The Determinants of Foreign Exchange Intervention by Central Banks: Evidence from Australia

Suk-Joong Kim
School of Banking and Finance
The University of New South Wales
2052 Australia
s.kim@unsw.edu.au

Jeffrey Sheen
Department of Economics
The University of Sydney
2006 Australia
jeffs@econ.usyd.edu.au

ABSTRACT
Intervention by the Reserve Bank of Australia on foreign exchange markets from 1983 to 1997 is conjectured to have been determined by exchange rate trend correction, exchange rate volatility smoothing and profitability considerations. Using Probit and friction models, we show that these factors were significant influences on intervention behaviour. Consistent with the constraint of intervening only when a clear trend is apparent, we find that above average measures of deviations from trend and of volatility muted the response of the Reserve Bank.

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1. Introduction

Central banks intervene frequently in foreign exchange markets, even if they have not adopted explicitly some form of an exchange rate target regime. However there are often long stretches of time when central banks withdraw from the market, and this can occur when markets are very orderly or even in periods when there has been considerable turbulence. In this paper, our aim is to unravel some of the factors that lead to central bank involvement and withdrawal.

We test three primary determinants of the behaviour of a central bank (in particular, the Reserve Bank of Australia) – daily deviations from a short-term trend of the spot exchange rate, the conditional volatility of daily changes in the spot rate, and a measure of the conditional profitability of past interventions. With regard to the first two, we conjecture that the response of a central bank is non-linear. That is, for sufficiently large disorderliness of the foreign exchange market, the central bank might back off from its normal intervention strategy. This may be because there is a very large probability that intervention will be ineffective at best, and that big and pointless losses may be incurred by the bank. However in normal times, we might expect the bank to intervene to bring the exchange rate closer to a perceived trend, and to reduce any upsurge in volatility. We see profitability as a constraint on the objective function of the central bank. This constraint will not bind at various times, and in such circumstances, a measure of profitability should not have a significant effect on intervention behaviour. However there are likely to be periods when the profitability constraint does bind, and therefore will have an important effect on the intervention response.
With many central banks now willing to release data\(^1\) on their daily net market purchases of foreign currency assets undertaken for intervention purposes, important research can be conducted to evaluate the effectiveness and the determinants of this intervention behaviour. A substantial literature has built up to conduct this evaluation\(^2\).

If central banks intervene, it must be true that they believe these actions are effective. However the evidence on the effectiveness of intervention is mixed. In general, the evolving view is disposed towards ineffectiveness – for example, Baillie and Osterberg (1997, p.909) conclude “there is little support for the hypothesis that intervention can consistently influence the exchange rate”. They find occasional evidence of effective ‘leaning against the wind’, but invariably detect counterproductive effects on volatility. There is a fundamental difficulty that has to be confronted in this area. The central bank is judged to be effective in the sense of stabilizing the foreign exchange market if its intervention can be seen to return the exchange rate towards an underlying trend, or to reduce the conditional volatility of that rate and the associated trading turmoil. However it only intervenes when the trend deviations and the volatility are noticeable. Thus basic regressions will indicate a positive correlation between these and the interventions, leading to an erroneous conclusion that the intervention was counter-productive. Kim, Kortian and Sheen (2000) introduce dummy variables to pick up sustained intervention effects and above-average size effects, and conclude that there is evidence to suggest that the Reserve Bank of Australia’s intervention behaviour stabilized to some degree the conditional mean and volatility of exchange rate changes.

\(^1\) Typically, this data is released after a lag – in the case of the Reserve Bank of Australia, this lag is six months.

With regard to the determinants, there is considerable evidence, from countries other than Australia, showing that central banks do respond to deviations of the spot rate from some target level (by ‘leaning against the wind’), and to exchange rate volatility (or ‘market calming’). Almekinders and Eijffinger (1994) construct a Tobit model for intervention by the U.S. Federal Reserve and the Bundesbank and show that target deviations mattered. In another paper, Almekinders and Eiffinger (1996) estimate a friction model, and find evidence of ‘leaning against the wind’ and of ‘market calming’. Dominguez and Frankel (1993) show that the Fed has responded to deviations from a purchasing power parity target and to targets that were announced at the Plaza and various Louvre accords from 1985 to 1990. Dominguez (1998) models the likelihood of Dollar-Mark and Dollar-Yen interventions by the G-3 countries by estimating Probit models, and reports no significant intervention response to deviations of the current level and volatility of exchange rate movements from their moving averages. Baillie and Osterberg (1997) model the probability of intervention by the Fed and the Bundesbank, and find that a GARCH measure of the deviations of conditional from unconditional volatility has no effect on interventions in the DM/US$ or Yen/US$ markets. However deviations of the spot rates from the accord targets did matter. Although there is an extensive literature on the profitability of intervention, to our knowledge, no one has tested to see whether profitability of a central bank’s intervention activity has a potentially constraining effect on its behaviour.

In Section 2, we present an analysis of the key features of the Reserve Bank of Australia’s (RBA) foreign intervention from December 1983 to December 1997. Section 3 presents our approach to modeling the behaviour of the Reserve Bank. We show how we have

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3 See Sweeney (1997) for a recent survey. In general, the profitability depends on whether appropriate risk measures are included in the calculations.
obtained measures of trend deviations, conditional volatility and of profitability. In Section 4, we discuss our two econometric approaches to estimating the effects of these explanatory variables on intervention. Our results are given in Section 5, and some concluding comments offered in Section 6.

2. Statistical Features of Reserve Bank Interventions

The daily foreign exchange interventions carried out by the Reserve Bank of Australia are purchases or sales of $A “almost always against the US$ with the aim of influencing the (US$/A$) exchange rate” (Rankin, 1998). The daily net market purchases are measured in $A billions (see Panel B of Figure 1) and reported in its official publication (occasional paper no. 10 and its biannual updates) along with the daily inter-bank close mid-rate US$/A$ exchange rate. The data used in this study is provided by the RBA.

Since the floating of the Australian dollar in December 1983 until December 1997, the Reserve Bank intervened on 46.5% of all trading days. Table 1 shows the preponderance of days of zero activity (1903 days), and the asymmetry of intervention with 13.75% of trading days involving purchases of Australian dollars compared to 32.75% being sales. However the average transaction value of purchases of the Australian dollar exceeded that of sales (A$75m to A$48m), while the average absolute size of all transactions was A$56m. On two-thirds of the active days, the intensity of the interventions was in the modest range of –A$50m to +A$50. Outside these limits, there were only a small number of particularly large interventions (4 above A$0.5b and 4 less than -A$1b.).

Intervention policy was not uniform over the sample. The Reserve Bank has published a description of its intervention strategies over 5 distinct sub-periods (see Rankin, 1998). The
first period (I) was from December 1983 to June 1986. In this period, interventions were frequent (85%), modest in size (averaging A$8m) and symmetric in purchases and sales. In effect, the Reserve Bank was in a ‘learning’ mode after the deregulation of the foreign exchange market – it was “smoothing and testing” the market. In the second period (II) which was from July 1986 to September 1991, the activity frequency remained high (70%) while the intensity increased dramatically (to A$63m). In this period, the Reserve Bank claimed it was ‘leaning against the wind’, mainly aiming to ease the strengthening of the A$ in 1988 and 1990 (for 84% of transactions). Accordingly, there were fewer defenses of the currency, but the average size of these was twice as big. The largest purchase of A$1.026b took place at the time of the October 1987 worldwide stock-market crash. The third period (III) lasted from October 1991 to November 1993, and the Reserve Bank reduced its frequency (to 25%), significantly raised its average intensity (A$145m) and mainly defended the A$. In effect, it was using foreign exchange intervention to support its easing of monetary policy. This period of exchange rate weakness came to an end, and in the fourth period (IV) from December 1993 to June 1995, the Reserve Bank kept out of the foreign exchange market. It returned in the fifth period (V) from July 1995 to December 1997 to unwind the large swap position built up during the third period. They intervened frequently with moderate average sales (A$40m) of Australian dollars, thus replenishing reserves.

Over the whole sample, interventions were less than or equal to A$2m on 75 trading days. In period I and II, there were only a few days (16) of very small A$ purchases (A$1m-2m) and (38) of very small A$ sales. In period V, there were 21 days of sales of US$ that were less than A$1m in value. The smallest defense of the A$ in period III was an outlier of A$2.8m. Our friction model, below, will provide estimates of purchase and sale thresholds beyond which intervention will take place.
3. Modeling Intervention Behaviour

We conjecture that a central bank intervenes with the objective of minimizing disorderliness over time in the foreign exchange markets for its currency, depending on its perception of the effectiveness of that intervention, and subject to a floor constraint on its losses. Thus they would intervene in foreign exchange markets for a number of reasons – trend correction, volatility smoothing, profitability and inventory considerations.

Firstly, they might wish to reduce disorderliness by returning the exchange rate to what they perceive to be the appropriate trend. This requires the central bank to be convinced about the underlying trend. With a very long horizon, purchasing power parity considerations might drive intervention behaviour, which would then have to be conducted in conjunction with its monetary policy. At lesser horizons, a central bank may aim to correct any short-term speculative bubble or bandwagon surge. This would be in keeping with the widely used term, ‘leaning against the wind’. In our econometric tests, we focus on the latter short-term consideration, recognizing that the Reserve Bank of Australia has never declared that it intervenes to achieve long horizon targets. If the ‘wind’ blows too fiercely, we might expect the central bank to recognize that its intervention may be futile.

Secondly, a central bank may be concerned about disorderly conditions in foreign exchange markets that might show up as excessive uncertainty and trading. They may intervene to calm the market, by trying to reduce uncertainty. This uncertainty may be measured by the conditional volatility of the daily change in the exchange rate, which tends to be correlated with transaction volumes. Again, we might expect that there is a threshold of disorderliness beyond which a central bank would back away from the market. In these

\[\text{\footnote{Dominguez and Frankel (1993, p80) report significant estimates for the response of the Federal Reserve to a purchasing power parity target from 1982-88.}}\]
circumstances, the volatility and trading volumes may be sufficiently large to swamp any attempts by the central bank to calm the market. In these circumstances, their interventions would be ineffective, and would be likely to inflict serious losses on the central bank. We test to see whether a derived measure of conditional volatility of the spot exchange rate changes has this non-linear influence on intervention.

A third influence on central banks is the profitability of their foreign intervention operations. Clearly, this is not a matter of primary importance. Rather profitability is a potential constraint on the behaviour of a central bank. Prudential central bank managers would put procedures in place to prevent excessive cumulative losses. If the people conducting foreign exchange intervention were particularly unskillful traders, big losses may be incurred by a central bank. Further, in achieving the first two objectives described above, the central bank may inevitably suffer losses. This might explain the apparent speculative profits earned by taking an opposite position to central bank’s intervention transactions (see Neely, 1998 and Szakmary and Mathur, 1997). At some point, these losses may become a binding constraint, and then profitability would be an additional determinant of intervention behaviour. If the constraint does not bind, profitability will not matter. We test to see whether a measure of conditional profitability had an influence on Reserve Bank intervention in the whole sample or any of the sub-periods. A related constraint is the inventory one. A central bank will need to maintain an optimal inventory of foreign exchange assets to enable it to conduct its intervention operations over time. Naturally there will be occasions when they will re-balance their portfolios, presumably when the conditions in the foreign exchange market are very orderly. Unfortunately, central banks do not provide high frequency data on the level and compositions of their portfolios, and so inventory considerations cannot be tested empirically.
Our model of intervention behaviour reduces to three key explanatory variables – daily deviations from an orderly exchange rate trend, the conditional volatility of daily exchange rate changes, and profitability of past interventions. We will estimate Probit models for purchases and sales of foreign currency (in US$) separately, and then we will estimate a friction model of intervention whereby the Reserve Bank chooses to buy/sell only beyond threshold limits. Before we turn to the econometric tests, we present details on the three explanatory variables.

3.1 Measuring the Trend Deviations

It is not uncommon for central banks to target exchange rate movements, officially or unofficially. In the case of the US dollar exchange rates, announced target exchange rates existed under the Plaza and Louvre agreement in the 1980s, and any deviations from these caused market interventions by various central banks involved in the arrangements. In the absence of such arrangements, it is rather difficult to ascertain the existence and the level of target exchange rates. Nevertheless, central banks do appear to undertake ‘leaning against the wind’ interventions, whenever current exchange rate movements deviate significantly from a longer-term trend. This trend might be modeled as a moving target exchange rate represented by some moving average. Though the length of the moving average can vary from one week to many months, if the central bank’s main concern is to ensure an orderly foreign exchange market, it is reasonable to consider that it concentrates on managing short-term exchange trends. The current exchange rate deviation can then be measured as the difference between the current US$/A$ exchange rate \( s_t \) and its one-week moving average as below:$
\[ ERDEV_t = s_t - \frac{1}{4} \sum_{i=0}^{4} s_{t-i}. \]

The time series plot of the one-week deviations is shown in Figure 2 (Panel A). It is expected that a positive/negative deviation (or an appreciation/depreciation relative to the trend of the $A$) would invite a positive/negative (purchase/sale of foreign currency) intervention response by the RBA to moderate the current trend. Furthermore, the RBA may be expected to engage more (or perhaps, less) intensively if deviations are sizeable and continuing over a number of days.

### 3.2 Measuring Conditional Volatility

In general, parsimonious GARCH (1,1) models with Student-\(t\) distribution are found to be useful for modeling the conditional volatility of daily exchange rate changes (see Hsieh, 1989; Baillie and Bollerslev, 1989; and Kim, 1998) - the estimated conditional volatility addresses the observed volatility very closely. Daily foreign exchange market volatility is approximated by the estimated conditional variance, \(h_t\), of the daily US$/A$ exchange rate changes arising from an EGARCH(1,1) model with a conditional \(t\) distribution as reported in Kim, Kortian and Sheen (2000), and as shown below.

\[
\Delta s_t = a_t + \sum_{i=MON}^{THU} a_i D_{t,i} + a_{HOL} D_{HOL,i} + (a_{INTV} + a_{CIDUM} CIDUM_i + a_{SIDUM} SIDUM_i + a_{RIDUM} RIDUM_i ) \text{Intv}_i + a_{STDUM} STDUM_i + e_t
\]

\[
e_t = z_i \sqrt{h_t}; \quad e_t \sim t(0,h_t,d), \quad z_t \sim iid(0,1)
\]

\[ 5 \text{ days represent one week.} \]
\[
\ln h_t = b_{i_t} + b_n \ln h_{t-1} + b_{e_t} e_{t-1} + b_{t} e_{t+1} - \frac{\sqrt{2}}{\sqrt{h_{t-1}}} + \sum_{i=MIN}^{THI} b_{D,t} + b_{HOL,t} + b_{CIDUM,t} + b_{SIDUM,t} + b_{RIDUM,t} + b_{STDUM,t} + b_{INTV,t} + b_{STDM,t} \]

where:

- \( D_{i,t} = \) Daily dummy that takes the value of one for day \( i \) and zero otherwise.
- \( D_{HOL,t} = \) Holiday dummy that takes the value of one for the day immediately after public holidays.
- \( Inv_t = \) The RBA intervention proxied by net market purchases of foreign currency, measured in $A billions.
- \( CIDUM_t = \) Cumulative intervention dummy variable that takes the value of one if intervention at day \( t \) is preceded by intervention in the same direction at day \( t-1 \) and \( t-2 \), and zero otherwise.
- \( SIDUM_t = \) Intervention size dummy variable that takes the value of one if the absolute amount of intervention at day \( t \) is greater than the whole sample average daily net market purchase of $A56m, and zero otherwise.
- \( RIDUM_t = \) Reported intervention dummy variable that takes the value of one for the days of known intervention proxied by a report of such in the Australian Financial Review the following day, and zero otherwise.
- \( STDUM_t = \) Official statement dummy that takes the value of positive (negative) one for days of official statement suggesting the value of the $A should rise (fall), and zero otherwise.
- \( h_t = \) Conditional variance of daily exchange rate changes.

The conditional mean and variance of the daily exchange rate changes are modeled by considering the differential impacts of particularly large interventions, of sustained interventions, and of publicly known interventions. Given the size of the Australian foreign exchange market (daily volume of $US46.6bn in April 1998⁶), the size of intervention has to be substantial enough to be able to move the ‘equilibrium’ exchange rate. It is also important to determine whether an intervention transaction on a day is a one-off episode, or a part of a series over many days. The RBA may spread out the intervention transaction over a number of days to maximize the effects of the intervention through the signaling channel. An intervention stance may be perceived to be more credible to market participants if they see a series of intervention transactions rather than a one-off entry into the market. Publicized interventions may have different effects to secret ones. Publicized interventions will have

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their greatest effects if the RBA action is seen as a credible source of information about future market conditions, in particular the future monetary policy stance. Secret interventions may also have some effect if the RBA can stimulate herding behavior in a desired direction by entering the market and placing large disguised orders. Dummy variables for each are included in the analysis to pick up these differential effects. Other dummy variables included address seasonal effects (days of the week and holidays) and pick up the possible impacts on the market created by the release of official statement by either the RBA or the Federal Treasury commenting on the current conditions in the foreign exchange market.

The estimation results for the above model over the whole sample from December 1984 to December 1997 and four sub-samples, as identified in the previous subsection, are presented in Table 2\textsuperscript{7}. The estimated conditional variance for the whole sample that will be used in subsequent estimations is shown in the second panel of Figure 2. The major findings are that the RBA’s interventions appear to have stabilizing influences on the conditional mean and variance of the daily changes of the US$/A$ rate. There is the commonly observed contemporaneous positive correlation between the direction of intervention and the conditional mean and variance of exchange rate returns as indicated by the positive coefficients for $a_{INTV}$ and $b_{INTV}$. But more importantly, sustained and large interventions have a stabilizing influence in the foreign exchange market in terms of both the direction and volatility, as shown by the significant negative coefficients for the cumulative and size slope dummy variables for both the conditional mean and variance equations ($a_{CIDUM}$ and $b_{CIDUM}$; $a_{SIDUM}$ and $b_{SIDUM}$). Without these interventions, the market would have moved further and exhibited more volatility.

\textsuperscript{7} For a further analysis, see Kim, Kortian and Sheen (2000).
3.3 Measuring the Profitability of Intervention

In general, central banks do not disclose full information on their portfolio of international reserve assets and liabilities. It is therefore difficult for outsiders to properly assess the profitability of their operations. However the trend towards disclosing the size of their daily interventions on foreign exchange markets has made it possible to get some perspective on the issue. We measure the conditional profit of all past interventions, starting at an arbitrary point, by computing the current net value of every past intervention and summing them up\(^8\).

The current net value of a past intervention is its current yield value less its current opportunity cost value. For a A$1 value purchase of a US$ asset \( m \) periods in the past, the current \((t)\) benefit value in A$ is given by \((1+i_{US}(t-m)) (1+i_{US}(t-m-1)) \ldots (1+i_{US}(t-1)) s_{t-m} s_t\) where \( i_{US} \) is the overnight Federal Funds rate, and \( s \) is the spot exchange rate (US$/A$). The current opportunity cost value of such a purchase would be \((1+i_{A}(t-m)) (1+i_{A}(t-m-1)) \ldots (1+i_{A}(t-1))\) where \( i_{A} \) is the overnight Australian cash rate.\(^9\) Thus the current net value is in fact the cumulated value of \textit{ex-post} uncovered interest disparity, \( CUID(t,m) \):

\[
CUID(t, m) = \prod_{i=1}^{m} (1 + i_{US} (t - i)) \frac{s_{t-m}}{s_t} - \prod_{i=1}^{m} (1 + i_{A} (t - i))
\]  

By multiplying each net market purchase, \( Intv(t-i) \), of foreign currency at \( i \)-th by \( CUID(t,i) \), and adding them up yields a measure of the conditional profit, \( CProfit(t) \):

\(^8\) See Leahy(1995) and Neely(1998) for a similar calculation

\(^9\) To make the computation, the US interest rates must be taken as the previous day’s value in recognition of the different time zones.
\[ CProfit(t) = \sum_{i=1}^{n} Inv(t - i) CUID(t, i) \] (4)

This measure has some strengths and weaknesses. By adding up these current values, any intervention purchase of US$ at \( t-m \), followed by an equivalent sale some time later, say at \( t-m+n \), will cancel out in terms of inventory, but the profit/loss implications will be cumulated forwards in value until time \( t \), when conditional profits are being measured. This seems to be a powerful representation of economic profitability in the absence of detailed stock data. However the profit measure is sensitive to the value of the exchange rate at \( t \), and so care in its use is needed when exchange rate volatility is high. Equally the measure is sensitive to the exchange rate at the starting point for the summation. Further the Reserve Bank does declare accounting profits and dividends every year to the Australian government\(^{10} \), and so cumulated profits may be debited annually from the intervention fund. It is possible that accounting profits, rather than our \( CProfit \) affects intervention behaviour. Accounting profits measures the annual net return on the total stock of net assets in the intervention fund. However, accounting profits will be based on the change in value of the fund of reserves, which may arise from transactions unrelated to intervention – for example, swaps with other central banks, transactions on behalf of the government etc. Insofar as the movements in these two profit measures are fairly closely correlated over reasonable horizons, our results would be unaffected. Finally, we evaluate the current benefit value of a foreign currency purchases in terms of the US$. Since the Reserve Bank does not provide data on their currency portfolio compositions, this is an unavoidable approximation.

\(^{10}\) In practice, the RBA, in its Annual Report, has often declared profits from its intervention activities. Andrew and Broadbent (1994) report that the RBA’s intervention had been profitable generating realised profits of A$382 million by June 1994.
From (4), conditional profit will certainly be positive if $Intv(t-i)$ and $CUID(t,i)$ always have the same sign i.e. when Reserve Bank purchases (sales) of US$ at $t-i$ are associated with positive (negative) cumulated disparities at $t$.

Our measure of the *ex-post* cumulated uncovered interest disparity is not expected to be zero, nor is it expected to be zero on average. The *ex-post* measure is not the appropriate determinant of the behaviour of private arbitrageurs or speculators, or even of the intervenors – it is the *ex-ante* measure that matters, which involves market exchange rate expectations and risk.

Thus an observed *ex-post* disparity may reflect exchange rate forecast errors, which could be rational or irrational and may well be persistent. If the disparity was due solely to expectation errors, a negative $CUID(t,m)$ would mean that the market was *ex-ante* excessively pessimistic about the Australian dollar at $t-m$, and the Reserve Bank would have made a profitable intervention if $Intv(t-m)$ had been negative – that is, they should have bought the Australian dollar. Since the A$ did turn out to be stronger than expected, this profitable intervention would have been inherently stabilizing.

Further, exchange rate risk, interest rate risk and potentially default risk will be priced in the market equilibrium, and so the *ex-post* disparity may also reflect a risk discount or premium. If expectations were never wrong, then a negative value of $CUID$ would suggest that the Australian dollar is priced at a risk premium. In this event, the rule for Reserve Bank profitability might suggest buying the A$. However this might not be a stabilizing move. It may add profitability, but it would add excessive risk if the market valuation of risk were efficient. If the Reserve Bank judges that the market risk is mis-priced, then the profitable intervention may be stabilizing.

In Figure 3, we present $CProfit$ and $CUID$ over the whole period. The whole sample calculations show that conditional profits were reasonably close to zero on average until 1988.
Serious losses were sustained thereafter until 1997, when these cumulative losses began to be rolled back. By the end of the sample, conditional profits were back into the range of the 1980s. Cumulated uncovered interest disparity (U.S. relative to Australia) was positive from 1984-7, but negative thereafter. The positive values probably represented expectation errors, with excessive optimism about the A$ - indeed, the Federal Treasurer in 1986, Paul Keating even felt the need to warn markets that Australia was heading to be a ‘banana republic’. The predominantly negative CUID over the whole sample suggests that the A$ was priced with a risk premium. In period I, the Reserve Bank was willing to take small losses as it smoothed and tested the market. In period II, Figure 3 indicates an increasingly negative CUID, while most interventions were positive (purchases of foreign currency). Not surprisingly, profits began to suffer. Monetary policy was tightened in 1988 and the Reserve Bank was largely selling A$es even though CUID was negative. These losses slowed in period III while the Reserve Bank used intervention to support its easy monetary policy in the face of excessive pessimism with regard to the A$. In period IV (December 1993- June 1995), no intervention took place. However CUID was declining further, and profitability considerations might have tempted the Reserve Bank to defend the A$. The current net value of earlier interventions was declining, thus reducing profit. The cumulative current value loss of all previous interventions since the float peaked at around A$12bn\textsuperscript{11}. In period V, the Reserve Bank began to restore its inventory of foreign currency assets. Conditional profits only began to improve after 1996 when CUID began to improve. This was simply because the A$ depreciated.

\textsuperscript{11} This loss figure is only indicative, and care should be taken when comparing it to a simple sum of declared annual profits by the RBA. Our measure is a current value sum, and also does not include capital gains or losses on the full stock of net assets in the RBA’s intervention fund.
4. Econometric modeling

Econometric modeling of the daily intervention series poses some practical challenges owing to the unique nature of the series. As shown in Table 1, it has the feature known as a ‘zero-inflated process’ – 1903 out of 5334 observations have a value of zero. One approach to this problem is to consider the intervention series to be generated from a mixture of three distinct probability distributions with non-overlapping sample spaces. That is, the three types of events (positive intervention, negative intervention and zero intervention) are drawn from different distributions. An implication is that the dependent variable, i.e. the intervention series, is discontinuous and so modeling it using standard regression techniques is inappropriate. We use two methods to address this issue.

Firstly, we generate a binary choice dependent variable corresponding to intervention/no intervention outcomes for each of the two types of interventions, and model the probability of each type of intervention using the Probit estimation method. Baillie and Osterberg (1997) adopt this method, modeling separately positive and negative interventions of the US Federal Reserve using intervention dummy variables. As an initial approach, we adopt this method and estimate the probability of positive and negative interventions of the RBA’s foreign exchange market interventions:

\[ \text{Intv}_{\text{Post},t} = \alpha_c + \alpha_{\text{ERDEV}} \text{ERDEV}_t + \alpha_{n} \text{h}_t + \alpha_{\text{CProfit}} \text{CProfit}_t \]

\[ \text{Intv}_{\text{Neg},t} = \alpha_c + \alpha_{\text{ERDEV}} \text{ERDEV}_t + \alpha_{n} \text{h}_t + \alpha_{\text{CProfit}} \text{CProfit}_t \]

where

\[ \text{Intv}_{\text{Post},t} = \] A dummy variable that takes the value of one if there is a positive (negative) intervention (i.e. purchase of foreign currency with A$), and zero otherwise.

\[ \text{Intv}_{\text{Neg},t} = \] A dummy variable that takes the value of one if there is a negative intervention (i.e. sale of foreign currency with A$), and zero otherwise.

\[ \text{ERDEV}_t = \] Deviation of current exchange rate \((s_t)\) from one-week moving average rate \((\frac{1}{4} \sum_{i=0}^{4} s_{t-i})\).
\[ h_t = \text{Conditional variance of daily exchange rate returns generated from an EGARCH(1,1) model in section 3.2.} \]
\[ CPROFIT_t = \text{Conditional profit index of all intervention carried out by the RBA as described in section 3.3} \]

The Probit\(^{12}\) models employ three variables, \(ERDEV\), \(h\) and \(CPROFIT\), to explain the probability of observing a positive/negative intervention on a given day. To the extent that a central bank wishes to ‘lean against the wind’ so as to smooth the market’s trend, rapid movements in the exchange rate that overshoot the trend may incite it to enter the market. In addition, higher exchange rate volatility representing greater uncertainty in the market may also induce an intervention by a central bank, aimed at dampening unnecessary speculation and trading in the market. Lastly, to the extent that cumulated losses from interventions might place some restrictions on the intervention behavior, conditional profitability of all the interventions may also influence the RBA’s intervention decisions.

A second method, the friction model, as adopted by Almekinders and Eijffinger (1996), involves specifying three separate distributional assumptions for the intervention series, corresponding to the three different states of the intervention outcome. This approach allows a direct modeling of the relationship between the interventions and their determinants. The central bank is assumed to react to market conditions (encapsulated in deviations of current exchange rate from some target rate and current volatility level) and a profitability constraint, but only after an intervention threshold is reached. The thresholds may differ for positive and negative interventions (purchase/sale of foreign currency) and these may be estimated. We adopt this method with a view to extending our empirical understanding of the determinants of the Reserve Bank of Australia’s intervention.

\(^{12}\) Separate Probits suffer from selection bias. We report separate Probit results for the sake of comparison with previously published results – eg Dominguez (1998).
Instead of modeling the intervention by deviations of current level and volatility from target level only, we allow for the possibility that central banks pay attention to the nature of such deviations. That is, exchange rate deviations that persist over a number of days and/or large deviations may attract more (or less) central bank attention than small and transitory movements. The market calming effects of intervention may be realized if the size of the intervention is large enough and the intervention is carried out openly and consistently over a number of days to convince market participants of the information content of the intervention. However on days of very high volume and volatility with unusually large information processing taking place, intervention may be dwarfed, and the central bank may prefer to stay out of the market, waiting for the emergence of a clearer trend and a return to normal trade volumes. Thus, while a small trend deviation or small rise in market volatility may invite an intervention response, beyond some high deviation or level of volatility the central bank may withdraw its intervention.

In previous work (Kim, Kortian and Sheen, 2000 and as reported here in section 3.2), we showed that persistent intervention was effective. We might then expect the Reserve Bank to recognize this effectiveness and to persist in an intervention strategy over a number of days. Thus in addition to the 3 types of explanatory variables (trend deviations, volatility and profitability), we add the lagged value of the intervention variable.

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13 Ideally, intervention and the exchange rate processes ought to be simultaneously estimated. This is difficult, given the complications of the separate models. Our two-stage method will suffer a bias, but may give us better estimates than if we ignore the effects of intervention on the exchange rate process.
We model the RBA intervention as below:

\[
Intv_t = (\alpha_c \cdot I_{dev,c} \cdot \alpha_{cum,c} \cdot I_{cum,c} \cdot \alpha_{size,c} \cdot I_{size,c} \cdot |ERDEV_t| + \beta_d \cdot I_{ds,d} \cdot I_{ds,c} \cdot I_{size,d} \cdot h_t + \gamma \cdot CPROFIT_t + \delta \cdot Intv_{t-1} + \epsilon_t
\]  \tag{7}

where

- \( Intv_t \) = Daily net market purchase of foreign currency by the Reserve Bank of Australia, measured in A$ m.
- \( ERDEV_t \) = Deviation of current exchange rate \( (s_t) \) from its one-week moving average rate \( \left( \frac{1}{5} \sum_{i=1}^{5} s_{t-i} \right) \).
- \( I_{dev,c} \) = An indicator variable that takes the value of positive (negative) one if \( ERDEV_t \) is positive (negative) and zero otherwise.
- \( I_{cum,c} \) = An indicator variable that takes the value of positive (negative) one if \( ERDEV_t \) is positive (negative) for four consecutive days (i.e. t-3 to t), and zero otherwise.
- \( I_{size,c} \) = An indicator variable that takes the value of positive (negative) one if \( ERDEV_t \) is positive (negative) and by more than 1%, and zero otherwise.
- \( I_{ds,d} \) = An indicator variable that takes the value of positive (negative) one if the daily exchange rate change \( (\Delta s_t) \) is positive (negative), and zero otherwise.
- \( I_{size,d} \) = An indicator variable that takes the value of one if the current conditional variance is higher than the unconditional (or average conditional) variance for each sample.
- \( h_t \) = Conditional variance of daily exchange rate returns generated from the EGARCH(1,1) model described in section 3.2.
- \( CPROFIT_t \) = Conditional profit index of all intervention carried by the RBA.

The model employs essentially the same three independent variables used in the Probit models, plus the lagged independent variable. However, we now allow for the possibility that the RBA’s intervention response depends on the nature of the market disturbances.

The market calming objective of the RBA’s intervention would suggest that the slope dummy coefficients \( (\alpha_c \text{ and } \beta_c) \) are positive. This is because a rise/fall in the current exchange rate compared to the longer-term trend in both its level and volatility may be deemed to be undesirable, inviting a positive/negative intervention response. The three slope coefficients associated with the exchange rate deviations would pick up the disaggregated effects of deviations: the first represents an average effect, the second addresses the effect of continuing deviations, and the third deals with large current deviations. Also, a rise in the conditional volatility above its unconditional volatility, associated with a current positive/negative
deviation of the exchange rate from the longer-term trend, may generate a positive/negative intervention response. Thus, \textit{a priori}, we expect positive coefficients for these variables. It is rather difficult to place an economic meaning on the sign of the coefficient for the profit variable without having detailed information on the RBA’s portfolio positions and perceptions. Instead, only the significance issue will be discussed.

In general, the intervention action is assumed to occur after the breaching of positive and negative thresholds. Denoting $f(\cdot)$ as the right hand side of (7) excluding the error, we assume:

- positive intervention, $Intv_t > 0$, when $f(\cdot) > \theta^+$
- negative intervention, $Intv_t < 0$, when $f(\cdot) < \theta^-$
- no intervention when $\theta^- < f(\cdot) < \theta^+$.

The resulting likelihood of (7) becomes

$$L = \prod_{Intv_t > 0} \frac{1}{\sigma \sqrt{2\pi}} \exp \left( -\frac{(\varepsilon_t + \theta^+)^2}{2\sigma^2} \right) \prod_{Intv_t < 0} \left\{ \phi \left( \frac{\theta^+ - (Intv_t - \varepsilon_t)}{\sigma} \right) - \phi \left( \frac{\theta^- - (Intv_t - \varepsilon_t)}{\sigma} \right) \right\} \prod_{Intv_t = 0} \left\{ \phi \left( \frac{\theta^+ - (Intv_t - \varepsilon_t)}{\sigma} \right) - \phi \left( \frac{\theta^- - (Intv_t - \varepsilon_t)}{\sigma} \right) \right\}$$  \hspace{1cm} (8)

where $\phi$ denotes the probability density of the N(0,1) distribution.
5. Empirical Results

5.1 Probit Models

The estimation results for the Probit models are reported in Table 3. The estimation periods are for the whole sample and for each of the sub-sample periods, except for the fourth sub-sample in which there was no RBA intervention\textsuperscript{15}. Both the exchange rate deviations and conditional variances are shown to have significant effects on the positive and negative intervention probabilities.

The coefficients for the current rate deviations ($ERDEV_t$) are significant and positive for the positive intervention estimations and negative for the negative intervention estimations. This suggests that a higher probability of intervention purchase (sale) of foreign currency by the RBA is associated with a current appreciation (depreciation) of the A$, providing empirical support for the ‘leaning against the wind’ hypothesis of market intervention. The absolute size of the estimated parameters for negative interventions is higher than for positive ones, in the whole sample and in the first two periods. This suggests that, in general, the Reserve Bank was more likely to jump to the defense of the Australian dollar when it was weakening, than to attack it when strengthening. This is similar to the finding reported by Baillie and Osterberg (1997) for the Federal Reserve’s US$ interventions.

The conditional volatility of daily exchange rate movements shows a significant negative effect over the whole period for positive interventions, indicating a lower probability of intervention purchase of foreign currency in response to a higher conditional volatility. Interestingly, the coefficient is positive and significant for period I, which indicates a higher

\textsuperscript{14} See Almekinders and Eijffinger (1996) for further details.

\textsuperscript{15} See Rankin (1998) and Kim et al. (2000) for the details of the RBA intervention history.
likelihood of attacking the A$ when there is high volatility of the A$. For negative interventions, the conditional volatility has a significant and positive coefficient over the whole period. In general, the magnitude of the coefficient is larger than that for the positive interventions, except for period III, suggesting a higher probability of intervention defense of the A$ in response to a higher current conditional variance of exchange rate movements. That is, when defending the A$, the RBA was more likely to do so when \( h \) rose; when attacking the A$, the RBA was less likely to do so when \( h_i \) rose, suggesting that they did not worry about market turbulence when the A$ was perceived to be strong.

5.2 Friction Models

Table 4 reports the estimation results for the friction models. The positive and negative intervention threshold estimates are highly significant. In period III, the thresholds were particularly large – the RBA intervened less frequently (1 in 4 days compared to 1 in 2 in the whole sample), but the average absolute value of interventions in period III was 3 times higher than the average.

The significant coefficients for the slope dummy variables are positive for the exchange rate deviations except for the whole period and period III suggesting, in general, an intervention purchase (sale) of foreign currency by the RBA in response to a positive (negative) deviation of current exchange rate from a longer-term trend. The average effect of current deviations is positive as expected and the coefficient is significant in all estimation periods except for periods I and II. Period I was a learning period where the Reserve Bank was doing minor ‘smoothing and testing’. The cumulative deviations appeared to have a significant positive in all but periods I and III. The deviation size dummy is negative and significant in period III (and in the whole period due to this). The overall effects of deviations
on the large deviation days is still positive as evidenced by the smaller magnitude of the size coefficient than the one that picks up the average effects of the normal deviation days ($\alpha_{size} < \alpha_c$). Thus, the RBA’s ‘leaning against the wind’ intervention is still a relevant factor in period III but it is less intense on large deviation days. This suggests the RBA retreated when the exchange rate moved too far from trend.

The intervention responses to conditional variance of exchange rate changes are picked up by the two slope coefficients for the conditional variance term. The estimated positive sign for the $\beta_{c}$'s are significant in all estimation periods but period III, which suggests that a high (but moderate) conditional variance associated with an appreciation (depreciation) of the A$ would lead to an intervention purchase (sale) of foreign currency. The $\beta_{hsise}$ picks up the differential effects, if any, of conditional volatility on days with larger than sample average conditional volatility. As with the trend deviations, we observe a negative sign for this size coefficient that is significant in all periods except period III\(^{16}\). This suggests that on the days of above average volatility, a further rise in volatility associated with an appreciation (depreciation) leads to an intervention sale (purchase) of foreign currency, which might seem to be going against the stated RBA’s intervention aim of smoothing. Note, however, that the magnitude of $\beta_{hsise}$ is very close to that of $\beta_{c}$, with the opposite sign suggesting that on the days of high volatility the total effect of the current conditional variance is the sum of the two coefficients, and so the positive effects shown in the former is almost cancelled out by the latter (except for period V where there is a net negative effect on these high volatility days).

Thus in all periods, the Reserve Bank backed off from its objective of dampening the

\(^{16}\) The intervention decision was apparently not influenced by conditional volatility in period III. Instead, the RBA’s intervention decision was dictated by its desire to keep domestic interest rates relatively low. Any imbalance in the foreign exchange market generated by the monetary policy stance was corrected by an appropriate intervention by the RBA.
conditional volatility of the exchange rate on days of above-average volatility. On days of lower volatility, only the first coefficient is relevant as the second term inside the volatility coefficient bracket is zero. In sum, the empirical evidence indicates that, though the RBA did intervene to smooth the market’s volatility, it stayed out of the market on above-average volatility days owing to the lower likelihood of the effectiveness of intervention on such high volatility and volume trading days. Our results provide an empirical confirmation of the RBA’s claim that its intervention aim is to smooth out the market by eliminating residual volatility once a clear trend has been established. In periods of excessive volatility and volume, the trend is unclear, and the smoothing operations may be useless.

Finally, the coefficient for the conditional profitability of intervention operations is significant at less than 1% in all periods except for period II (only 3.7%) suggesting that the RBA’s intervention strategy was influenced by current profitability of all past interventions carried out. Period II represents an active intervention period for the RBA and the profitability constraint might not have been a high priority. In all but period V the parameter was positive, and was negative for the whole sample. In period V, with restoring inventories and net profitability through net market purchases being the main objectives, these foreign exchange purchases would improve (the negative) profitability if the exchange rate was felt to be too strong, or the exchange risk premium of the A$ too low.

6. Conclusion

The aim of this paper has been to assess the relative importance of the various determinants of the RBA’s foreign exchange market interventions. In general, movements in the first and second moments of daily exchange rate changes are considered to be the main determinants of
intervention. We have conjectured that the RBA’s intervention decisions were influenced by current exchange rate movements about a short-term trend, the level of volatility and conditioned by the profitability of past interventions. The empirical evidence suggests that RBA’s interventions since the float of the A$ in 1983 have been significantly influenced by these three. In general, it has been found that a moderate appreciation (depreciation) of the A$ from its one-week average lead to an intervention purchase (sale) of foreign currency designed to slow the rise (fall) of the value of the A$. This is in accordance with the stated aim of the ‘leaning against the wind’. In addition, it intervened to calm the market whenever there were moderate surges in exchange rate volatility. Most importantly, we find that the RBA has responded to market disorderliness only when it is at a manageable level. The RBA apparently smoothed the market’s disorderliness by intervening whenever there was a rise that it perceived it could successfully reverse, and refrained from possibly futile intervention on days with excessive one-way speculation or highly volatile exchange rate movements. This provides empirical support for the RBA’s stated claim that it aimed to reduce only the residual volatility in the market once the market had sufficiently calmed down to reveal its clear trend. It was also found that the RBA appeared to have paid attention to the profitability level of its past intervention activities. However it is also appears that this attention did not necessarily make these activities profitable (which ought not to be the objective); our interpretation is simply that profitability was at times a binding constraint on the behaviour of the Reserve Bank.

Acknowledgements

We thank John Dokovic of the Reserve Bank of Australia for providing the data, and Ike Mathur for useful comments.
References


### Table 1: Post-Float Intervention Features:

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<th>Intervention volume ($A mil.)</th>
<th>Frequency</th>
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<tr>
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<td>-1000 to -400</td>
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<tr>
<td>-100 to -50</td>
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<td>-50 to 0</td>
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<tr>
<td>0 to 0</td>
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<td>50 to 100</td>
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<td>99.89%</td>
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<td>More than 500</td>
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Total: 3557 100%
Table 2: EGARCH(1,1) estimation results

\[
\Delta_t = a_t + \sum_{i=1}^{m} a(D_i) + a_{\text{res}} D_{n_{n+1}} + (a_{\text{res}} + a_{\text{res}}) C_{\text{res}} M_{\text{res}} + (a_{\text{res}} + a_{\text{res}}) S_{\text{res}} M_{\text{res}} + a_{\text{res}} R_{\text{res}} M_{\text{res}} N_{t} + a_{\text{res}} S_{\text{res}} T_{\text{res}} M_{\text{res}} + \varepsilon_t
\]

\[
\ln b_t = b_t + b_{ln b_t} + b_{t} \frac{\varepsilon_t}{\sqrt{\ln}} + b_t \left( \frac{\varepsilon_t}{\sqrt{\ln}} \right) + \sum_{i=0}^{m} b(D_i) + b_{\text{res}} D_{n_{n+1}} + \varepsilon_t
\]

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<td>( \Delta_t = a_t + \sum_{i=1}^{m} a(D_i) + a_{\text{res}} D_{n_{n+1}} + (a_{\text{res}} + a_{\text{res}}) C_{\text{res}} M_{\text{res}} + (a_{\text{res}} + a_{\text{res}}) S_{\text{res}} M_{\text{res}} + a_{\text{res}} R_{\text{res}} M_{\text{res}} N_{t} + a_{\text{res}} S_{\text{res}} T_{\text{res}} M_{\text{res}} + \varepsilon_t )</td>
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</table>

Notes:

Q(20) and Q²(20) are the Q statistics for the Ljung-Box test of white noise for the linear and squared standardised residuals.

\( \chi^2(3) \) refers to the Engle-Ng’s Joint test of asymmetric response of conditional variance to lagged innovations in the underlying series. The null is a presence of significant positive and negative asymmetric effects.

Numbers inside the brackets are asymptotic p-values.

\(*\): Significance at 10%
\(*\): Significance at 5%
\(*\): Significance at 1%
Table 3: Probit estimation results

\[ Intv_{Pos, t} = \alpha_c + \alpha_{ERDEV} \times ERDEV_t + \alpha_h \times h_t + \alpha_{\text{CWB deviation}} \times \text{CPROFIT}_t, \]

\[ Intv_{Neg, t} = \alpha_c + \alpha_{ERDEV} \times ERDEV_t + \alpha_h \times h_t + \alpha_{\text{CWB deviation}} \times \text{CPROFIT}_t, \]

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<td>(\alpha_c)</td>
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<td>-0.9567 ** (0.0000)</td>
<td>0.5675 ** (0.0000)</td>
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<td>0.5158 ** (0.0048)</td>
<td>-0.2179 † (0.0978)</td>
<td>-3.4824 † (0.0540)</td>
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Notes:

- Nobs: Number of observations for the estimation
- LogL: Estimated value of log-likelihood
- † Denotes significance at 10%
- * Denotes significance at 5%
- ** Denotes significance at 1%
Table 4: Friction model estimation results

\[ \text{Int}_t = (\alpha_c I_{dev} + \alpha_{cum} I_{cum} + \alpha_{size} I_{size}) \cdot \left| \text{ERDEV} \right| + (\beta_c I_{dev} + \beta_{size} I_{size}) \cdot \left| h_{i} \right| + \gamma \cdot \text{PROFIT} + \delta \cdot \text{Int}_{t-1} + \varepsilon_t \]

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<th>Period II (July 86 - Sep 91)</th>
<th>Period III (Oct 91 - Nov 93)</th>
<th>Period V (Jul 95 - Dec 97)</th>
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<td>Coeff</td>
<td>p-value</td>
<td>Coeff</td>
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<td>( \alpha_c )</td>
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<td>(0.2838)</td>
<td>1.6416</td>
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<td>( \alpha_{cum} )</td>
<td>2.2768 **</td>
<td>(0.0000)</td>
<td>0.2483</td>
<td>(0.1840)</td>
<td>2.5938 **</td>
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<tr>
<td>( \alpha_{size} )</td>
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<td>1.0843 **</td>
<td>(0.0000)</td>
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<td>( \beta_c )</td>
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<td>0.0346 **</td>
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<td>(0.0000)</td>
<td>-0.0296 **</td>
<td>(0.0000)</td>
<td>-0.0386 **</td>
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<td>( \gamma )</td>
<td>-0.0013 **</td>
<td>(0.0000)</td>
<td>0.0121 **</td>
<td>(0.0003)</td>
<td>0.0008 *</td>
</tr>
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<td>( \delta )</td>
<td>0.7364 **</td>
<td>(0.0000)</td>
<td>0.4296 **</td>
<td>(0.0000)</td>
<td>0.6169 **</td>
</tr>
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<td>( \sigma )</td>
<td>0.1119 **</td>
<td>(0.0000)</td>
<td>0.0186 **</td>
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<tr>
<td>( \theta^+ )</td>
<td>0.0851 **</td>
<td>(0.0000)</td>
<td>0.0187 **</td>
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<tr>
<td>( \theta^- )</td>
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<td>LogL</td>
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<td>548.19</td>
<td>333.83</td>
<td>-181.14</td>
<td>341.76</td>
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Notes:

- LogL Estimated value of log-likelihood
- * Denotes significance at 5%
- ** Denotes significance at 1%
Figure 1: Daily US$/A$ Exchange Rate and the RBA’s Foreign Exchange Interventions

A: Daily Spot Exchange Rate - US$/A$

B: Net Market Purchases of Foreign Assets
Figure 2: Exchange Rate Deviations and Conditional Volatility of Daily US$/A$ Rate

A: Deviation of Current US$/A$ Rate from One-Week Moving Average

B: Conditional Volatility of Daily US$/A$ Returns
Figure 3: Profitability of the RBA’s Foreign Exchange Interventions

A: Conditional Profit of All Interventions

December 1983 - December 1997

B: Cumulated Uncovered Interest Disparity [US-A]

December 1983 - December 1997