange rate movements and intervention as discussed in the previous section. More importantly, however, we find the positive contemporaneous effect is partially reversed during the following day as seen by the negative and significant coefficient for the lagged intervention in all cases except for period III. This is a strong evidence for the ability of the RBA to clearly dampen the exchange rate trend at least with a day's lag⁶.

When examining the coefficients for the two slope dummy variables, the evidence for intervention effectiveness become much more compelling. Consistent with *a priori* expectations, the coefficients for the cumulative and size dummy variables are negative and statistically significant in all cases except for the size dummy in period V. A negative coefficient indicates the currency moves in the desired direction (AUD purchases leading to appreciation) in response to intervention. These results demonstrate that those interventions that continued over a number of days and those that were above average size were successful in moderating the simultaneity problem and suggest that they were effective in restraining speculative surges in the exchange rate. Moreover, a large intervention appears to be more important than a cumulative intervention as seen by the magnitude of the size dummy coefficient which is substantially larger across all estimations. This indicates that the larger is the intervention, the greater is the impact on the first moment of exchange rate returns. This is

⁶ The intervention variable might be serially correlated and as such a robust check on the estimation results is warranted. For this purpose we carried out estimations of the three models with the contemporaneous and lagged intervention coefficients ($INTV_t$ and $INTV_{t-1}$) included one at a time. That is, $INTV_t$ ($INTV_{t-1}$) is dropped from both the conditional mean and variance equations to produce $INTV_{t-1}$ ($INTV_t$). We find that the results of these separate estimations of intervention coefficients are qualitatively the same as previously reported. We do not report these results due to space constraint, however, interested readers may obtain them from the corresponding author. We appreciate an anonymous referee for pointing this out.

intuitively plausible since the intervention would have to be large enough to be taken seriously by the market participants considering the large size and turnover of the Australian foreign exchange market⁷. A policy implication following from this is that the RBA should consider undertaking sufficiently large interventions preferably over a number of days in order to successfully “lean against the wind” and break bandwagon surges. In fact, the RBA has adopted this strategy in recent times (Becker and Sinclair, 2004).

4.2. Conditional Variance Results

As in the conditional mean equation, contemporaneous effects represent the simultaneity bias. A significantly elevated level of exchange rate volatility is observed in all cases. However, a significant volatility reducing effect is visible one day after the intervention transactions, and in the whole sample, the level of volatility is reduced to below pre-intervention level. The RBA’s interventions have successfully contained the level of volatility on the days of intervention with its desired effect fully shown with a day’s delay. However, disaggregated influences of the interventions are not as significant in the volatility equation. There is only mild evidence that sustained interventions had the volatility reducing effect offsetting some of the contemporaneous influence as shown by the negative coefficient in all cases. However, it is significant only in Period V. The large intervention dummy is significant only for the whole sample, and the positive coefficient suggests an addition to the level of volatility when large interventions occur. As the subsample results are inconsistent and insignificant, the whole sample results may not be compelling, however.

4.3. Diagnostics of the E-GARCH (1,1) Model

The residual diagnostics are shown in the last panel of Table 3. The serial correlation in the first and second moments of the standardised residuals is eliminated in all but two cases. We were able to remove these imperfections by employing higher lags in the moving average and

⁷ The Australian foreign exchange market recorded a daily average turnover volume of 81 billion USD, and the AUD was ranked 6th in terms of world volume accounting for 5.5% of the total (BIS, 2004).

EGARCH orders without much material difference to the estimation results reported here. However, for the consistency, we proceeded with the parsimonious model for all the estimations. Finally, in all instances the asymmetric effects on the volatility have been accounted for. Thus, the EGARCH(1,1) specification successfully addressed the observed statistical properties of the exchange rate return series.

5. RBA's intervention effects in the interest rate futures markets

In general, intervention transactions, properly sterilized by open market operations, should have no material influence in the cash (overnight money) market. However, to the extent that sterilized interventions may work via signalling channel to achieve the stated aims, short-term interest rates that are based on market's expectations of current and future cash rates may be influenced by the potential information content of interventions. In addition, there may also be second moment influences.

There are various reasons for potential intervention effects in short-term interest rates. Firstly, foreign exchange interventions can be considered an indicator of the level of commitment to the stated monetary policy stance at the time and possibly a hint of future change in the policy direction. For example, during the period 1991 to 1993 (Period III) the RBA utilized interventions to ease the downward pressure on the currency as a result of the continuation of monetary easing. In this case, a series of intervention purchases of the AUD played a supporting role for the then current policy stance. In the case of Bank of Japan, Kim and Sheen (2005) report that the BOJ's Yen interventions could have been used to complement their monetary policy stance. Even if interventions do not provide an entirely clear signal, there may still be visible second moment effects depending on how they are interpreted. To the extent that heterogeneity exists in the futures markets and the interventions signals can be interpreted differently, there is a potential for increased trading activates following interventions leading to a volatility hike. Secondly, to the extent that the foreign

exchange and debt markets share common fundamentals through the interest rate parity conditions, there is a distinct possibility for information transfer to occur. Baillie and Osterberg (1997b) find that central bank intervention does have a significant impact on deviations from uncovered interest rate parity. Fatum (1999) reports increased Fed fund rate futures volatility in response to Fed interventions.

As for long-term rates, we envisage that the role of inflation expectation to be of more importance. If the RBA's interventions are seen as addressing its directional aim for the currency, this will have a longer term implication for the level of future inflation. To the extent that interventions are associated with a contemporaneous volatility rise in the foreign exchange market, a potential exists for an elevated level of uncertainty with respect to future inflation. This in turn can be translated into higher levels of trading in the 10-year futures markets with a commensurate rise in volatility.

Despite the potential for significant indirect effects of intervention in the interest rates, except for Fatum and Huchison (1999) the literature is rather silent on this issue. In this section we present detailed evidence of short- and long-term interest rate responses to the RBA's currency interventions. We investigate the intervention effects to the interest rate futures markets under the same modelling framework of equations (1) and (2). Daily 90-day and 10-year futures interest rate changes (market open at t to open at $t+1$) are modeled and the intervention influences are investigated. The results are shown in Tables 4 and 5 for the 90-day and 10-year rates, respectively.

5.1. Conditional Mean Results

Period III is the only sample that contains a significant intervention effect on the 90-day rate changes. A negative and significant coefficient for the contemporaneous effect suggests a significant fall (rise) in the rate in response to an intervention purchase (sale) of USD by the RBA. A one billion USD sale (i.e. purchase of the AUD) led to a 27.94 basis point rise in the

90-day futures rate. Apparently, the market participants expected a significant movement in the spot interest rate despite sterilization. This might suggest a lack of confidence by the futures market in the RBA's sterilisation process⁸, meaning that there is a perception that the RBA's foreign exchange activities will instigate an eventual alteration to the overnight cash rate. Eighty nine percent of the interventions in this period were aimed at supporting the AUD, and these led to significant upward pressures on the short-term interest rate (i.e. negative coefficient implies a rise in the interest rate when the net market purchase is negative – intervention purchase of the AUD). Remembering that the RBA practiced monetary easing in Period III and used interventions to relieve downward pressures on the currency, the interest rate futures rise is undesirable as it reduces the monetary policy effectiveness to some extent. We showed that the exchange rate aims are largely met, but in this period this came at the cost of putting undue pressure on the short-term interest rate suggesting that the market participants in the 90-day futures may have regarded the monetary and exchange rate policy aims as conflicting.

We also report significant intervention effect on the 10-year rate in periods II and III. The interest rate increasing effect of the intervention purchase of the AUD is more pronounced as evidenced by significantly larger magnitude of the coefficients compared to the 90-day rate. We argue that this is due to an increase in the inflation premium component in the long-term rate. As the 90-day bank bill rate represents market's forecast of the current and future path of the overnight cash rate that the RBA targets, the undesirable effect of the intervention purchases of the AUD on the 90-day rate futures put into question the RBA's ability to achieve its inflation rate target (which is purported to be 2-3% over the economic

⁸ Instead of the traditional open market operations, the RBA has moved to foreign exchange swaps in the 1990s to sterilize the liquidity effects of the intervention to avoid a destabilizing influence of open market operations on its balance sheet (Rankin, 1998). This involves the spot leg of the swap being in the opposite direction of the intervention and the forward leg in the same direction. The significant indirect results on the future interest rates thus reflect this forward leg influence.

cycle). The resulting uncertainty over future inflation rates would have shown up as larger than otherwise inflation risk components in the 10-year rate with a commensurate increase in the rate. As the level of uncertainty raised in the long-term market is considered to be higher, the long-term rate was more sensitive to intervention. However, these effects were moderated by lagged intervention in Period II and when interventions were large in period III.

5.2. Conditional Variance Results

The contemporaneous influence is to raise the volatility of the 90-day rate in the whole sample which is more than offset in the following day. The volatility increasing effect is similar to what Fatum and Hutchison (1999) report for the US market. The cumulative interventions also helped offset this volatility hike whereas large interventions contributed to the volatility in all samples except Period III. This is similar to the result reported for the foreign exchange market in the previous section. It would appear that the cumulative interventions in the foreign exchange market appear to resolve uncertainty over future monetary actions (or at least the RBA's commitment to the current stance of the monetary policy) while large interventions tend to exacerbate it. A possible explanation for the volatility reducing influence of cumulative interventions is that there may be a perception that since they were effective in calming foreign exchange volatility, there would be less need on the part of the RBA to alter its monetary policy stance to achieve the exchange rate objectives. Accordingly, since there is a perception that the overnight cash rate will remain static such that the 90-day futures rate will remain largely unaffected, futures market participants would not be as compelled to engage in trading activities.

The 10-year rate also shows the similar response pattern of the volatility increasing effect of contemporaneous interventions which is partially offset by lagged interventions. Similarly, there is some mild evidence for large interventions triggering a temporary

escalation in the volatility in Period III. However, continued interventions are now adding to the volatility instead of moderating it in Period III and V.

The results of the investigation confirm that incidences of intervention by the RBA did affect fundamentals that are common between the two types of markets. The undesirable pressures on the interest rates in Period III meant a reduced effectiveness of monetary policy stance of the period. The escalation in volatility could be indicative of uncertainty about whether the intervention is sending a clear signal of the future direction of monetary policy. It could also be interpreted as evidence of a contagion effect where the second moment disturbances in the foreign exchange market, prompted by RBA intervention, has led to similar hikes in the level of uncertainty in the futures markets.

Two important considerations arise from the empirical results presented. First, the results demonstrate that it is possible for a large micro-structural and inventory disturbance in the foreign exchange market, in the form of a large intervention by the RBA, to be transmitted to another asset market. We also demonstrate that any uncertainty resolved in the foreign exchange market by cumulative interventions has also been transmitted to the interest rate futures markets. Secondly, the RBA may have to keep in mind the potential costs of its interventions in terms of higher volatility in the interest rates and a potential adverse impact on its monetary policy effectiveness. While cumulative interventions have a calming effect on the short-term interest rate market, large interventions tend to have a destabilising effect. However, we found that large interventions were the most effective channel through which speculative surges in the exchange rate could be curtailed. These results indicate that the RBA may have to consider whether it is willing to promote instability in the debt markets in order to achieve its foreign exchange objectives. It may be more prudent for the RBA to concentrate on sustained interventions instead to influence the first moment of the exchange rate as this has some effect in moderating short-term interest rate volatility as well.

5.3. Diagnostics of the E-GARCH (1,1) Model

The EGARCH parameters are shown to be effective in capturing the volatility clustering behaviour of the interest rate changes reported in Table 2. In all cases, the lag of volatility coefficient is significant at 1% while the lag of absolute residuals coefficient is significant at 1% in most cases. The serial correlation in the first and second moments of the standardised residuals is eliminated in all cases, except for the marginally significant linear serial correlation for the 10-year rate in the whole sample. In addition, the asymmetric effect of innovations on volatility has been accounted for in the majority of cases.

6. Conclusion

Whether foreign exchange market interventions have been effective in moderating exchange rate trends and volatility is an empirical question that continues to promote substantial and ongoing controversy. Utilizing recently release revised intervention dataset that is free from various transcription errors, we provide new evidence on the effects of the RBA's interventions in the USD/AUD market and the interest rate futures markets in Australia. We make a number of important contributions to the intervention literature at large.

We found that large interventions were particularly effective in moderating excessive trends in the exchange rate. Cumulative interventions were also found to break bandwagon surges, though the effect was not as strong as large interventions. However, we found that in order to effectively calm volatility, intervention operations should be carried out over a number of days. These results demonstrate that the homogenisation of information, and alleviation of uncertainty, is more adequately facilitated if the same message is repeatedly released to the market. Another important contribution we make is the investigation into the effect of the RBA's foreign exchange interventions on the first and second moments of the 90-day and the 10-year interest rate futures traded on the Sydney Futures Exchange. We found that there were both price and volatility effects of the intervention operations. In

particular, cumulative interventions tended to calm volatility in the 90-day rate while large interventions exacerbated it. These results are consistent with the foreign exchange estimations where cumulative interventions had a calming effect while there was some mild evidence since 1995 to suggest that large interventions caused second moment disturbances in the exchange rate. Thus, the report the existence of common fundamentals between the two types of markets via interest rate parity conditions and/or monetary policy signalling approach.

The results have strong policy implications for the RBA. Large interventions were found to be the most effective means for the RBA to break speculative surges in the exchange rate. However, this was at the cost of higher short term interest rate volatility and potential reduction in monetary policy potency in some periods. Consequently, the RBA may have to decide whether it is willing to promote a greater amount of volatility in the debt market, and threaten overall financial stability, in order to influence the trend of the exchange rate in the desired direction. That is, there is a trade-off between the two markets in terms of intervention effectiveness. In addition, the RBA should consider spreading its interventions over a number of days to maximize the exposure. Cumulative interventions have shown to be effective in moderating the exchange rate trends and partially offsetting a contemporaneous rise in volatility in both the foreign exchange and the 90-day future interest rate markets. In addition, the results we report could provide information that is useful for international investors for asset allocation and overall risk management purposes.

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Table 1: Summary Statistics for the RBA's Foreign Exchange Intervention Transactions

	Post-Float Dec-83 Dec-03	Period II-V July 86 Dec 03	Period I Dec 83 Jun 86	Period II July 86 Sep 91	Period III Oct 91 Nov 93	Period IV Dec 93 Jun 95	Period V Jul 95 Dec 03
Size of Intervention							
Ave. Absolute Intervention	57.1	76.3	13.8	64.3	138	-	52.8
Average Buy of AUD	82.1	131.7	15.9	107.9	151.3	-	152
Average Sell of AUD	48.2	50.9	8.6	56.7	35.4	-	44.4
Maximum Buy	1256	1256	90	1025	1256	-	1188.5
Maximum Sell	659	659	44	659	150	-	376
Frequency of Intervention (% of Business Days)							
Frequency of Intervention	0.39	0.38	0.49	0.66	0.23	-	0.31
Frequency of Buy	0.26	0.18	0.7	0.15	0.89	-	0.08
Frequency of Sell	0.74	0.82	0.3	0.85	0.11	-	0.92

Table 2: Summary statistics of daily USD/AUD returns and 90-day and 10-year interest rate futures changes

	Period II - Period V Jul 1986 - Dec 2003	Period II Jul 1986 - Sep 1991	Period III Oct 1991 - Nov 1993	Period V Dec 1993 - Dec 2003
USD/AUD returns ^(a)				
Mean	0.0024	0.0127	-0.0340	0.0024
Variance	0.4062	0.4802	0.2462	0.4294
Skewness	-0.1615	-0.6633	-0.2264	0.2083
Kurtosis	3.2567	3.8678	1.0932	2.6823
J-B	2038	954	33	681
Q2(20)	41.5959 *** {0.0031}	28.5228 * {0.0976}	38.7265 *** {0.0072}	28.9716 * {0.0883}
Q ² (20)	703.51 *** {0.0000}	375.12 *** {0.0000}	54.90 *** {0.0000}	131.11 *** {0.0000}
E-N	60.2506 *** {0.0000}	43.8647 *** {0.0000}	7.2137 * {0.0654}	6.2851 * {0.0985}
Daily Changes in 90 Day Bank Bill Futures ^(b)				
Mean	-0.0017	-0.0030	-0.0075	-0.0010
Variance	0.0204	0.0534	0.0054	0.0039
Skewness	-0.7517	-0.9438	0.1964	1.1813
Kurtosis	142.0174	65.1223	10.2682	23.0799
J-B	3837572	242288	2490	49722
Q2(20)	75.7133 *** {0.0000}	35.2655 ** {0.0187}	49.0677 *** {0.0003}	22.1880 {0.3304}
Q ² (20)	70.4019 *** {0.0000}	14.6774 {0.7946}	30.6854 * {0.0595}	63.8180 *** {0.0000}
E-N	7.3033 * {0.0628}	2.8430 {0.4165}	8.7940 ** {0.0322}	50.7784 *** {0.0000}
Daily Changes in 10 year treasury bond interest rate Futures ^(b)				
Mean	-0.0016	-0.0018	-0.0059	-0.0016
Variance	0.0082	0.0105	0.0078	0.0056
Skewness	0.3239	0.2232	0.8864	0.2868
Kurtosis	5.3026	7.8687	4.0005	1.2863
J-B	5429	3546	452	183
Q(20)	89.2626 *** {0.0000}	54.0238 *** {0.0001}	31.8610 ** {0.0448}	18.0303 {0.5854}
Q ² (20)	829.80 *** {0.0000}	237.83 *** {0.0000}	16.27 {0.6997}	85.49 *** {0.0000}
E-N	153.945 *** {0.0000}	76.3581 *** {0.0000}	3.3460 {0.3413}	5.2656 {0.1534}

(a) The continuously compounding exchange rate returns are measured as $R_t = \ln(ER_{t+1}^{Open} / ER_t^{Open}) \times 100$, where ER_t^{Open} is the 9am rate of the USD/AUD.

(b) Interest rate changes are measured as use the opening rate of the 90-day banking bill and 10-year government bond futures ($\Delta IR_t = (IR_{t+1}^{Open} - IR_t^{Open})$), where IR_t^{Open} is the opening interest rates implied from the futures prices (i.e. 100 – futures price). Q(20) and Q²(20) are Ljung-Box tests of white noise for the returns and squared returns up to 20th lags, respectively.

***, **, *:Significance at 1, 5 and 10%, respectively.

Table 3: Tests of effectiveness of RBA's intervention in the USD/AUD

$$\Delta S_t = \alpha_c + \sum_{i=MON}^{THU} \alpha_i \cdot D_{i,t} + \alpha_{HOL} \cdot D_{HOL,t} + \varepsilon_t + \alpha_{MA} \cdot \varepsilon_{t-1} + (\alpha_{INTV} + \alpha_{CINTV} \cdot CIDUM_t + \alpha_{SINTV} \cdot SIDUM_t) \cdot Intv_t + \alpha_{INTV1} \cdot Intv_{t-1}$$

$$\ln h_t = \beta_c + \beta_h \ln h_{t-1} + \beta_{\varepsilon 1} \frac{\varepsilon_{t-1}}{\sqrt{h_{t-1}}} + \beta_{\varepsilon 2} \left(\frac{|\varepsilon_{t-1}|}{\sqrt{h_{t-1}}} - \sqrt{\frac{2}{\pi}} \right) + \sum_{i=MON}^{THU} \beta_{i,t} D_{i,t} + \beta_{HOL} D_{HOL,t}$$

$$(\beta_{INTV} + \beta_{CINTV} \cdot CIDUM_t + \beta_{SINTV} \cdot SIDUM_t) \cdot |Intv_t| + \beta_{INTV1} \cdot |Intv_{t-1}|$$

	Period II - Period V Jul 1986 - Dec 2003		Period II Jul 1986 - Sep 1991		Period III Oct 1991 - Nov 1993		Period V Dec 1993 - Dec 2003	
	Conditional Mean Equations							
α_c	-0.0175	{0.2839}	-0.0164	{0.5791}	-0.0184	{0.5828}	-0.0191	{0.4698}
α_{MON}	0.0153	{0.5204}	0.0663	{0.1554}	0.0235	{0.6961}	-0.0170	{0.6309}
α_{TUE}	0.0322	{0.1710}	0.0713	* {0.0984}	0.0649	{0.1893}	-0.0209	{0.5677}
α_{WED}	0.0185	{0.4204}	0.0300	{0.4470}	0.0356	{0.4705}	-0.0113	{0.7856}
α_{THU}	0.0215	{0.3805}	0.0039	{0.9253}	0.0136	{0.8080}	0.0258	{0.5463}
α_{HOL}	0.0099	{0.8002}	-0.0162	{0.8054}	0.0962	{0.2757}	0.0490	{0.4372}
α_{MA}	-0.0923	*** {0.0000}	-0.1479	*** {0.0000}	-0.1043	** {0.0186}	-0.0603	*** {0.0014}
α_{INTV}	4.1899	*** {0.0000}	4.5356	*** {0.0000}	4.6173	*** {0.0013}	4.0234	*** {0.0000}
α_{CINTV}	-1.1041	*** {0.0009}	-0.8529	* {0.0911}	-1.4306	** {0.0366}	-1.1655	* {0.0928}
α_{SINTV}	-1.7208	*** {0.0005}	-2.0543	*** {0.0050}	-2.4026	* {0.0974}	-1.3218	{0.1624}
α_{INTV1}	-0.5795	*** {0.0000}	-0.8964	*** {0.0003}	-0.3216	{0.2067}	-0.7059	** {0.0498}
	Conditional Variance Equations							
β_c	-0.1005	{0.2009}	-0.0903	{0.5825}	-0.4795	** {0.0216}	-0.1464	{0.2014}
$\beta_{\varepsilon 1}$	-0.0096	{0.2622}	-0.0166	{0.5877}	0.0775	** {0.0113}	-0.0165	** {0.0276}
$\beta_{\varepsilon 2}$	0.1163	*** {0.0000}	0.2846	*** {0.0000}	0.0705	* {0.0638}	0.0377	*** {0.0037}
β_h	0.9899	*** {0.0000}	0.9410	*** {0.0000}	0.9809	*** {0.0000}	0.9925	*** {0.0000}
β_{MON}	0.1525	{0.2579}	-0.1096	{0.6984}	1.2249	*** {0.0009}	0.2351	{0.2345}
β_{TUE}	0.1018	{0.3529}	0.1286	{0.4926}	-0.2143	{0.4638}	0.2087	{0.1973}
β_{WED}	0.0408	{0.7125}	-0.2269	{0.2839}	0.4950	{0.1101}	0.1860	{0.2658}
β_{THU}	0.1452	{0.2838}	0.2060	{0.3777}	0.5793	{0.1073}	0.0386	{0.8467}
β_{HOL}	0.1558	*** {0.0025}	0.0272	{0.8846}	0.0600	{0.6128}	0.1761	** {0.0103}
β_{INTV}	2.7641	*** {0.0000}	5.0739	*** {0.0017}	4.6021	** {0.0185}	2.7315	*** {0.0028}
β_{CINTV}	-0.1216	{0.4076}	-0.4331	{0.4816}	-0.6624	{0.2760}	-0.7011	*** {0.0003}
β_{SINTV}	0.5977	** {0.0272}	-1.2641	{0.3482}	-1.3613	{0.4229}	0.2931	{0.3560}
β_{INTV1}	-3.1117	*** {0.0000}	-2.9558	*** {0.0016}	-2.5861	*** {0.0091}	-2.5910	*** {0.0049}
d	6.4360	*** {0.0000}	5.5906	*** {0.0000}	19.9744	{0.3963}	6.8381	*** {0.0000}
	Diagnostics ^(a)							
LogL	-1236.7		-372.9		-3.1		-748.9	
Skew	-0.2246		-0.5454		-0.0519		-0.0088	
Kurt	1.6021		1.8135		0.2314		2.1685	
E-N	4.7464	{0.1913}	3.7724	{0.2871}	3.8044	{0.2834}	0.8898	{0.8279}

ΔS_t is continuously compounding daily exchange rate returns measured as $\ln(ER_{t+1}^{Open} / ER_t^{Open}) \times 100$ where ER_t^{Open} is the 9am observation of the USD/AUD exchange rate for the period 1 July 1986 up to 31 December 2003.

(a) The diagnostic tests are for the hypotheses of white noise for the standardized residuals from the estimations,

$$z_t = \varepsilon_t / \sqrt{h_t}.$$

Table 4: Spillover effects of the RBA's USD/AUD interventions on the 90-day interest rate futures

$$\Delta IR_t^{90D} = \alpha_c + \sum_{i=MON}^{THU} \alpha_i \cdot D_{i,t} + \alpha_{HOL} \cdot D_{HOL,t} + \varepsilon_t + \alpha_{MA} \cdot \varepsilon_{t-1} + (\alpha_{INTV} + \alpha_{CINTV} \cdot CIDUM_t + \alpha_{SINTV} \cdot SIDUM_t) \cdot Intv_t + \alpha_{INTV1} \cdot Intv_{t-1}$$

$$\ln h_t = \beta_c + \beta_h \ln h_{t-1} + \beta_{\varepsilon 1} \frac{\varepsilon_{t-1}}{\sqrt{h_{t-1}}} + \beta_{\varepsilon 2} \left(\frac{|\varepsilon_{t-1}|}{\sqrt{h_{t-1}}} - \sqrt{\frac{2}{\pi}} \right) + \sum_{i=MON}^{THU} \beta_{i,t} D_{i,t} + \beta_{HOL} D_{HOL,t}$$

$$(\beta_{INTV} + \beta_{CINTV} \cdot CIDUM_t + \beta_{SINTV} \cdot SIDUM_t) \cdot |Intv_t| + \beta_{INTV1} \cdot |Intv_{t-1}|$$

	Period II - Period V Jul 1986 - Dec 2003		Period II Jul 1986 - Sep 1991		Period III Oct 1991 - Nov 1993		Period V Dec 1993 - Dec 2003	
	Conditional Mean Equations							
α_c	-0.0036	{0.0205}	-0.0004	{0.9466}	-0.0096	{0.0195}	-0.0044	{0.0182}
α_{MON}	0.0036	* {0.0660}	0.0002	{0.9743}	0.0047	{0.4402}	0.0074	*** {0.0021}
α_{TUE}	0.0012	{0.5735}	-0.0003	{0.9704}	0.0029	{0.6031}	0.0027	{0.2805}
α_{WED}	0.0017	{0.4275}	-0.0003	{0.9578}	0.0036	{0.5485}	0.0044	* {0.0902}
α_{THU}	0.0036	{0.1020}	0.0003	{0.9632}	0.0077	{0.1940}	0.0058	** {0.0308}
α_{HOL}	-0.0017	{0.5973}	-0.0005	{0.9638}	-0.0225	** {0.0147}	-0.0037	{0.4155}
α_{MA}	-0.0239	** {0.0169}	-0.0151	{0.2699}	-0.1558	*** {0.0000}	-0.0273	{0.1279}
α_{INTV}	0.0504	{0.2686}	0.0254	{0.7971}	-0.2794	** {0.0375}	0.0294	{0.5845}
α_{CINTV}	0.0261	{0.3511}	-0.0009	{0.9892}	0.0913	{0.2794}	0.0421	{0.2378}
α_{SINTV}	-0.0634	{0.1561}	-0.0200	{0.8275}	0.1360	{0.3157}	-0.0588	{0.2611}
α_{INTV1}	-0.0023	{0.8661}	-0.0019	{0.9441}	0.0001	{0.9980}	-0.0098	{0.6571}
	Conditional Variance Equations							
β_c	0.6513	** {0.0354}	3.2714	{0.1438}	-0.3046	{0.3594}	-0.5126	*** {0.0014}
$\beta_{\varepsilon 1}$	0.0280	{0.5171}	0.8296	{0.2092}	-0.0820	{0.2185}	-0.0654	** {0.0169}
$\beta_{\varepsilon 2}$	1.1756	*** {0.0006}	3.5286	{0.1812}	0.3210	*** {0.0018}	0.2801	*** {0.0000}
β_h	0.9517	*** {0.0000}	0.9273	*** {0.0000}	0.9075	*** {0.0000}	0.9258	*** {0.0000}
β_{MON}	-0.3672	** {0.0189}	-1.4004	*** {0.0000}	-0.2449	{0.5720}	-0.0724	{0.7412}
β_{TUE}	0.4288	*** {0.0009}	0.5455	** {0.0108}	-0.2636	{0.4665}	0.2963	{0.1065}
β_{WED}	0.1018	{0.4310}	-0.6065	*** {0.0047}	0.0845	{0.8131}	0.2846	{0.1158}
β_{THU}	0.3531	** {0.0274}	-0.3045	{0.1383}	-0.3240	{0.4565}	0.3583	{0.1039}
β_{HOL}	0.0608	{0.4190}	-0.2181	{0.1918}	0.0093	{0.9744}	0.2866	** {0.0406}
β_{INTV}	1.5942	** {0.0331}	-1.6524	{0.2572}	3.6826	{0.2996}	-1.5096	{0.2658}
β_{CINTV}	-1.5035	*** {0.0000}	-1.8089	*** {0.0053}	0.2973	{0.7630}	-1.3042	** {0.0428}
β_{SINTV}	1.0620	* {0.0571}	2.5498	** {0.0290}	-2.3256	{0.5082}	2.1966	** {0.0368}
β_{INTV1}	-1.8396	*** {0.0001}	-1.3243	** {0.0302}	-0.3940	{0.6484}	0.1828	{0.8322}
d	2.0103	{0.0000}	2.0008	{0.0000}	2.6136	{0.0000}	2.5968	{0.0000}
	Diagnostics ^(a)							
LogL	8660.1		2020.3		1147.4		4856.0	
Q(20)	5.6527	{0.9993}	21.6387	{0.3604}	20.9998	{0.3971}	14.7493	{0.7906}
Q ² (20)	0.4799	{1.0000}	9.1028	{0.9817}	2.3848	{1.0000}	2.7738	{1.0000}
E-N	0.8845	{0.8292}	2.1220	{0.5475}	0.8920	{0.8274}	2.7804	{0.4267}

ΔIR_t^{90D} is absolute daily change in the implied 90-day banking bill futures interest and is calculated as $(IR_{t+1}^{90D, Open} - IR_t^{90D, Open})$, where $IR_t^{90D, Open}$ is interest rate implied from the futures price (i.e. 100 – futures price at market open).

Table 5: Spillover effects of the RBA's USD/AUD interventions on the 10-year interest rate futures

$$\Delta IR_t^{10Y} = \alpha_c + \sum_{i=MON}^{THU} \alpha_i \cdot D_{i,t} + \alpha_{HOL} \cdot D_{HOL,t} + \varepsilon_t + \alpha_{MA} \cdot \varepsilon_{t-1} + (\alpha_{INTV} + \alpha_{CINTV} \cdot CIDUM_t + \alpha_{SINTV} \cdot SIDUM_t) \cdot Intv_t + \alpha_{INTV1} \cdot Intv_{t-1}$$

$$\ln h_t = \beta_c + \beta_h \ln h_{t-1} + \beta_{\varepsilon 1} \frac{\varepsilon_{t-1}}{\sqrt{h_{t-1}}} + \beta_{\varepsilon 2} \left(\frac{|\varepsilon_{t-1}|}{\sqrt{h_{t-1}}} - \sqrt{\frac{2}{\pi}} \right) + \sum_{i=MON}^{THU} \beta_{i,t} D_{i,t} + \beta_{HOL} D_{HOL,t}$$

$$(\beta_{INTV} + \beta_{CINTV} \cdot CIDUM_t + \beta_{SINTV} \cdot SIDUM_t) \cdot |Intv_t| + \beta_{INTV1} \cdot |Intv_{t-1}|$$

	Period II - Period V Jul 1986 - Dec 2003		Period II Jul 1986 - Sep 1991		Period III Oct 1991 - Nov 1993		Period V Dec 1993 - Dec 2003	
	Conditional Mean Equations							
α_c	-0.0042	{0.0903}	0.0032	{0.4588}	-0.0124	{0.0654}	-0.0061	{0.0577}
α_{MON}	0.0074	** {0.0318}	0.0017	{0.7834}	0.0002	{0.9857}	0.0111	*** {0.0097}
α_{TUE}	-0.0039	{0.2486}	-0.0100	{0.1083}	-0.0042	{0.6540}	-0.0014	{0.7930}
α_{WED}	-0.0015	{0.6675}	-0.0055	{0.3885}	-0.0086	{0.3565}	0.0030	{0.5461}
α_{THU}	-0.0002	{0.9673}	-0.0094	{0.1603}	0.0076	{0.5112}	0.0035	{0.4924}
α_{HOL}	-0.0005	{0.9360}	-0.0054	{0.5911}	-0.0233	{0.2023}	0.0065	{0.4311}
α_{MA}	-0.0760	*** {0.0000}	-0.0905	*** {0.0010}	-0.2140	*** {0.0000}	-0.0468	** {0.0137}
α_{INTV}	-0.0839	{0.2685}	-0.2301	** {0.0419}	-0.9467	*** {0.0000}	-0.0536	{0.6484}
α_{CINTV}	0.0545	{0.2045}	0.1138	{0.1354}	0.0671	{0.4536}	0.0600	{0.3168}
α_{SINTV}	-0.0259	{0.7315}	-0.0219	{0.8371}	0.8222	*** {0.0001}	0.0267	{0.8233}
α_{INTV1}	0.0328	{0.1002}	0.0955	** {0.0101}	0.0084	{0.7820}	-0.0305	{0.1623}
	Conditional Variance Equations							
β_c	-0.3600	*** {0.0000}	-0.9868	*** {0.0000}	-9.0481	*** {0.0000}	-0.3235	** {0.0269}
$\beta_{\varepsilon 1}$	0.0325	*** {0.0020}	0.0691	** {0.0202}	0.0402	{0.4088}	0.0214	{0.1708}
$\beta_{\varepsilon 2}$	0.1456	*** {0.0000}	0.2729	*** {0.0000}	0.1099	* {0.0818}	0.0689	*** {0.0024}
β_h	0.9626	*** {0.0000}	0.8612	*** {0.0000}	-0.8621	*** {0.0000}	0.9597	*** {0.0000}
β_{MON}	0.0850	{0.5198}	0.3667	{0.1120}	-0.1445	{0.5730}	-0.0953	{0.6005}
β_{TUE}	0.2424	** {0.0268}	0.3681	* {0.0602}	-0.1855	{0.5978}	0.1953	{0.1744}
β_{WED}	0.2664	** {0.0148}	0.3789	** {0.0467}	-0.4162	{0.2273}	0.2339	{0.1645}
β_{THU}	0.2844	** {0.0318}	0.2317	{0.3132}	0.0687	{0.7692}	0.2207	{0.2266}
β_{HOL}	0.1364	** {0.0426}	-0.0963	{0.6535}	0.0381	{0.8446}	0.1202	{0.1684}
β_{INTV}	1.2144	** {0.0453}	4.7277	*** {0.0083}	-5.3108	{0.1243}	0.8152	{0.3612}
β_{CINTV}	0.2068	{0.3530}	-0.5484	{0.4676}	1.8295	** {0.0460}	0.6337	* {0.0644}
β_{SINTV}	0.4046	{0.3305}	-2.2634	{0.1228}	5.7337	* {0.0764}	-0.2237	{0.6516}
β_{INTV1}	-1.5821	*** {0.0003}	-1.1625	* {0.0942}	0.7483	{0.3795}	-1.0854	{0.1472}
d	5.9739	{0.0000}	5.1072	{0.0000}	4.1853	{0.0000}	10.0706	{0.0000}
	Diagnostics ^(a)							
LogL	7571.7		2188.3		943.1		3933.8	
Q(20)	29.3487	* {0.0811}	26.6115	{0.1466}	27.2997	{0.1270}	11.1241	{0.9429}
Q ² (20)	10.1933	{0.9645}	27.5654	{0.1201}	10.0626	{0.9670}	16.2291	{0.7023}
E-N	6.6143	* {0.0853}	8.1509	** {0.0430}	3.0674	{0.3813}	0.4182	{0.9365}

ΔIR_t^{10Y} is absolute daily change in the implied 10-year treasury bond futures interest and is calculated as $(IR_{t+1}^{10Y, Open} - IR_t^{10Y, Open})$, where $IR_t^{10Y, Open}$ is interest rate implied from the futures price (i.e. 100 – futures price at market open).

Figure 1: Daily USD/AUD rate and RBA's intervention transactions:

July 1986 – December 2003