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Author:

Kim, Suk-Joong; Sheen, Jeffery

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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*
School of Economics & Political Science
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, the U.S. and Australian overnight interest rate differentials, profitability and foreign currency reserve inventory 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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* Corresponding author
Jeffrey Sheen
School of Economics and Political Science
The University of Sydney
2006 Australia
Tel: +61 2 9351-3075
Fax: +61 2 9351-4341
Email: jeffs@econ.usyd.edu.au

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 five primary determinants of the behaviour of a central bank (in particular, the Reserve Bank of Australia) – daily deviations from a representative long-term trend of the spot exchange rate, the conditional volatility of daily changes in the spot rate, the differentials between the U.S. and Australian overnight interest rates, a measure of the conditional profitability of past interventions, and foreign currency reserve inventory considerations. 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 at worst the bank may incur big and pointless losses. 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. When the overnight foreign interest rate rises more than the domestic one, an overshooting weakening of the domestic exchange rate may be expected, which might prompt a defense of the currency. From an operational view, central banks need to take profitability and inventory factors into consideration. One way of modeling these factors is as constraints on the objective function of the central bank. These constraints will not bind at various times, and in such circumstances, an inventory or profitability measure should not have a significant effect

on intervention behaviour. However there are likely to be periods when either or both of these constraints does bind, and therefore will have an important effect on the intervention response. Our introduction of profitability and inventory factors is a novel feature of this paper.

With many central banks now willing to release data¹ 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 evaluation². In this paper, we apply many (and extend some) of the ideas in this literature by using daily intervention data released by the Reserve Bank of Australia. This application is of general interest for a number of reasons: firstly, the RBA participates in an official arrangement with Pacific-Basin nations (including USA and Japan) and can access loans and support from associated central banks; secondly, the RBA has published its views on its intervention strategies and so it is of interest to see whether the data reflects its statements; thirdly, though Australia is a small economy, its currency is the ninth largest traded in the world (A\$70bn per day), reflecting its perceived importance as a commodity-based currency; and fourthly, the size and high frequency of active intervention in the sample, relative to that of the Fed, Bundesbank and Bank of Japan, provides many more observations for testing the hypotheses.

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)

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

² For example, see Dominguez (1998), Baillie and Osterberg (1997), Almekinders and Eijffinger (1994, 1996), Bonser-Neal and Tanner (1996), Dominguez and Frankel (1993), Edison (1993).

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 simultaneity 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. As a first step in dealing with this, Kim, Korian 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.

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\$ (though volatility in the Yen/US\$ markets did encourage US\$ purchases by the two central banks). However deviations of the spot rates from the accord targets did matter. Although there is an extensive literature on the profitability of intervention³, 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. The same goes for the testing of inventory considerations. Lewis (1995) has tested whether interest rate differentials determine intervention⁴. Using VAR modeling, she shows that interest rate differentials (between the US and Japan and Germany) do appear to predict the Fed's intervention with daily data; however when she introduces a logistic model to cope with the effects of the high frequency of inactive days, the interest rate effects disappear. Using a different method – the friction model (described below), we re-examine this hypothesis which Lewis had to reject.

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 obtained measures of trend deviations, conditional volatility, interest differentials, profitability and inventory. In Section 4, we discuss our econometric approaches to estimating the effects of these explanatory variables on intervention. It is important to appreciate that

³ See Sweeney (1997) for a recent survey. In general, the profitability depends on whether appropriate risk measures are included in the calculations.

⁴ Bonser-Neal, Roley and Sellon (1998) also show that monetary policy changes affect intervention; however they do not use interest rate differentials as a measure of policy.

intervention is not a continuous process. Typically there will be minimum sizes of daily positive or negative interventions, and there are many days of inactivity. To deal with these issues, we use two of the approaches from the previous literature, as mentioned above – Probit and friction modeling. The first assumes an asymmetry of determinants of positive and negative interventions, and is useful as a simple analysis of our five determinants for each. The friction model is an elegant method for recognizing that there may be three zones (zero, positive and negative) of the likelihood function for intervention. We contribute to the literature by extending these methodologies to investigate the empirical significance of additional constraints 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). These were always sterilized by the RBA and so only the composition of assets will change with no net effect on the monetary base. The daily net market purchases of US\$ are measured in A\$ (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. Although net market purchases include transactions carried out on behalf of the Commonwealth government as well as intervention

transactions, the degree of intervention can be inferred from these transaction data⁵. 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) 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

⁵ Neely(1998) reports that the inclusion of client transaction data does not significantly affect the statistical properties of intervention data in the US.

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 seemed to be using foreign exchange intervention to support its easing of monetary policy. It had not yet adopted an explicit inflation rate target for its monetary policy, but it may have been concerned that lower interest rates, needed in the face of a severe recession, might create inflationary pressure from an excessive depreciation. We test this hypothesis below, and find evidence that we cannot reject it. 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 it would

intervene in foreign exchange markets for a number of reasons – perceived trend correction, volatility smoothing, exchange rate overshooting, 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 behaviour⁶, which would then have to be conducted in conjunction with its monetary policy. In our econometric tests, we focus on short- and medium-term considerations, recognizing that the Reserve Bank of Australia has never declared that it intervenes to achieve very long horizon targets. At lesser horizons, a central bank may aim to correct any high frequency speculative bubble or bandwagon surge. This would be in keeping with the widely used term, ‘leaning against the wind’. 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 fluctuations in exchange rates through higher volatility due to higher levels of 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 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

⁶ Dominguez and Frankel (1993, p80) report significant estimates for the response of the Federal Reserve to a purchasing power parity target from 1982-88.

measure of conditional volatility of the spot exchange rate changes has this non-linear influence on intervention.

A third influence on central banks might be interest rate differentials. One explanation is that whenever local or foreign interest rates change, the differential may lead to the well known anticipated overshooting of the spot exchange rate, over a medium-term horizon, longer than the short-term trend correction phenomenon described earlier. This can occur for a number of reasons, the seminal one being that proposed by Dornbusch (1976). Though such overshooting represents a rational response, it may easily be a catalyst for longer horizon bandwagon effects. If the central bank gauges that excessive overshooting will take place, it may choose to intervene to mute the potentially distorting effects of that overshooting. An alternative explanation for the predictive role of interest rate differentials might be that the central bank has an explicit or implicit exchange rate target. Deviations from the target may arise with monetary policy shifts, and so intervention is activated to correct these. However, since floating the A\$ in 1983, the RBA has not declared an exchange rate target.

Another likely influence 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 the 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. There will be occasions when they will want to re-balance their portfolios, particularly when the conditions in the foreign exchange market are very orderly. Some minimum level of foreign reserves might trigger action to ensure that the central bank retains the ability to intervene in future disorderly markets. On the other hand, if reserves are accumulated beyond some unusually high level, the central bank may regard this situation as an inefficient allocation of its resources, and choose to reduce its inventory. A target ratio of reserves to some measure of market volumes should constitute the driving variable. Unfortunately, central banks do not provide high frequency data on the level and compositions of their portfolios, and data on daily market volumes in forex markets is not readily available, thus inventory considerations cannot be tested directly. However it is possible that there are derived measures that may have some explanatory power. Monthly stock levels of foreign currency reserves of the RBA are publicly available as are indicative trading variables such as imports. We construct the ratio of foreign currency reserves to imports as a measure of a possible constraint on intervention that may or may not bind at different times, and investigate its empirical importance.

Our model of intervention behaviour reduces to the five key explanatory variables described above. 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 five 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 trend. This trend might be modeled as a moving target exchange rate represented by some moving average. Although the choice of the length of a representative moving average window is somewhat arbitrary, LeBaron (1999) justifies his choice of 150 days as being very commonly used by market traders. Neely (1998) followed his lead, and we also adopt the 150 day window⁷. The current exchange rate deviation is then measured as the difference between the current US\$/A\$ exchange rate (s_t) and its 150 day moving average as below:

$$ERDEV_t = s_t - \frac{1}{150} \sum_{i=0}^{150} s_{t-i}$$

The time series plot of the daily deviations from the 150 day moving averages 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.

⁷ Estimation results using 150 day moving average reported in this paper did not differ significantly from alternative lengths (1, 4 and 13 week moving averages).

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, Korian and Sheen (2000), and as shown below.

$$\Delta s_t = a_c + \sum_{i=MON}^{THU} a_i D_{i,t} + a_{HOL} D_{HOL,t} + (a_{INTV} + a_{CIDUM} CIDUM_t + a_{SIDUM} SIDUM_t + a_{RIDUM} RIDUM_t) Intv_t + a_{STDUM} STDUM_t + e_t \quad (1)$$

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

$$\ln h_t = b_c + b_h \ln h_{t-1} + b_{e1} \frac{e_{t-1}}{\sqrt{h_{t-1}}} + b_{e2} \left(\frac{|e_{t-1}|}{\sqrt{h_{t-1}}} - \sqrt{\frac{2}{\pi}} \right) + \sum_{i=MON}^{THU} b_{i,t} D_{i,t} + b_{HOL} D_{HOL,t} + (b_{INTV} + b_{CIDUM} CIDUM_t + b_{SIDUM} SIDUM_t + b_{RIDUM} RIDUM_t) \cdot |Intv_t| + b_{STDUM} |STDUM_t| \quad (2)$$

where:

- $D_{i,t}$ = Daily dummy that takes the value of one for day of the week i and zero otherwise.
- $D_{HOL,t}$ = Holiday dummy that takes the value of one for the day immediately after public holidays.
- $Intv_t$ = 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 reported 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 with official statements 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 interventions⁸. Given the size of the Australian foreign exchange market (average daily volume of \$US46.6bn in April 1998⁹), 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 central bank may spread out the intervention transactions over a number of days to maximize the effects of 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 their greatest effects if the central bank action is seen as a credible source of

⁸ The interest rate differential between the U.S. Federal funds rate and the Australian overnight cash rate was also used to test the possible impact of changes in monetary policy by the two countries (but the results are not reported here). There is no evidence of a significant influence in any of the sub-periods except for a marginal contribution to higher volatility in sub-period 3. This is in contrast to the significant effects of the differential between U.S. and foreign rates (Japanese and German) reported in Dominguez (1998) for some sub-sample estimations. Lewis (1995), using VAR methods, finds evidence of a significant effect of interest rate differentials after a 6 week lag on the DM/US\$, but none on the Yen/US\$.

⁹ See Bank for International Settlement (1998).

information about future market conditions, in particular the future monetary policy stance. Secret interventions may also have some effect if the central bank 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 2¹⁰. The major findings are that the RBA's interventions appear to have some 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 contribute some 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. Although there is some suggestion of market calming, our method may not resolve the simultaneity problem, and so we cannot conclude unequivocally from the above that intervention does stabilize the exchange rate process.

¹⁰ For a further analysis, see Kim, Kortian and Sheen (2000).

We generate a series for conditional volatility (h_t) from the above estimated model, and use it in subsequent estimations as a possible determinant of intervention behaviour (see Panel B of Figure 2). Our use of a generated regressor for volatility has potential for introducing some downward bias in the standard errors in those estimations; however we note that i) it may be of little relevance in our large sample estimations using maximum likelihood (quasi-ML for the friction models), ii) those standard errors that matter are very small relative to the parameter estimates, and iii) this bias in our subsequent intervention model estimates is counter-balanced to a degree by the simultaneity bias that has been reduced by including the effects of past intervention on the exchange rate process¹¹.

3.3 Measuring interest rate differentials

Interest rate differentials pick up potential excessive exchange rate overshooting perceived by the central bank. In the case of the A\$ with daily data, it is appropriate to use the overnight money market rates of Australia and the USA. We use the Australian cash rate and the US Federal Funds rate¹². Their differential is graphed in the Figure 2 (Panel C). In both countries, the central bank operates monetary policy by setting a target for their respective overnight rates. At this short end, the differential is largely a reflection of monetary policy in the two countries and is, therefore, relatively exogenous.

3.4 Measuring the Profitability of Intervention

¹¹ Ideally a proper simultaneous equation approach is needed for modeling the GARCH/Friction processes of the exchange rate and intervention. This is not easy, and is the subject of further research by the authors.

¹² The interest rate data were obtained from the RBA and the U.S. Federal Reserve's data depository.

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 up¹³.

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 $(1+i_{US}(t-m)) (1+i_{US}(t-m-1)) \dots (1+i_{US}(t-1)) s_{t-m}/s_t$ 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 $(1+i_A(t-m)) (1+i_A(t-m-1)) \dots (1+i_A(t-1))$ where i_A is the overnight Australian cash rate.¹⁴ Thus the current net value is in fact the cumulated value of *ex-post* uncovered interest disparity, $CUID(t,m)$:

$$CUID(t, m) = \prod_{i=1}^m (1 + i_{US}(t-i)) \frac{s_{t-m}}{s_t} - \prod_{i=1}^m (1 + i_A(t-i)) \quad (3)$$

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

$$CProfit(t) = \sum_{i=1}^m Intv_{t-i} CUID(t,i) \quad (4)$$

¹³ See Leahy (1995) and Neely (1998) for a similar calculation.

¹⁴ To make the computation, the US interest rates must be taken as the previous day's value in recognition of the different time zones.

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. As the profit measure is sensitive to the value of the exchange rate at t , 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 government¹⁵, 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.

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 .

¹⁵ 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.

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 interveners – it is the *ex-ante* measure that matters for them, and 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 $CUID$ could 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 $CProfit$ (Panel A) and $CUID$ (Panel B) 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. Period II saw 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\$s 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. As *CUID* was declining further, 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\$12bn¹⁶. 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.

3.5 Measuring inventory imperatives

¹⁶ 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.

Inventory consideration of foreign currency reserves may have a significant impact on the likelihood of an intervention. A continued intervention sale of foreign currency to support the A\$ gradually depletes the existing stock of reserves, which eventually reaches a level that may prompt an intervention reversal. Equally, if stocks of reserves become too high, the central bank may judge this an inappropriate commitment of its resources. We use the ratio of foreign currency reserves to imports as a proxy of the true variable that drives the inventory consideration. Daily observations on the ratio are interpolated from monthly stock levels on the reserves and imports, as reported in the RBA's statistical Bulletin (see Panel C of Figure 3).

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 do the same and estimate the probability of positive and negative interventions of the RBA's foreign exchange market interventions:

$$Intv_{Posi,t} = \alpha_C + \alpha_{ERDEV}ERDEV_t + \alpha_h h_t + \alpha_{idiff} idiff_t + \alpha_{C Profit} CPROFIT_t + \alpha_{RM} RM_t \quad (5)$$

$$Intv_{Nega,t} = \alpha_C + \alpha_{ERDEV}ERDEV_t + \alpha_h h_t + \alpha_{idiff} idiff_t + \alpha_{C Profit} CPROFIT_t + \alpha_{RM} RM_t \quad (6)$$

where

$Intv_{Posi,t}$	=	A dummy variable that takes the value of one if there is a positive intervention (i.e. purchase of foreign currency with A\$), and zero otherwise.
$Intv_{Nega,t}$	=	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.
$ERDEV_t$	=	Deviation of the current exchange rate (s_t) from its 150 day moving average rate.
h_t	=	Conditional variance of daily exchange rate returns generated from the EGARCH(1,1) model in section 3.2.
$idiff_t$	=	Interest rate differentials between the U.S. Federal funds rate and the Australian official overnight cash rate.
$CPROFIT_t$	=	Conditional profit index of all intervention carried out by the RBA as described in section 3.4
RM_t	=	Ratio of the RBA's stock of foreign currency reserves to Australian imports. Monthly observations were converted to daily frequency by interpolation.

The Probit¹⁷ models employ five variables, $ERDEV$, h , $idiff$, $CPROFIT$ and RM , to explain the probability of observing a positive/negative intervention on a given day.

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 and constraints (encapsulated in our five postulated variables), but only after an intervention threshold is reached. The thresholds

¹⁷ Separate Probits suffer from selection bias. We report separate Probit results for the sake of comparison with previously published results – eg Dominguez (1998).

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.

Instead of modeling the intervention linearly, using deviations of the current level and volatility only, we allow for the possibility that central banks pay deeper 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.

We model the RBA intervention as below:

$$Intv_t = \delta \cdot Intv_{t-1} + (\alpha_c I_{dev,t} + \alpha_{cum} I_{cum,t} + \alpha_{size} I_{size,t}) \cdot |ERDEV_t| + (\beta_c I_{ds,t} + \beta_{hsize} I_{ds,t} I_{hsize,t}) \cdot h_t + \psi \cdot idiff_t + \gamma \cdot CPROFIT_t + \omega \cdot RM_t + \varepsilon_t \quad (7)$$

where

$Intv_t$	=	Daily net market purchase of foreign currency by the Reserve Bank of Australia, measured in A\$m.
$ERDEV_t$	=	Deviation of the current exchange rate (s_t) from its 150 day moving average rate
$I_{dev,t}$	=	An indicator variable that takes the value of positive (negative) one if $ERDEV_t$ is positive (negative) and zero otherwise.
$I_{cum,t}$	=	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.
$I_{size,t}$	=	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.
$I_{ds,t}$	=	An indicator variable that takes the value of positive (negative) one if the daily exchange rate change (Δs_t) is positive (negative), and zero otherwise.
$I_{hsize,t}$	=	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 3.2.
$idiff_t$	=	Interest rate differential between the U.S. Federal funds rate and the Australian overnight cash rate.
$CPROFIT_t$	=	Conditional profit index of all prior intervention carried by the RBA, as described in 3.4.
RM_t	=	Ratio of the RBA's stock of foreign currency reserves to Australian imports. Monthly observations were converted to daily frequency by interpolation.

The model employs essentially the same five 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 (α_c and β_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. 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, *a priori*, we expect positive coefficients for these variables. The interest differential coefficient (ψ) should be negative, since a rise in the US rate may be followed by an excessive overshooting and thus a possibly distorting depreciation of the A\$, requiring a net

market sale from reserves. In general, it may be expected that profitability is lost when the local currency is being defended. Therefore higher conditional profitability should ease the constraint on defenses, suggesting a negative coefficient (γ) for this variable. However it is difficult to place a definite economic meaning on the sign of γ without having detailed information on the RBA's portfolio positions and perceptions. If profitability reaches some low level of concern on a particular day, it is not always obvious whether a purchase or a sale of foreign currency would be seen as the way to restore future profits. We would expect to see some action, but the direction would be dependent on the perception of future market conditions by the interveners. It is quite possible that profitability can be restored by buying the local currency, if the bank correctly picks a future strengthening of the local currency. We cannot test here whether their actions are successful – only whether conditional profitability prompts action. Finally, as regards the inventory variable, RM , we expect a negative parameter (ω) since a higher reserve to imports ratio should lead to sales of those reserves. Finally, with regard to the lagged intervention variable, we would expect the estimated coefficient (δ) to be between 0 and 1. This implies persistence of intervention, which is likely to improve its effectiveness.

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) becomes¹⁸

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

$$\times \prod_{Intv_t < 0} \frac{1}{\sigma\sqrt{(2\pi)}} \exp\left(-\frac{(\varepsilon_t + \theta^-)^2}{2\sigma^2}\right)$$

where ϕ 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. We report two sets of results for each of the positive and negative interventions. In the first set, we exclude the inventory variable, and in the second set we include it. As this variable is only a proxy that required interpolation, it is important to see the results with its exclusion.

In the first set, the exchange rate deviations 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, except for period I, and significantly negative for the negative intervention estimations (apart from period I and V). 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

¹⁸ See Almekinders and Eijffinger (1996) for further details.

A\$, providing empirical support for the ‘leaning against the wind’ hypothesis of market intervention.

The conditional volatility of daily exchange rate movements shows a marginally significant negative effect over the periods III for positive interventions, indicating a lower probability of intervention purchase of foreign currency in response to a higher conditional volatility. For negative interventions, the conditional volatility has a significant and positive coefficient over all sub-periods (except for period III) and the whole period. This indicates a higher probability of intervention sale of the foreign currency was associated with a higher volatility of the exchange rate changes. That is, when defending the A\$, the RBA was more likely to do so when h_t rose; when attacking the A\$, the RBA was less likely to do so when h_t rose, suggesting that they did not worry about market turbulence when the A\$ was perceived to be strong.

The interest rate differential had a significant and correctly signed impact in all periods, except in period III when it was notably insignificant, this being a period when intervention policy was supporting monetary policy. From the Probit results, it appears that the central bank was not then concerned with an excessive overshoot of the depreciating exchange rate; indeed, they may have wanted this to occur to assist the economy in raising exports to get out of the recession of the early 1990s. However we will return to this issue with our friction modeling tests.

The cumulative intervention profit had a significant negative effect on the positive interventions overall and in period V, but was significantly positive in periods I and II. The negative interventions were positive throughout, but not significant in period III. This suggests that increasing profitability did ease the constraint on defending the A\$.

Introducing the reserves to imports ratio, in general, tended to lower the probabilities of a positive intervention in period I and III, though not overall; for the probabilities of

negative intervention, the overall impact was correctly positive and significant, but there was no consistency in its impacts in the sub-periods. This suggests that inventory considerations are relevant, but hard to predict accurately with our proxy.

5.2 Friction Models

Table 4 reports the estimation results for the friction models. We begin by discussing the first set of results that excludes the inventory variable.

Intervention is strongly correlated with lagged intervention (δ), which suggests that positive (negative) intervention was usually followed by positive (negative) intervention on the following day. This persistence implies that the RBA's interventions tended to be carried out over a number of days, which is likely to improve its effectiveness especially on volatility, as shown in the results in Table 2 (negative b_{CIDUM}).

The positive and negative intervention threshold estimates (θ^+ , θ^-) are highly significant everywhere. In period III, the thresholds are 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 negative threshold is significantly smaller, in absolute magnitudes, than the positive ones for periods I and III, suggesting the RBA was more likely to jump to support the A\$ than restricting the strengthening. These periods were associated with significant weakening of the A\$ (see Panel A of Figure 1). In periods II and V, the positive threshold is significantly smaller. The A\$ was less vulnerable in these periods, and so the desire to restore inventories and profitability may have been strong. Also, given Australia's chronic current account deficit problem, there is always an underlying competitiveness cost to intervention that strengthens the exchange rate– therefore the thresholds are biased downwards (Almekinders and

Eijffinger, 1996 have similar results and interpretation for the US Federal Reserve's intervention).

The average effect (α_c) of current deviations from longer-term trends proxied by the 150 day moving averages is positive as expected and the coefficient is significant in all estimation periods except for period II. This suggests, in general, an intervention purchase (sale) of foreign currency by the RBA in response to a positive (negative) deviation of the current exchange rate from a longer-term trend.

The persistent deviations from trend appeared to have a highly significant negative effect (α_{cum}) on intervention in all periods considered. This is not what may be expected from 'leaning against the wind' intervention. However, it may be consistent with the idea that when a persistent current deviation from the longer-term trend suggests a permanent change in the equilibrium rate, the RBA chooses to add to the trend to hasten the movement to the new equilibrium.

The size deviation dummy effect (α_{size}) is positive and highly significant in all periods except for period III. Apparently the RBA reacted to correct large current deviations from longer-term trends. In Period III when intervention was supporting monetary policy, large deviations had a negative influence on intervention activities, but the overall effect on the intervention remained positive.

The overall effects of deviation on these days of cumulative or large deviations are still positive for all but period I (ie $\alpha_c + \alpha_{cum}$ and/or $+ \alpha_{size}$ is significantly greater than 0). Thus, the RBA's 'leaning against the wind' intervention is still a relevant factor in these periods but it is less intense on persistent deviation days. In period I, however, the negative influence of the cumulative deviations outweigh the average effect and/or size effect resulting in the overall intervention moving in the same direction as the market movements. This

suggests the RBA retreated to some degree when the exchange rate deviations proved to be persistent.

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 β_c 's are highly significant in all estimation periods 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 β_{hsize} picks up the differential effects, if any, of conditional volatility on days with larger than sample average conditional volatility. We observe a negative sign for this size coefficient that is significant in all periods. 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 β_{hsize} is generally close to that of β_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 nearly 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 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.

The interest differential parameter, ψ , is correctly signed and significant at less than 1% in all periods but period III. Thus it seems that in period III the RBA may have been looking to an over-depreciating exchange rate to boost exports in the midst of a recession. However once we introduce our inventory variable to the regression, the sign, size and significance of the interest differential parameter leads us to not reject the hypothesis that the RBA was using intervention to support its monetary policy easing, in fear of the inflationary consequences of excessive depreciation.

The coefficient for the conditional profitability of intervention operations, γ , is significant and negative in all but period I and II, suggesting that the RBA's intervention strategy was constrained at various times by the current profitability of all past interventions. Period I was a training period, and in II profitability had no effect. Only after 1991 did the profitability constraint appear to bind.

Finally, in our second set of results when we include the inventory constraint variable (proxied by the reserves to imports ratio), we obtain the correct sign and significance for that variable's coefficient (ω) in periods I and III, but significance and the wrong sign for the whole sample and in period II. The significance of a few other parameters is affected in some sub-periods. This mixed performance is not surprising given the measurement errors incurred in producing the proxy.

6. Conclusion

The aim of this paper has been to assess the importance of the various determinants of the RBA's foreign exchange market interventions. We have conjectured that the RBA's

intervention decisions were influenced by current exchange rate movements about a trend, the level of volatility, interest rate differentials between the U.S. and Australian rates, and conditioned by the profitability of past interventions and inventory considerations. The empirical evidence suggests that RBA's interventions since the float of the A\$ in 1983 have been significantly influenced by these five factors. In general, it has been found that a moderate appreciation (depreciation) of the A\$ from its 150 day average leads 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 short horizon aim of '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. Evidence was also found that the RBA did respond to interest rate differentials, possibly to mute excessively overshooting exchange rates over the medium-term, and appeared to have paid attention to the profitability level of its past intervention activities. However it 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. Finally, there is mixed evidence of the presence of an inventory motive, but the available data is not sufficient for a robust test.

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Table 1: Post-Float Intervention Features:

13 December 1983 – 31 December 1997

Intervention volume (\$A mil.)		Frequency	Cumulative
Less than	-1000	4	0.11%
-1000	to -400	12	0.45%
-400	to -250	15	0.87%
-250	to -150	29	1.69%
-150	to -100	31	2.56%
-100	to -50	78	4.75%
-50	to 0	320	13.75%
0	to 0	1903	67.25%
0	to 50	803	89.82%
50	to 100	229	96.26%
100	to 150	73	98.31%
150	to 200	30	99.16%
200	to 250	15	99.58%
250	to 500	11	99.89%
More than	500	4	100.00%
		3557	100%

Table 2: EGARCH(1,1) estimation results

$$\Delta s_t = a_c + \sum_{i=MON}^{THU} a_i D_{i,t} + a_{HOL} D_{HOL,t} + (a_{INTV} + a_{CIDUM} CIDUM_t + a_{SIDUM} SIDUM_t + a_{RIDUM} RIDUM_t) \cdot Intv_t + a_{STDUM} STDUM_t + e_t$$

$$\ln h_t = b_c + b_h \ln h_{t-1} + b_{e1} \frac{e_{t-1}}{\sqrt{h_{t-1}}} + b_{e2} \left(\frac{|e_{t-1}|}{\sqrt{h_{t-1}}} - \sqrt{\frac{2}{\pi}} \right) + \sum_{i=MON}^{THU} b_i D_{i,t} + b_{HOL} D_{HOL,t} + (b_{INTV} + b_{CIDUM} CIDUM_t + b_{SIDUM} SIDUM_t + b_{RIDUM} RIDUM_t) |Intv_t| + b_{STDUM} |STDUM_t|$$

Where: $D_{i,t}$ = Daily dummy, $D_{HOL,t}$ = Holiday dummy, $Intv_t$ = RBA intervention, $CIDUM_t$ = Cumulative intervention dummy, $SIDUM_t$ = Large Intervention size dummy, $RIDUM_t$ = Reported intervention dummy, $STDUM_t$ = Official statement dummy, h_t = Conditional variance of daily exchange rate changes

	Whole Post Float Period Dec 83 - Dec 97		Period I Dec83 - Jun86		Period II July86 - Sep91		Period III Oct91 - Nov93		Period V Jul95 - Dec97	
	Coeff	p-value	Coeff	p-value	Coeff	p-value	Coeff	p-value	Coeff	p-value
a_c	-0.0294 *	(0.0603)	-0.0150	(0.6350)	-0.0306	(0.2361)	0.0375	(0.2448)	-0.1758 ***	(0.0000)
a_{MON}	0.0218	(0.3389)	-0.0124	(0.8159)	0.0205	(0.5831)	-0.0267	(0.6257)	0.1204 **	(0.0179)
a_{TUE}	0.0208	(0.3451)	0.0467	(0.3133)	0.0436	(0.2330)	-0.0127	(0.8028)	0.0426	(0.3921)
a_{WED}	0.0415 *	(0.0567)	0.1295 ***	(0.0098)	0.0586 *	(0.0930)	-0.0019	(0.9685)	0.0525	(0.3209)
a_{THU}	0.0082	(0.7129)	0.0560	(0.2939)	0.0060	(0.8738)	-0.0374	(0.3978)	0.0542	(0.2898)
a_{HOL}	0.1056 **	(0.0212)	0.1345 *	(0.0726)	0.0578	(0.4329)	0.1680	(0.4144)	0.2025 **	(0.0159)
a_{INTV}	4.4184 ***	(0.0000)	33.3426 ***	(0.0000)	3.4816 ***	(0.0000)	3.8530 **	(0.0165)	8.5854 ***	(0.0000)
a_{CIDUM}	-0.2792	(0.1584)	-4.3331	(0.4417)	-0.5491 *	(0.0697)	0.0737	(0.9222)	-3.5565 ***	(0.0009)
a_{SIDUM}	-2.2115 ***	(0.0000)	-15.6778 *	(0.0576)	-0.8359	(0.2376)	-3.6575 **	(0.0258)	-2.0132 *	(0.0597)
a_{RIDUM}	-0.7314 ***	(0.0023)	-0.1227	(0.9803)	-0.7856 **	(0.0147)	1.1517 **	(0.0476)	***	
a_{STDUM}	0.1011	(0.2450)	0.5727 *	(0.0689)	0.1253	(0.2719)	-0.1757	(0.2976)	***	
b_c	-0.1917 **	(0.0189)	-0.7715 ***	(0.0001)	-0.4061 ***	(0.0016)	-0.1263	(0.5715)	0.0070	(0.9741)
b_{e1}	-0.0222	(0.1381)	0.0412	(0.4124)	0.0259	(0.3445)	0.0246	(0.5588)	-0.0547	(0.1782)
b_{e2}	0.2389 ***	(0.0000)	0.3621 ***	(0.0000)	0.2516 ***	(0.0000)	0.1889 ***	(0.0037)	0.1374 **	(0.0333)
b_h	0.9537 ***	(0.0000)	0.8915 ***	(0.0000)	0.9431 ***	(0.0000)	0.9354 ***	(0.0000)	0.8875 ***	(0.0000)
b_{MON}	0.3624 ***	(0.0095)	1.1981 ***	(0.0005)	0.5405 **	(0.0143)	0.5287	(0.1351)	-0.3368	(0.3438)
b_{TUE}	0.0372	(0.7509)	-0.1764	(0.5211)	0.4391 **	(0.0231)	-0.1966	(0.5336)	-0.1423	(0.6300)
b_{WED}	0.1928	(0.1009)	1.0147 ***	(0.0004)	0.1638	(0.3814)	-0.0866	(0.7701)	0.0736	(0.7996)
b_{THU}	0.0930	(0.5050)	0.5617 *	(0.0867)	0.4190 *	(0.0575)	-0.2831	(0.4502)	-0.2794	(0.4080)
b_{HOL}	0.1349	(0.1887)	0.4651	(0.1361)	-0.0346	(0.8517)	0.5799	(0.1404)	-0.5054	(0.1167)
b_{INTV}	0.7841	(0.2726)	26.2766 ***	(0.0000)	1.8617	(0.1888)	-0.2369	(0.9407)	-4.1049 *	(0.0862)
b_{CIDUM}	-0.5610 **	(0.0394)	-13.5642 *	(0.0649)	-0.8663 **	(0.0343)	-5.2948 ***	(0.0012)	-3.4081 **	(0.0499)
b_{SIDUM}	-0.3187	(0.6851)	4.7326	(0.6460)	-1.0633	(0.4444)	3.4942	(0.3068)	8.0486 ***	(0.0013)
b_{RIDUM}	0.3818	(0.3356)	-12.4546	(0.1589)	0.5166	(0.3614)	-1.9785	(0.2617)	***	
b_{STDUM}	0.1697	(0.1633)	0.3218	(0.4352)	0.3918 **	(0.0340)	-0.0690	(0.8117)	***	
d	4.5090 ***	(0.0000)	6.1524 ***	(0.0000)	5.0120 ***	(0.0000)	7.0919 ***	(0.0062)	5.4281 ***	(0.0002)
Diagnostics for Standardised Residuals, Z_t										
Skewness	-0.4341		0.0539		-0.2499		-0.3060		-0.1760	
Kurtosis	2.9082		2.7958		2.0184		1.1104		1.5908	
$Q(20)$	27.4545	(0.1230)	32.8394 **	(0.0351)	12.8450	(0.8839)	18.0259	(0.5857)	28.5019 *	(0.0980)
$Q^2(20)$	14.2929	(0.8153)	6.8043	(0.9973)	38.0616 ***	(0.0087)	24.1896	(0.2342)	20.3280	(0.4376)
$\chi^2(3)$	3.3827	(0.3363)	3.7904	(0.2850)	0.9106	(0.4352)	2.7021	(0.4399)	0.9250	(0.8194)
Ln L	-578.13		-167.69		-221.24		17.74		3.90	

Notes:

$Q(20)$ and $Q^2(20)$ 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.

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

Table 3: Probit estimation results

$$Intv_{Nega,t} = \alpha_C + \alpha_{ERDEV}ERDEV_t + \alpha_h h_t + \alpha_{idiff} idiff_t + \alpha_{CProfit} CPROFIT_t + \alpha_{RM} RM_t$$

$$Intv_{Posi,t} = \alpha_C + \alpha_{ERDEV}ERDEV_t + \alpha_h h_t + \alpha_{idiff} idiff_t + \alpha_{CProfit} CPROFIT_t + \alpha_{RM} RM_t$$

Where: $Intv_{Posi,t}$ = Positive intervention (purchase of foreign currency) dummy, $Intv_{Nega,t}$ = Negative intervention dummy, $ERDEV_t$ = Deviation of current exchange rate (s_t) from 150 day moving average rate, h_t = Conditional variance of daily exchange rate returns, $idiff_t$ = Interest rate differentials, $CPROFIT_t$ = Conditional profit index of all intervention, RM_t = Ratio of foreign currency reserves to imports.

	Whole Post Float Period Dec 83 - Dec 97		Period I Dec83 - Jun86		Period II July86 - Sep91		Period III Oct91 - Nov93		Period V Jul95 - Dec97	
	Coeff	p-value	Coeff	p-value	Coeff	p-value	Coeff	p-value	Coeff	p-value
A: Estimations without Inventory (RM) variable										
Positive Intervention										
α_c	-0.9931 ***	(0.0000)	-1.0263 ***	(0.0000)	0.2658 *	(0.0845)	-0.3214	(0.6770)	-0.9281 ***	(0.0025)
α_{ERDEV}	13.1661 ***	(0.0000)	-11.0860 ***	(0.0000)	13.3750 ***	(0.0000)	28.7810 **	(0.0157)	15.0085 ***	(0.0099)
α_h	-0.0543	(0.5869)	-0.0401	(0.8499)	-0.1299	(0.3277)	-3.5249 *	(0.0889)	-0.5854	(0.4347)
α_{idiff}	-0.1142 ***	(0.0000)	-0.0567 ***	(0.0011)	-0.0366 **	(0.0390)	0.2607	(0.2035)	-0.5621 ***	(0.0000)
α_{Profit}	-0.0146 *	(0.0610)	3.8377 ***	(0.0000)	0.0829 ***	(0.0000)	0.5822	(0.1677)	-2.4529 ***	(0.0000)
Nobs	3552		640		1334		553		613	
LogL	-1991.60		-245.45		-814.73		-53.91		-252.36	
Negative Intervention										
α_c	-0.8224 ***	(0.0000)	-0.4221 ***	(0.0000)	-1.4758 ***	(0.0000)	-1.6451 ***	(0.0000)	-4.0759 ***	(0.0001)
α_{ERDEV}	-9.0130 ***	(0.0000)	-2.7368	(0.1666)	-9.6332 ***	(0.0000)	-43.770 ***	(0.0000)	1.4821	(0.9538)
α_h	0.4716 ***	(0.0000)	0.5936 ***	(0.0004)	0.8752 ***	(0.0000)	0.3367	(0.4361)	1.7600 *	(0.0714)
α_{idiff}	0.0323 ***	(0.0005)	0.0257 *	(0.0630)	-0.0027	(0.9050)	-0.0531	(0.6617)	-0.4731	(0.3720)
α_{Profit}	0.1454 ***	(0.0000)	0.9793 **	(0.0161)	0.0827 ***	(0.0000)	0.2106	(0.1371)	0.6027	(0.2817)
Nobs	3552		640		1334		553		610	
LogL	-1178.07		-402.02		-372.03		-233.19		-13.87	
B: Estimations with Inventory (RM) variable										
Positive Intervention										
α_c	-1.2646 ***	(0.0000)	0.0720	(0.9083)	-0.1531	(0.7288)	2.6585	(0.1251)	-0.0529	(0.9396)
α_{ERDEV}	13.1445 ***	(0.0000)	-11.0722 ***	(0.0000)	13.2963 ***	(0.0000)	18.010	(0.2150)	10.4875	(0.1163)
α_h	-0.0459	(0.6472)	0.0064	(0.9761)	-0.1302	(0.3267)	-6.7468 **	(0.0175)	-0.3993	(0.6007)
α_{idiff}	-0.1155 ***	(0.0000)	-0.0246	(0.3330)	-0.0502 **	(0.0240)	-0.3324	(0.3060)	-0.5410 ***	(0.0000)
α_{Profit}	-0.0203 **	(0.0123)	3.8427 ***	(0.0000)	0.0948 ***	(0.0000)	0.9202 *	(0.0914)	-2.8266 ***	(0.0000)
α_{RM}	0.0725 **	(0.0129)	-0.2817 *	(0.0748)	0.0956	(0.3117)	-1.1681 **	(0.0196)	-0.3748	(0.1643)
LogL	-1988.52		-243.68		-814.22		-50.31		-251.41	
Negative Intervention										
α_c	-1.1572 ***	(0.0000)	-2.3847 ***	(0.0000)	0.3656	(0.5363)	-2.0763 ***	(0.0002)	14.8693	(0.1275)
α_{ERDEV}	-9.1880 ***	(0.0000)	-2.2511	(0.2602)	-8.8715 ***	(0.0000)	-43.262 ***	(0.0000)	-19.4721	(0.5364)
α_h	0.4703 ***	(0.0000)	0.5148 ***	(0.0024)	0.9259 ***	(0.0000)	0.2984	(0.4930)	3.5519 *	(0.0531)
α_{idiff}	0.0277 ***	(0.0034)	-0.0294	(0.1303)	0.0623 **	(0.0384)	0.1905	(0.2594)	1.2437	(0.1994)
α_{Profit}	0.1411 ***	(0.0000)	0.7836 *	(0.0590)	0.0267	(0.2793)	0.1395	(0.3651)	0.7254	(0.2867)
α_{RM}	0.0875 **	(0.0314)	0.4983 ***	(0.0000)	-0.4221 ***	(0.0011)	0.0372	(0.7972)	-7.3772 *	(0.0684)
LogL	-1175.76		-393.62		-366.66		-232.55		-11.49	

Notes:

Nobs Number of observations for the estimation

LogL Estimated value of log-likelihood

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

Table 4: Friction model estimation results

$$Intv_t = \delta \cdot Intv_{t-1} + (\alpha_c I_{dev,t} + \alpha_{cum} I_{cum,t} + \alpha_{size} I_{size,t}) \cdot |ERDEV_t| + (\beta_c I_{ds,t} + \beta_{hsize} I_{ds,t} I_{hsize,t}) \cdot h_t + \psi \cdot idiff_t + \gamma \cdot CPROFIT_t + \omega \cdot RM_t + \varepsilon_t$$

Where: $Intv_t$ = Intervention proxied by daily net market purchase of foreign currency, $ERDEV_t$ = Deviation of current exchange rate (s_t) from 150 day moving average rate, $I_{dev,t}$ = Positive deviation dummy, $I_{cum,t}$ = cumulative intervention dummy, $I_{size,t}$ = above average intervention dummy, $I_{ds,t}$ = dummy for sign of exchange rate change, $I_{hsize,t}$ = larger than average volatility dummy, h_t = Conditional variance of daily exchange rate returns, $idiff_t$ = Interest rate differentials, $CPROFIT_t$ = Conditional profit index of all intervention, RM_t = Ratio of foreign currency reserves to imports.

	Whole Post Float Period Dec 83 - Dec 97		Period I Dec83 - Jun86		Period II July86 - Sep91		Period III Oct91 - Nov93		Period V Jul95 - Dec97		
	Coeff	p-value	Coeff	p-value	Coeff	p-value	Coeff	p-value	Coeff	p-value	
	A: Estimations without Inventory (RM) variable										
δ	0.7768 ***	(0.0000)	0.5288 ***	(0.0000)	0.6115 ***	(0.0000)	0.4636 ***	(0.0000)	0.5460 ***	(0.0000)	
α_c	1.4324 ***	(0.0000)	0.0889 ***	(0.0020)	-0.7534 ***	(0.0000)	26.0953 ***	(0.0000)	2.6697 ***	(0.0000)	
α_{cum}	-1.2824 ***	(0.0000)	-0.7636 ***	(0.0000)	-0.5197 ***	(0.0000)	-8.3576 ***	(0.0000)	-2.4754 ***	(0.0000)	
α_{size}	0.7280 ***	(0.0000)	0.6410 ***	(0.0000)	2.0040 ***	(0.0000)	-8.2152 ***	(0.0000)	0.3507 ***	(0.0000)	
β_c	0.0951 ***	(0.0000)	0.0370 ***	(0.0000)	0.0796 ***	(0.0000)	0.3062 ***	(0.0000)	0.0614 ***	(0.0000)	
β_{hsize}	-0.0608 ***	(0.0000)	-0.0299 ***	(0.0000)	-0.0394 ***	(0.0000)	-0.2205 ***	(0.0000)	-0.0667 ***	(0.0000)	
ψ	-0.0055 ***	(0.0000)	-0.0005 ***	(0.0000)	-0.0012 ***	(0.0016)	0.0016	(0.8420)	-0.0112 ***	(0.0000)	
γ	-0.0037 ***	(0.0000)	0.0203 ***	(0.0000)	0.0008	(0.2836)	-0.0321 *	(0.0941)	-0.0449 ***	(0.0000)	
σ	0.1093 ***	(0.0000)	0.0190 ***	(0.0000)	0.0987 ***	(0.0000)	0.2731 ***	(0.0000)	0.0438 ***	(0.0000)	
θ^+	0.1178 ***	(0.0000)	0.0216 ***	(0.0000)	0.0332 ***	(0.0000)	0.5398 ***	(0.0000)	0.0350 ***	(0.0000)	
θ^-	-0.0964 ***	(0.0000)	-0.0096 ***	(0.0000)	-0.1004 ***	(0.0000)	-0.4018 ***	(0.0000)	-0.2017 ***	(0.0000)	
$LogL$	-163.73		539.28		348.07		-170.67		346.96		
	B: Estimations with Inventory (RM) variable										
δ	0.7776 ***	(0.0000)	0.5112 ***	(0.0000)	0.6104 ***	(0.0000)	0.4548 ***	(0.0014)	0.5475 ***	(0.0000)	
α_c	1.4123 ***	(0.0000)	-0.0006	(0.9669)	0.1279	(0.1579)	26.7621 ***	(0.0000)	3.0128 ***	(0.0000)	
α_{cum}	-1.1585 ***	(0.0000)	-0.8173 ***	(0.0000)	-0.6552 ***	(0.0000)	-8.0034 *	(0.0593)	-2.6592 ***	(0.0000)	
α_{size}	0.6224 ***	(0.0000)	0.7712 ***	(0.0000)	1.2430 ***	(0.0000)	-9.6071 ***	(0.0000)	0.2070	(0.7009)	
β_c	0.0959 ***	(0.0000)	0.0364 ***	(0.0000)	0.0820 ***	(0.0000)	0.3118 ***	(0.0000)	0.0610 ***	(0.0000)	
β_{hsize}	-0.0614 ***	(0.0000)	-0.0294 ***	(0.0000)	-0.0415 ***	(0.0000)	-0.2276 ***	(0.0001)	-0.0665 ***	(0.0000)	
ψ	-0.0055 ***	(0.0000)	0.0000	(0.8504)	-0.0036 **	(0.0272)	-0.0321 ***	(0.0000)	-0.0115 ***	(0.0035)	
γ	-0.0040 ***	(0.0000)	0.0231 ***	(0.0000)	0.0025 ***	(0.0064)	-0.0123	(0.5321)	-0.0447 ***	(0.0000)	
ω	0.0042 ***	(0.0000)	-0.0051 ***	(0.0000)	0.0144 ***	(0.0000)	-0.0618 ***	(0.0009)	0.0017	(0.7155)	
σ	0.1092 ***	(0.0000)	0.0190 ***	(0.0000)	0.0986 ***	(0.0000)	0.2725 ***	(0.0000)	0.0439 ***	(0.0000)	
θ^+	0.1328 ***	(0.0000)	0.0018	(0.1414)	0.0989 ***	(0.0000)	0.4194 ***	(0.0000)	0.0399 ***	(0.0005)	
θ^-	-0.0814 ***	(0.0000)	-0.0296 ***	(0.0000)	-0.0351 ***	(0.0000)	-0.5268 ***	(0.0000)	-0.1971 ***	(0.0000)	
$LogL$	-162.58		543.87		350.61		-169.44		347.01		

Notes:

LogL Estimated value of log-likelihood
 *, ** and ***: Significance at 10, 5 and 1%

Figure 1: Daily US\$/A\$ Exchange Rate and the RBA's Foreign Exchange Interventions

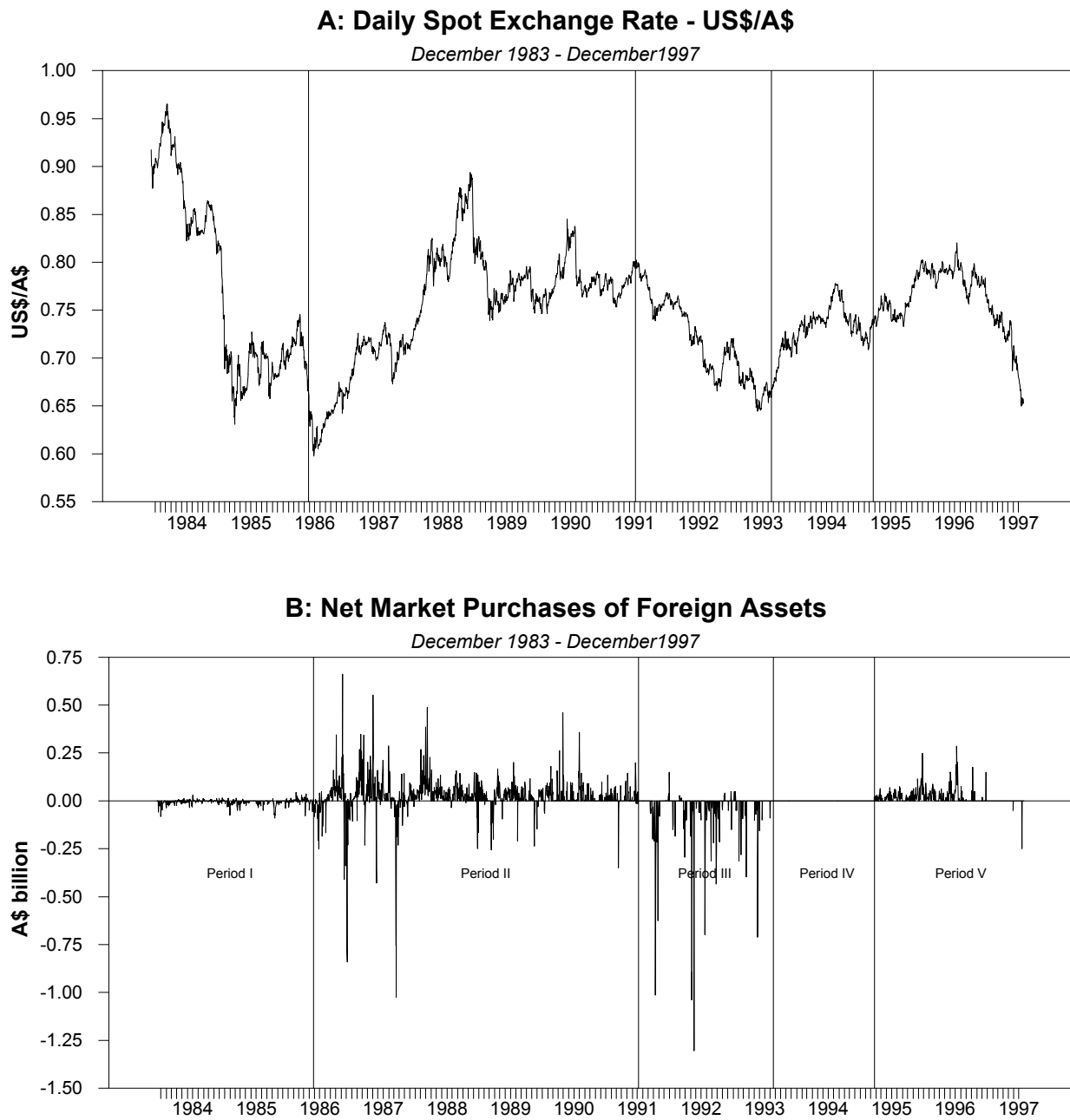


Figure 2: Determinants of RBA's Interventions: Exchange rate Deviations, Conditional Volatility and Interest rate differential (12 December 1983 to 31 December 1997)

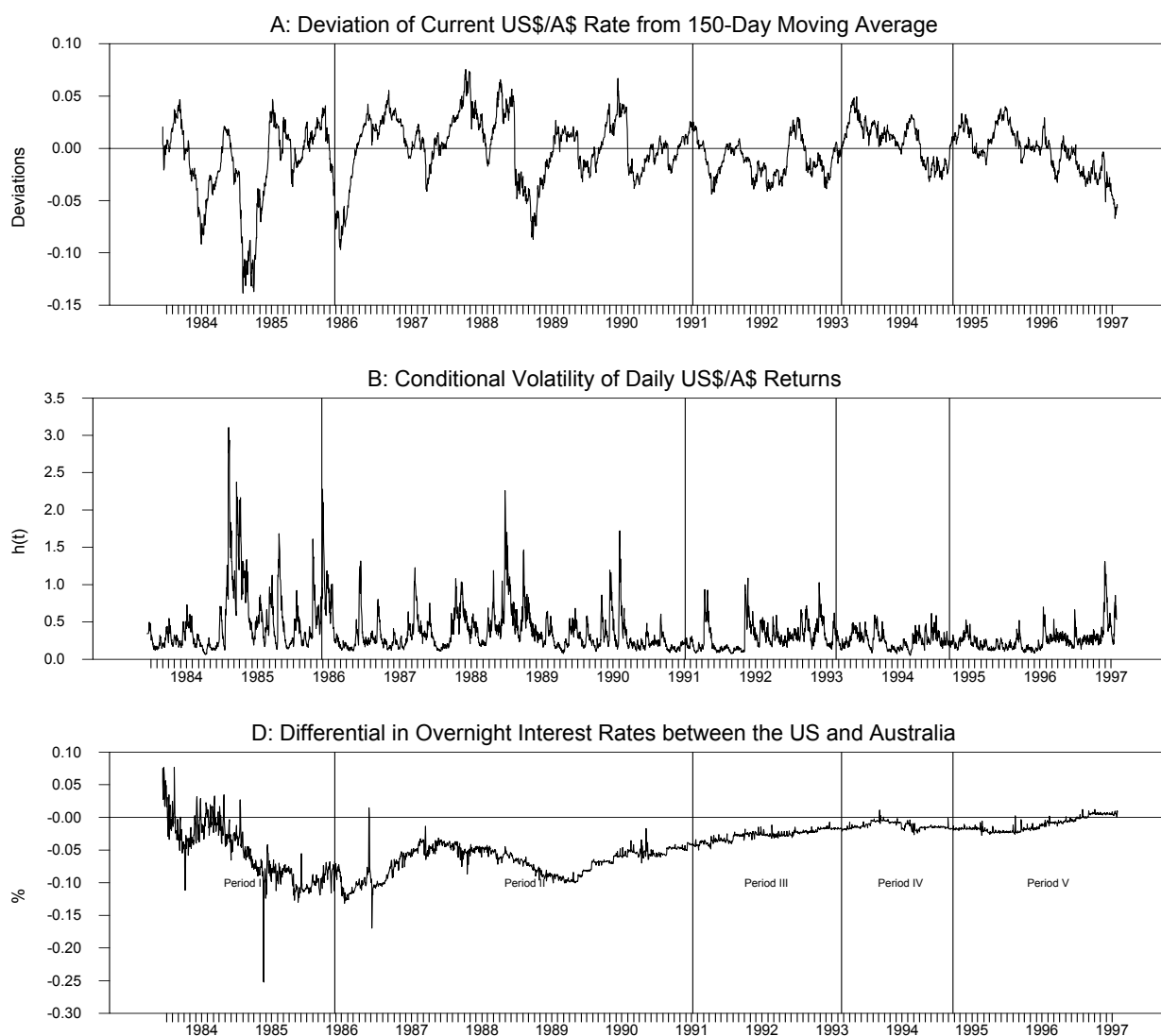


Figure 3: Determinants of RBA's Interventions: Conditional Profitability Measures and Reserves (12 December 1983 to 31 December 1997)

