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How Costly is Exchange Rate Stabilisation for an Inflation Targeter? The Case of Australia*

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This paper quantifies the costs of mitigating exchange rate volatility within the context of a flexible inflation targeting central bank. Within a standard linear-quadratic formulation of inflation targeting, we append a term that penalises deviations in the exchange rate to the central bank's loss function. For a simple forward-looking new-Keynesian model, we show that the central bank can reduce volatility in the exchange rate relatively costlessly by aggressively responding to the real exchange rate. However, when we append correlated shocks to better match summary statistics of the Australian data, we find that the costs associated with reducing exchange rate volatility are larger: output volatility increases substantially. Finally, we apply our method to a variant of a small backward-looking new-Keynesian model of the Australian economy. Under this model, large increases in inflation and output volatility accrue if the central bank attempts to mitigate exchange rate volatility.

I Introduction

Most central banks within the OECD currently have a low inflation rate as their main target of policy, with other possible policy objectives relegated to second place. In most of the theoretical literature regarding central bank behaviour the two variables that enter a central bank's loss function are the rate of inflation and the level of output growth (or the output gap). This is despite the fact that several other candidate objectives might reasonably be expected to be of interest to central banks. In this paper we explore the idea that central banks are often interested in limiting exchange rate variability. Obviously different central banks have different objectives in this regard, ranging from strong limits to exchange rate variability as in China, to heavy interventions but some exchange rate variation in Singapore, to the Reserve Bank of Australia's (RBA) approach of leaning against only large movements in either direction of the exchange rate.

The issue of whether or not central banks should more actively manage the exchange rate is an open question. In this paper we simply take it as given that the central bank may want to limit exchange rate volatility. There is now a vast literature that examines the empirical impact of exchange rate volatility on the real economy, with the findings

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being mixed over whether such volatility affects real variables at the macroeconomic level (see Arize *et al*. (2000) and Crosby (2004) for recent papers on this topic and for a summary of the evidence).

While the evidence at the macroeconomic level tends to give mixed results, models developed from the micro-founded behaviour of optimising agents frequently suggest that there exist significant welfare gains to mitigating exchange rate volatility. Agents might be prepared to give up a certain fraction of consumption in each period in return for reduced exchange rate volatility that otherwise increases risk and uncertainty around economic decisions (see Obstfeld & Rogoff, 1998; de Paoli, 2004). Bergin *et al*. (2006) present an alternative view that the costs from exchange rate volatility are small. The aim of this paper is not to quantify the welfare costs of exchange rate volatility but rather to explore the trade-offs of an open economy that central bank faces in attempting to reduce exchange rate volatility.

This paper seeks to quantify the costs of mitigating exchange rate volatility for a small open economy with an inflation targeting central bank. The central bank seeks to minimise deviations of inflation from target in the context of a flexible, market determined, exchange rate regime. The central bank is flexible in their inflation targeting and seeks to reduce volatility in output, interest rates and the exchange rate. We view the RBA as a prime example of a small open economy inflation targeter operating within the framework specified. The specific policy experiment we explore is increasing the weight on exchange rate stabilisation relative to other macroeconomic objectives.

We first present results for a simple forward-looking new-Keynesian model. To foreshadow the results, this model suggests mitigating exchange rate volatility can be achieved relatively costlessly by responding more aggressively to the real exchange rate only. However, the model fails to replicate the correlation in the data.

To address this failure, we consider two other models that better fit the Australian data. First, we append the simple new-Keynesian model with a shock correlation matrix derived from Australian data in the same manner as West (2003). This model suggests some costs associated with reducing exchange rate volatility.

Second, the robustness of these results are checked for a smaller variant of the backward-looking model due to Beechey *et al*. (2000), which has been used for policy simulations at the RBA. This model also suggests large costs to reducing exchange rate volatility.

The following section presents the forward-looking model and the small variant of the RBA Beechey *et al*. (2000) model.[1]

This paper provides an update on the current structure of the model and the main changes that have been made to it since Beechey *et al*. While the details of the model have changed, its core features have not. The model remains small, highly aggregated, empirically based, and non-monetary in nature. It also retains a well-defined long-run steady state with appropriate theoretical properties, even though its primary role is to analyse short-run macroeconomic developments.

Section 3 presents results of the policy experiment. Section 4 concludes.

II Three Small Open Economy Models

In the following section we consider the three model economies that will be used in our analysis. The first two economies can be represented in the canonical forward-looking structure:

$$A_0X_t + A_1E_tX_{t+1} = U_t, \tag{1}$$

where $X = (y, \pi, i, q, y^*, \pi^*, i^*)'$ contains the small open economy's output gap, inflation rate, nominal interest rate, real exchange rate, foreign output gap, foreign inflation and foreign nominal interest rate, respectively. The vector of exogenous random variables $U = (u_y, u_\pi, u_m, u_r, u_y^*, u_\pi^*, u_i^*)'$[2] collect the respective shocks to each equation in the system ordered according to the vector X. The difference between the first and the second small open economies will be in the stochastic processes for U. In the former, U will be an independently and identically distributed random vector, while in the latter, U will be a Markov process whose dynamics are determined jointly by the structural model's calibration and the data.

We will compare our results for the new-Keynesian models with a third model that has purely backward-looking dynamics that contrast with the forward-looking aspect of the first two economies.

[1] The Reserve Bank of Australia Research Discussion Paper Stone, Wheatley and Wilkinson (2005), provide an updated version of the Beechey *et al*. (2000) model, and is available on the Reserve Bank of Australia's website: http://www.rba.gov.au.

[2] Note that there is a structural shock attached to the interest rate equation that can be considered to represent imperfect control over the 90 day interest rate and is useful for ensuring exact structural identification of the shocks in the model.

This third model takes a backward-looking structural vector autoregressive (VAR) form:

$$X_{t+1} = AX_t + U_t \quad (2)$$

and the elements of X in this case include a richer set of variables including domestic good inflation and the domestic terms of trade.

(ii) A Forward-Looking New-Keynesian Model

Our first model is a variant of the new-Keynesian model used in West (2003). The model is extremely simple. This simplicity yields a lack of dynamics but offers analytical solutions for optimal simple rules. These solutions clarify the mapping from the weights on stabilisation objectives within the central bank's loss function, to response coefficients within the central bank's reaction function. The model is characterised by the following IS curve:

$$y_t = \alpha_{y^*} y_t^* - \alpha_q q_t - \alpha_r (i_t - E_t \pi_{t+1}) + u_{y,t}, \quad (3)$$

a simple Phillips curve equation:

$$\pi_t = \beta_\pi E_t \pi_{t+1} + \beta_y y_t + u_{\pi,t}, \quad (4)$$

and the real interest rate parity condition:

$$q_t = E_t q_{t+1} + (i_t - E_t \pi_{t+1}) + (i_t^* - E_t \pi_{t+1}^*) + u_{q,t}. \quad (5)$$

We follow West (2003) and close the model by assuming the interest rate is set according to the following monetary policy rule with no interest rate smoothing:

$$i_t = \gamma_\pi \pi_t + \gamma_y y_t + \gamma_q q_t, \quad (6)$$

where γ_π, $\gamma_y > 0$ and $\gamma_q < 0$.

All variables are as noted in the previous section; the output gap is represented with y_t, q_t is the real exchange rate, i_t is the monetary policy instrument (assumed to be the 90-day interest rate), π_t is domestic consumer price inflation, while y_t^*, i_t^* and π_t^* represent the foreign output gap, the foreign nominal interest rate and foreign inflation, respectively. The foreign sector is assumed to be exogenous and simply determined by shock process such that

$$(y^*, \pi^*, i^*)' = (u_y^*, u_\pi^*, u_i^*)'.$$

As West (2003) notes, the model has much in common with the new-Keynesian models derived from explicit micro-foundations (e.g. Rotemberg & Woodford, 1998; Gali & Monacelli, 2005), although a clear departure from these models is the lack of forward-looking behaviour in the output gap equation. McCallum and Nelson (1999) show that optimising behaviour on the part of households implies that the consumption Euler equation contains the expectation of future consumption. However, based on US data, Fuhrer and Rudebusch (2004) find little to recommend using expectations of future output to determine current output. Estrella and Fuhrer (2002) note that a purely forward-looking new-Keynesian model cannot replicate the US data.

The Phillips equation is closely related to the derivations in Clarida *et al.* (1999) and represents the summation of firms' pricing decisions. There is disagreement in the literature regarding the degree of forward-looking behaviour. Dennis (2004), Lindé (2005) and Söderlind *et al.* (2005) find a fairly limited role for expectations. Initially we explore a purely forward-looking Phillips relationship and then consider a more persistent process for inflation in subsequent models.

The real exchange rate is modelled by assuming that uncovered real interest rate parity holds. Empirically, this equation is difficult to maintain – the real exchange rate typically moves through cycles largely unexplained by exchange rate arbitrage.[3] To address this, we model the persistence in the exchange rate in subsequent representations of the economy.

The model contains no lagged processes, although lags are necessary for the model to replicate the autocorrelation typically observed in key macroeconomic series such as inflation, the output gap, and the real exchange rate. The following subsection extends the baseline model by specifying processes for the foreign variables and allowing the data to determine the degree of correlation in the residuals of Equations (3)–(10).

(ii) A Model with Persistence

Our second model allows the structural shocks to take a VAR (1) specification:

$$U_t = \Phi U_{t-1} + W_t, \quad (7)$$

where the matrix Φ and the variance–covariance matrix Ω_W, associated with the shock process W_t, are determined by the data. West (2003) details how iterating on discrete Lyapunov equations produces a numerical solution for Γ_X, the variance–covariance matrix of the state variables, X_t, and

[3] Meese and Rogoff (1983) find that uncovered interest parity (UIP) cannot beat a random walk in forecasting the exchange rate and West (2003) appears correct in relabelling the UIP condition 'uncertain interest rate parity'.

the method is presented in the technical appendix, available from the authors on request. When the model allows the data to determine the process of the structural shocks (encapsulated in the matrix Φ), and allows autocorrelation in the foreign sector, the optimal policy rule is no longer restricted to only the three state variables in Equation (10). Instead, the rule will be a function of all the state variables, including the foreign sector and the structural shocks. Rather than pursue fully optimal rules we determine the dynamics and variances of key macroeconomic variables under a simple policy rule that takes its arguments from Equation (10). That is, the rule responds contemporaneously to inflation, the output gap and the real exchange rate. The response coefficients can no longer be solved analytically but a simple numerical algorithm searches for optimal coefficients until gains from search are negligible.

We use Australian data over the period 1990Q1–2003Q4; the data are detailed in the data appendix to the paper. The sample period represents a flexible exchange rate regime, where the interest rate was manipulated with the primary goal of achieving inflation objectives.[4]

Both Australian and US output is HP filtered ($\lambda = 1600$) to construct stationary output gap series. We annualise the RBA's weighted median measure of quarterly Australian consumer price inflation. The exchange rate is the real effective exchange rate and is expressed as a percentage deviation from its mean over the entire data period. The quarterly 90 days interest rate is constructed by averaging monthly data. The US federal funds rate is also the quarterly average of monthly data. US consumer price inflation is constructed as the annualised quarterly increase in the consumer price index. The data appendix lists data sources and series identifiers.

Obtaining the variance–covariance matrix of the structural shocks (and thus the variance–covariance of the state variables) is achieved by obtaining the variance–covariance of the reduced-form residuals (see the technical Appendix). To this end, we estimate an unrestricted reduced-form VAR model and include a constant that effectively removes variable means that are unimportant for determining the dynamics and variances of state variables.[5]

First-pass estimation of the VAR (1) model returns residuals for the interest rate equation that are severely non-normal: the Jarque-Bera test of normality is rejected at the 1 per cent level. This is suggestive of some misspecification in the model. This is attributable to the increase in the Australia 90-day interest rate in 1994Q4 and 1995Q1, which the model fails to replicate. Bernanke *et al*. (1999) note that this period represents the first acid test of the RBA's commitment to inflation targeting and note the RBA raised the cash rate 100 basis points on both 24 October and 14 December.

Our model cannot replicate the rapid increased in interest rates over this period, when the RBA was surprised about the strength of the economy, at a time that called for a sign of commitment to the new inflation targeting regime.[6] A richer model of the evolution of the public's believes about the credibility of the RBA's commitment to inflation targeting may be required to explain this history. Since we are concerned with obtaining a plausible model of current dynamics, instead, we use an additive dummy that takes the same value in both 1994Q4 and 1995Q1 to account for this non-normality. The VAR (1) representation of the model (excluding constant terms) is presented on the following page.

The diagonal elements of the VAR (1) representation are relatively high and generally significant, suggesting most of the explanatory power of each variable is contained within lags of the left hand side variable in question. This is particularly true of annual inflation. The diagnostics associated with the VAR (1) model are presented in Table 1 on the following page.

The VAR (1) returns high R^2 values across each equation. The standard error of the real exchange rate is 2.576: much higher than the standard errors associated with the other variables.

According to the Jarque-Bera test, the errors are all normal at the 5 per cent level of significance. However, the Ljung-Box statistics, which test for

[4] Bernanke *et al*. (1999) note that interest rate behaviour from the late 1980s is consistent with a central bank that has inflation as a key monetary policy objective.

[5] Thus, over the period the mean of the exchange rate is treated as the equilibrium exchange rate.

[6] Bernanke *et al*. (1999) quote (see page 232) the RBA directly: 'This further tightening has occurred rather sooner than some might have expected, basically because of evidence that the economy overall has been growing more strongly than previously thought ... (Reserve Bank of Australia, 1995, January, p. 27)' de Brouwer and Gilbert (2005) express a similar concern and state: 'The speed of the rise suggests that the Reserve Bank was keen to establish its credibility as an inflation fighter.'

$$\begin{bmatrix} y_{t+1} \\ \pi_{t+1} \\ i_{t+1} \\ q_{t+1} \\ y^*_{t+1} \\ \pi_{t+1} \\ i^*_{t+1} \end{bmatrix} = \begin{bmatrix} \underset{(0.102)}{0.746} & \underset{(0.102)}{-0.010} & \underset{(0.132)}{-0.002} & \underset{(0.020)}{0.005} & \underset{(0.064)}{0.080} & \underset{(0.323)}{-0.143} & \underset{(0.353)}{-0.006} \\ \underset{(0.110)}{0.068} & \underset{(0.110)}{0.741} & \underset{(0.142)}{0.122} & \underset{(0.021)}{0.042} & \underset{(0.069)}{0.164} & \underset{(0.347)}{0.022} & \underset{(0.380)}{-0.091} \\ \underset{(0.054)}{0.116} & \underset{(0.054)}{0.176} & \underset{(0.070)}{0.684} & \underset{(0.010)}{-0.020} & \underset{(0.034)}{0.044} & \underset{(0.172)}{0.064} & \underset{(0.188)}{0.051} \\ \underset{(0.547)}{-1.198} & \underset{(0.548)}{0.142} & \underset{(0.709)}{-1.426} & \underset{(0.105)}{0.763} & \underset{(0.343)}{1.247} & \underset{(1.730)}{2.250} & \underset{(1.893)}{0.825} \\ \underset{(0.086)}{0.110} & \underset{(0.087)}{-0.034} & \underset{(0.112)}{-0.065} & \underset{(0.016)}{-0.028} & \underset{(0.054)}{0.837} & \underset{(0.273)}{-0.103} & \underset{(0.299)}{-0.045} \\ \underset{(0.091)}{-0.183} & \underset{(0.091)}{-0.082} & \underset{(0.118)}{0.287} & \underset{(0.017)}{0.023} & \underset{(0.057)}{0.158} & \underset{(0.287)}{0.337} & \underset{(0.314)}{0.011} \\ \underset{(0.067)}{0.179} & \underset{(0.067)}{0.046} & \underset{(0.086)}{-0.212} & \underset{(0.013)}{-0.045} & \underset{(0.042)}{0.139} & \underset{(0.211)}{0.149} & \underset{(0.231)}{0.973} \end{bmatrix} \begin{bmatrix} y_t \\ \pi_t \\ i_t \\ q_t \\ y^*_t \\ \pi^*_t \\ i^*_t \end{bmatrix} \begin{bmatrix} \varepsilon_{yt} \\ \varepsilon_{\pi t} \\ \varepsilon_{it} \\ \varepsilon_{qt} \\ \varepsilon_{y^*t} \\ \varepsilon_{\pi^*t} \\ \varepsilon_{i^*t} \end{bmatrix}$$

TABLE 1
Baseline Model

Equation	R^2	SE	JB	LB
y_{t+1}	0.720	0.481	5.143 (0.076)	1.766 (0.622)
π_{t+1}	0.892	0.517	2.105 (0.349)	4.453 (0.217)
i_{t+1}	0.989	0.256	0.049 (0.976)	0.754 (0.861)
q_{t+1}	0.892	2.576	0.693 (0.707)	1.014 (0.798)
y^*_{t+1}	0.797	0.407	2.835 (0.242)	1.194 (0.754)
π^*_t	0.813	0.428	3.725 (0.155)	17.160 (0.001)
i^*_{t+1}	0.969	0.314	3.398 (0.183)	11.350 (0.010)

Note: JB, Jarque-Bera statistic; LB, Ljung-Box statistic; SE, standard errors.

autocorrelation in the residuals with up to four lags, shows the model may be susceptible to correlation in the US inflation and interest rate series.

(iii) A Backward-Looking Model

As a final check on the policy experiment we use a simplified version of the Beechey *et al.* (2000) model used in the past at the RBA. The model is close to the simplification of the Beechey *et al.* model used in Dennis (2003).[7] The aim here is to explore whether the costs of exchange rate stabilisation are similar within a reasonable backward-looking representation of the economy. Our simplified model takes the form:

[7] The full model was used for actual policy simulations within the RBA.

$$y_t = 0.75y_{t-1} - 0.1q_t + 0.05s_{t-1} - 0.22(i_{t-1} - \pi_{t-1}) + \varepsilon_{yt} \quad (8)$$

$$q_t = 1.09\Delta s_t + 0.63q_{t-1} + 0.25s_{t-1} + 0.66(i_{t-1} - \pi_{t-1}) + \varepsilon_{qt} \quad (9)$$

$$s_t = 1.68s_{t-1} - 0.81s_{t-2} + \varepsilon_{st} \quad (10)$$

$$\pi_t^d = \pi_{t-1}^d + 0.64y_{t-1} + \varepsilon_{\pi_t^d} \quad (11)$$

$$\pi_t^f = 0.5\pi_{t-1}^f + 0.5\Delta q_t + \varepsilon_{\pi_t^f} \quad (12)$$

$$\pi_t^c = 0.5\pi_t^d + 0.5\pi_t^f \quad (13)$$

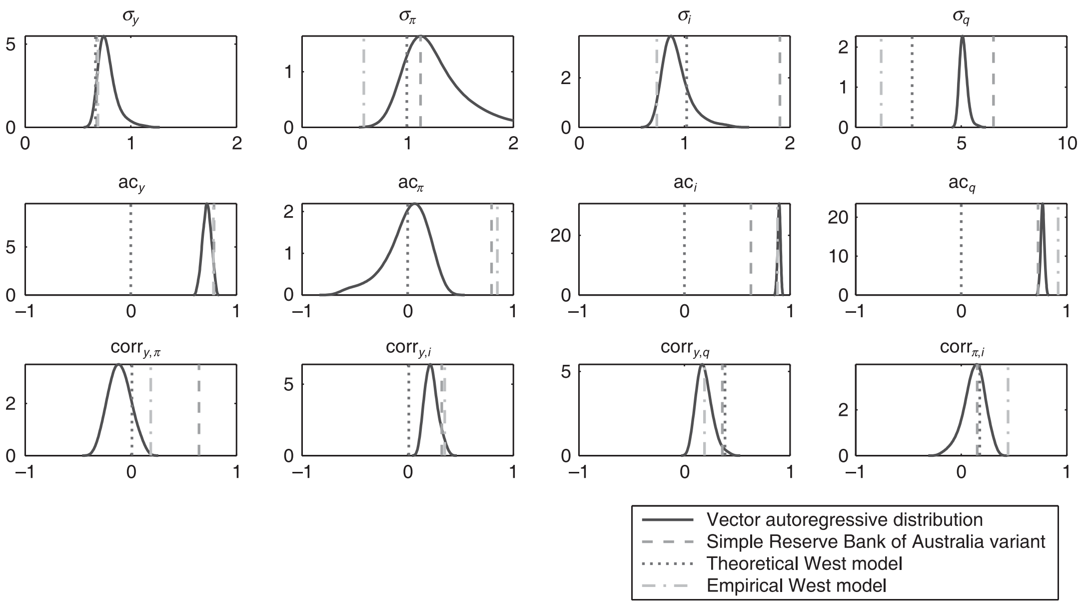
$$i_t = 1.5\pi_t^d + 0.5y_t. \quad (14)$$

Note that π_t^d is domestic good inflation, π_t^f is foreign good inflation, π_t^c is consumer price inflation and s_t is the terms of trade. Equations (8)–(10) are identical to the representation of the small RBA model in Dennis (2003). We abstract from the change in labour costs and the error correction mechanism between the prices of consumption goods, import good and labour costs in the Dennis, 2004) model such that Equations (11)–(13) represent a simplified process for consumer price inflation. Consumer price inflation is the equally weighted average of domestic good inflation (which is driven by the output gap) and foreign good inflation (which contains imperfect exchange rate pass-through). Finally, the model is closed with the Taylor rule.

(iv) Model Fit

It is natural to evaluate alternative models based on fit. To this end, we match several summary statistics (standard deviations, autocorrelations and cross-correlations of key macroeconomic variables) implied by each model, under a specific loss function, to the summary statistics implied by the data. Rather than to construct summary statistics from a specific data sample we use a Bayesian approach to characterise parameter uncertainty. We estimate a VAR and draw from

FIGURE 1
Summary Statistics for Three Small Empirical Models



the distribution of VAR parameters to construct distributions for key summary statistics. The VAR (3) is estimated over the output gap, inflation, the interest rates and the exchange rate. The companion form of the VAR (3) can be represented as:

$$X_t = AX_{t-1} + \varepsilon_t. \qquad (15)$$

We define $g(A) = \Pi_i g(A_i)$ to be an uninformative prior density for A where $i = 1, 2, \ldots \infty$. If $g(A)$ is uninformative and X_t is normally distributed, A will take a Normal–Wishart distribution (see Schorfheide, 2000 and Canova, 2005). We draw 5000 sets of stationary parameters estimates from the Normal-Wishart distribution for A, using an indicator function that removes parameter draws that imply non-stationarity in the VAR model. For each parameter draw, A_i, the variance–covariance matrix of the simulated data y_i is:

$$\textstyle\sum_{Xi} = A_i \sum_{Xi} A_i' + \sum_e, \qquad (16)$$

where Σ_e is the variance–covariance matrix of the errors of the companion form VAR. Rather than to simulate data we solve for the variance–covariance matrix with the vector operator that stacks columns of A in a single vector:

$$vec(\textstyle\sum_{Xi}) = [I - (A_i \otimes A_i)]^{-1} vec(\sum_e). \qquad (17)$$

We construct distributions of summary statistics from the variance–covariance matrix. Comparison of the summary statistics implied by the models to the distributions of the data yields a sense of distance regarding which summary statistics 'miss' the data and which merely reflect genuine uncertainty in the data sample itself. Figure 1 depicts the distributions of the data implied by the VAR (3) model against summary statistics for all three models under a specific loss function where

$$L_t = \pi_t^2 + y_t^2 + 0.5 i_t^2 + 0.1 q_t^2.$$ [8]

Turning first to the standard deviation of the output gap in the first cell of the figure, the models match the narrow range of estimates implied by the data. The mode of the distribution in the data peaks at 0.745. In comparison, the standard deviations of the models are 0.666, 0.690

[8] Of course, other loss function specifications will yield different dynamics. Table 2 shows the effect of the choice of loss function on one particular summary statistic: the standard deviation of key macroeconomic variables.

and 0.678 for the forward-looking model, West's empirical model and the small RBA model, respectively. Although these estimates are all below the mode, they are comfortably within the distribution of estimates. Thus all three models match output volatility particularly well.

Both the forward-looking and simple RBA model match the volatility of quarterly inflation relatively well. However, West's empirical model suggests inflation is much less volatile than the data would suggest. Furthermore, West's empirical model substantially underestimates the volatility of the exchange rate and implies the standard deviation of the nominal interest rate is about the same in the models as in the data. Summing across these volatility measures, the model suggests the shocks to the model are too small relative to the VAR (3) specification of the data.

In contrast, the simple RBA model variant predicts about twice as much interest rate volatility as the data. Interest rates must be manipulated relatively vigorously to achieve stability of output, inflation and the exchange rate in the variant of the RBA model.

The second row of the figure depicts the autocorrelations of the four key time series. Note that because the theoretical model contains no lagged dynamics, the variables are functions of the *i.i.d.* shocks each period and thus the implied autocorrelation for each series is zero.

Both the empirical model and the small RBA model match the autocorrelation in output, which the data clearly identifies as very persistent. However, both models also predict highly autocorrelated inflation processes that are inconsistent with the data: the VAR (3) model suggests inflation is not particularly persistent. This marks the largest deviation of these models from the data. The task of reducing persistent inflation deviations appears particularly difficult under both West's empirical model and the variant of the small RBA model, relative to the persistence observed in the data.

Although the distributions for the autocorrelations evident in both the interest rate and the exchange rate are relatively tight, both the empirical West specification and the small RBA model also specify relatively high interest and exchange rate persistence.

Finally, the last row of the table displays four cross-correlations for key variables. The data are more agnostic relative to the autocorrelations for each variable, reflecting a higher degree of uncertainty in off-diagonal elements in the underlying VAR (3) model. However, although both the theoretical and empirical model appear to match the low correlation between the output and inflation, the simple RBA model predicts much correlation. The theoretical West model fails to match the correlation between the output gap and the interest rate and the simple RBA model overestimates the low correlation between inflation and the nominal interest rate.

The next section undertakes our experiment across the three open economy models. The goal is to explore the extent of the trade-off between minimising deviations of the exchange rate from equilibrium and other macroeconomic objectives, within an inflation targeting framework. Overall the results in this section suggest that the empirical model and the RBA model are a much better fit for the Australian data than the theoretical model. However, for the sake of comparison we include all three models in the next section.

III Results

Our key experiment departs from West (2003) in describing the motivation for the behaviour of the central bank. We explicitly model the central bank's problem as one of selecting an interest rate rule that minimises an objective function whereas West (2003) explores the implications of policy rules that include explicit responses to the exchange rate.

We assume that the central bank is an inflation targeter and is thus concerned with the volatility of inflation but is flexible in its approach and in addition, is also concerned with volatility in the output gap, the interest rate and the real exchange rate. The key innovation in this paper is to uncover the implied behaviour for the central bank and the economy when the central bank possesses a concern for exchange rate stabilisation, over and above the concerns for macroeconomic objectives encapsulated by flexible inflation targeting. The simple rule is restricted to output gap, inflation and exchange rate arguments and can be considered a Taylor-type rule appended with a response to the contemporaneous exchange rate.[9]

Specifically, the central bank in each of the three economies seeks to minimise the lifetime loss criterion:[10]

[9] Taylor (2001) also discusses appending exchange rate arguments to Taylor-type rules.

[10] Note, the targets are assumed zero for convenience. These can be easily recovered from the constants in the VAR solution by allowing for a VAR with a constant vector.

$$W = \frac{1}{2}E_0\sum_{t=0}^{\infty} \beta^t L_t(y_t, \pi_t, q_t, i_t);\quad \beta \in (0, 1), \lambda_y, \lambda_i, \lambda_q > 0, \tag{18}$$

$$L_t(y_t, \pi_t, q_t, i_t) = \frac{1}{2}[\pi_t^2 + \lambda_y y_t^2 + \lambda_i i_t^2 + \lambda_q q_t^2] \tag{19}$$

subject to the constraints imposed by the models' dynamics in (Eqn 1) for the first two new-Keynesian economies, or in (Eqn 2) for the backward-looking economy. We assume that there is no discounting such that the lifetime loss criterion in the limit is:

$$\lim_{\beta\to 1} W = \frac{1}{2}[\sigma_\pi^2 + \lambda_y\sigma_y^2 + \lambda_i\sigma_i^2 + \lambda_q\sigma_q^2]. \tag{20}$$

If the central bank cares about the current and expected future continuation value of its policy program, it must commit to a policy rule that minimises the expected present value of lifetime losses. This is equivalent to having asymptotic variances in its loss function in the case of quadratic period losses.

Rather than finding the optimal solution to the central bank's dynamic problem in each model, we let the central bank in all three candidate economies solve a problem of committing to some simple rule that minimises (Eqn 20) subject to the model constraints each period. Again, we restrict the class of optimal simple rules to Taylor-type rules provided in Equation (6):

$$i_t = \gamma_\pi\pi_t + \gamma_y y_t + \gamma_q q_t$$

as in West (2003) with γ_π, $\gamma_y > 0$ and $\gamma_q < 0$.

First, we report the results for the theoretical model, with no autocorrelation in the shock processes for the model Equations (3)–(5). Recall that we can derive the optimal discretionary rule given the model and parameterisation of the central bank loss function.

The key parameter for our policy experiment is the relative weight the central bank places on stabilising the real exchange rate relative to its equilibrium. This is restricted to the preference set $\lambda_q = \{0.0, 0.1, 0.2\}$. A small weight on the variance of the real exchange rate is appropriate because observed deviations of the exchange rate from equilibrium (expressed in percentage terms) are larger, by an order of magnitude, than deviations of inflation from target, the output gap, and deviations of the interest rate from neutral.

For West's theoretical model, we set the variances of inflation, the output gap and the interest rate shocks to one and set the variance of the exchange rate to eight to approximately match the variance of the key macroeconomic variables in the data. The variances of the shocks for West's empirical model are data determined. For the small backward-looking model, the variances of the shocks are those from Dennis (2003) for the output gap, exchange rate and the terms of trade equations, while the variance of the domestic and foreign good inflation equations are set to 0.1.

Table 2 on the following page displays the results of the policy experiment for all three models with columns 2–4 of the table displaying the range of weights within the central bank's loss function. Columns 5–8 list the standard deviations of inflation, output, the interest rate and the exchange rate, respectively. Columns 9–11 give the optimal response coefficients in the monetary policy rule. Column 12, labelled 'L', gives the loss associated with the optimal policy in the immediately preceding columns.

To evaluate the cost of exchange rate stabilisation we include column 13, labelled 'L^{nq}'. In this column we compute loss function values using the loss function which excludes exchange rate volatility (i.e. $\lambda_q = 0$), but inserting the volatilities estimated over the full model. In other words, in loss function terms, how much does the weight put on exchange rate volatility cost in terms of increases in output, inflation and interest rate volatility.

For example, row lb inserts the volatilities in this row into the loss function implied by la to compute the loss function value of 1.53. The next column shows the percentage increase in the loss function. Finally, column 15 assumes the true loss function contains no exchange rate term and shows how much inflation the central bank would be willing to incur, in every period, to move from the policy rule under the exchange rate argument, to the rule optimised with no exchange rate argument.[11] For example, the policy rule in row lb achieves a

[11] The inflation equivalent measure is the extra inflation the central bank operating with loss function L requires to be indifferent between the optimal policy and implementing the optimal policy from the alternative loss function that contains an exchange rate argument. That is,

$$(\pi + \tilde{\pi})_t^2 + \lambda_y y^2 + \lambda_i i_t^2 + \tilde{\pi} = \pi_t^2 + \lambda_y y^2 + \lambda_i i_t^2 + \lambda_q q_t^2.$$

Taking the square root of both sides and solving for the inflation equivalent measure yields:

$$\tilde{\pi} = \sqrt{L^{nq} - L}.$$

TABLE 2
Standard Deviations, Loss, Optimal Rules for Alternative Preferences

	λ_y	λ_i	λ_q	σ_π	σ_y	σ_i	σ_q	γ_y	γ_π	γ_q	L	L^{nq}	%Δ	$\tilde{\pi}$
I West's theoretical model														
1a	0.5	0.5	0	0.99	0.77	0.56	2.98	0.26	0.65	0.00	1.43	1.43	0.00	0.00
1b	0.5	0.5	0.1	0.99	0.74	0.74	2.62	0.26	0.65	–0.20	2.21	1.53	6.99	0.31
1c	0.5	0.5	0.2	0.99	0.76	0.95	2.34	0.26	0.65	–0.40	2.82	1.73	20.98	0.55
2a	0.5	1	0	1.00	0.90	0.33	3.04	0.13	0.33	0.00	1.53	1.53	0.00	0.00
2b	0.5	1	0.1	1.00	0.86	0.46	2.81	0.13	0.33	–0.10	2.38	1.59	3.92	0.25
2c	0.5	1	0.2	1.00	0.85	0.62	2.62	0.13	0.33	–0.20	3.12	1.75	14.38	0.47
3a	1	0.5	0	0.99	0.60	0.81	2.92	0.26	1.30	0.00	1.66	1.66	0.00	0.00
3b	1	0.5	0.1	0.99	0.59	0.90	2.63	0.26	1.30	–0.20	2.43	1.73	4.22	0.27
3c	1	0.5	0.2	0.99	0.62	1.03	2.40	0.26	1.30	–0.40	3.06	1.91	15.06	0.50
4a	1	1	0	1.00	0.77	0.53	2.98	0.13	0.65	0.00	1.87	1.87	0.00	0.00
4b	1	1	0.1	1.00	0.75	0.61	2.79	0.13	0.65	–0.10	2.70	1.93	3.21	0.23
4c	1	1	0.2	1.00	0.74	0.72	2.62	0.13	0.65	–0.20	3.43	2.06	10.16	0.44
II West's empirical new-Keynesian model														
1a	0.5	0.5	0	0.67	0.69	0.65	1.21	2.34	2.13	–2.01	0.89	0.89	0.00	0.00
	0.5	0.5	0.1	0.65	0.71	0.68	1.16	1.89	1.48	–1.78	1.03	0.90	1.12	0.07
1b	0.5	0.5	0.2	0.63	0.73	0.72	1.11	1.56	0.99	–1.60	1.16	0.91	2.25	0.14
1c	0.5	1	0	0.67	0.74	0.60	1.24	1.70	2.37	–1.81	1.08	1.08	0.00	0.00
2a	0.5	1	0.1	0.66	0.75	0.61	1.21	1.47	1.99	–1.67	1.23	1.09	0.93	0.07
2b	0.5	1	0.2	0.65	0.76	0.62	1.18	1.28	1.67	–1.57	1.38	1.10	1.85	0.12
2c	1	0.5	0	0.71	0.57	0.72	1.25	6.35	3.10	–3.38	1.09	1.09	0.00	0.00
3a	1	0.5	0.1	0.69	0.59	0.74	1.21	4.65	1.97	–2.70	1.24	1.09	0.00	0.07
3b	1	0.5	0.2	0.67	0.61	0.76	1.17	3.60	1.25	–2.28	1.38	1.11	1.83	0.13
3c	1	1	0	0.71	0.63	0.65	1.27	3.98	3.22	–2.63	1.32	1.32	0.00	0.00
4a	1	1	0.1	0.69	0.64	0.65	1.24	3.29	2.60	–2.33	1.47	1.33	0.76	0.05
4b	1	1	0.2	0.68	0.66	0.66	1.22	2.78	2.12	–2.10	1.63	1.34	1.52	0.11
4c	0.5	0.5	0	1.07	0.68	1.93	6.64	2.53	1.51	–0.13	3.23	3.23	0.00	0.00
III Simplified Reserve Bank of Australia model														
1a	0.5	0.5	0	1.07	0.68	1.93	6.64	2.53	1.51	–0.13	3.23	3.23	0.00	0.00
1b	0.5	0.5	0.1	1.13	0.69	1.90	6.52	2.45	1.46	–0.16	7.56	3.31	2.48	0.28
1c	0.5	0.5	0.2	1.21	0.70	1.91	6.41	2.36	1.40	–0.20	11.75	3.52	8.98	0.54
2a	0.5	1	0	1.20	0.69	1.81	6.60	2.18	1.29	–0.12	4.96	4.96	0.00	0.00
2b	0.5	1	0.1	1.23	0.69	1.80	6.52	2.14	1.27	–0.15	9.26	5.01	1.01	0.23
2c	0.5	1	0.2	1.28	0.70	1.81	6.44	2.09	1.25	–0.17	13.46	5.16	4.03	0.45
3a	1	0.5	0	1.07	0.67	1.93	6.64	2.58	1.50	–0.13	3.46	3.46	0.00	0.00
3b	1	0.5	0.1	1.12	0.68	1.90	6.53	2.50	1.44	–0.16	7.79	3.53	2.02	0.27
3c	1	0.5	0.2	1.20	0.69	1.91	6.42	2.41	1.39	–0.20	11.99	3.74	8.09	0.53
4a	1	1	0	1.20	0.68	1.81	6.60	2.21	1.28	–0.12	5.19	5.19	0.00	0.00
4b	1	1	1	1.23	0.69	1.80	6.52	2.17	1.27	–0.15	9.50	5.24	0.96	0.23
4c	1	1	0.2	1.27	0.70	1.81	6.45	2.13	1.25	–0.17	13.70	5.29	1.93	0.45

Notes: Per cent Δ is the percentage change in loss evaluated under the loss function with no exchange rate terms (loss functions 'a'). That is, percentage $\Delta = 100(1 - L^{nq}/L)$. $\tilde{\pi}$ is the inflation equivalent measure such that the central bank is indifferent between loss function a and the loss function with the exchange rate argument; that is, $\tilde{\pi} = \sqrt{L - L^{nq}}$.

reduction in exchange rate volatility of about 13 per cent (the standard deviation of the exchange rate falls from 2.98 to 2.62). However, the volatility of the other arguments changes such that the central bank is indifferent between implementing the optimal policy plus an additional 0.31 percentage points of inflation in every period, or implementing the policy that optimises the loss function with the exchange rate argument. Jensen (2002) and Dennis and Söderström (2006) use the 'inflation-equivalent' to measure the benefits of commitment policy relative to discretion.

The analytical results for West's theoretical model are presented in the top section of the table. Under this model, increasing the weight on exchange rate stabilisation from 0 to 0.1 (moving from the first, to the second row of the table) leaves both inflation and output volatility relatively constant, but increases interest rate volatility since the interest rate now responses to the exchange rate ($\gamma_q = -0.2$). This reduces exchange rate volatility at very little cost since the model is so forward-looking: the volatility of both output and inflation are mostly determined by the size of the shocks to the inflation and output equations. The volatility of the exchange rate (as measured by the standard deviation) falls by 12 per cent (from 2.98 to 2.62) with a concomitant percentage increase in loss of 6.99.

As the weight placed on exchange rate stabilisation increases, the response to the inflation and the output gap remain unchanged, but the central bank responds more aggressively to movements in the real exchange rate. The central bank decreases the nominal interest rate by 40 basis points in response to a positive 1 per cent deviation of the exchange rate relative to trend. This again reduces the standard deviation of the real exchange rate (by approximately 27 per cent) in return for particularly small increases in the volatility of inflation, but large increases in the volatility of the interest rate. Relative to the loss function in row la, the percentage reduction in loss is 21 per cent. Now, the central bank requires an inflation equivalent measure of 0.55-inflation percentage points.

The remainder of the top third of the table repeats the experiment of incrementally adding an exchange rate argument with different weights on output and interest rate stabilisation. Similar results accrue. Most noticeably, the volatility inflation of inflation changes only marginally (actually obscured by rounding to two decimal places). This is driven by the assumption that the new-Keynesian model is forward-looking, an unrealistic assumption revealed in the failure of the model to match the data in Figure 1. Better informed policy advice must surely be obtained from models with more persistence that can better match the observed persistence in the data. The second and third sections of the table address these models.

For West's empirical model, stabilising the economy is easier relative to the theoretical Keynesian model: throughout the table, the loss evaluated under this model is lower under the forward-looking model. This is because the size of the shocks, determined by the VAR (l) representation in Section II(ii), are much smaller than the shocks in the theoretical Keynesian model. The first row of section 2 of the table shows that the optimal rule responds more aggressively towards both inflation and output. The response coefficient on the real exchange rate is higher, a direct function of the smaller volatility of the real exchange rate in this model.

When an exchange rate argument is added to the model, the volatility of the real exchange rate falls and is actually associated with a reduction in inflation volatility since our calculations show the real exchange rate and inflation are correlated. The volatility of output and the interest rate increases and the small reduction in exchange rate volatility of just over 4 per cent is associated with a percentage increase in loss of less than 1 per cent. Furthermore, the inflation equivalent measure is 0.07 percentage points. However, these small values are associated with only a small fall in the volatility of the exchange rate. If we multiply both the percent fall in exchange rate volatility and the inflation equivalent measure by the same constant that returns the fall in exchange rate volatility in the equivalent loss function in the first section of the table, the inflation equivalent measure is much higher, 0.24 percentage points.

Similar results obtain when real exchange rate arguments are appended to loss functions with a higher weight on interest rate and output stabilisation. For example, moving from loss function 3a to 3b, reduces exchange rate volatility by just under 3.5 per cent with an inflation equivalent measure of 0.07 percentage points. Assuming a linear increase in volatilities a decrease in exchange rate volatility of 13 per cent, would be associated with an inflation equivalent measure of about 0.28 percentage points on inflation. Interestingly, the policy rule responds particularly aggressively to the output gap when the weight on output stabilisation increases under the West empirical new-Keynesian model.

The third section of the table shows the variant of the small RBA model that simplifies Beechey *et al.* (2000). Within this model, the costs of stabilising the exchange rate are relatively large. The first two rows of the last section of the table show that decreasing a 2.26 per cent decrease in loss that is associated with an inflation equivalent measure of 0.28 percentage points of inflation. To obtain a decrease in exchange rate volatility of 13 per cent, as is the case in the standard new-Keynesian model in the first two rows of the first section of the table, there is a percentage increase in the loss of about 16 per cent.

Similar trade-offs accrue across the other loss function specifications. The average decrease in exchange rate volatility is 1.5 per cent, which is associated with an average increase in loss of 1.6 per cent, as measured by the increase in inflation, output and interest rate volatility. Larger decreases in exchange rate volatility can be obtained simply by increasing the weight on exchange rate stabilisation in the loss function.

To summarise these results, both West's empirical new-Keynesian model and the simplified RBA model suggest stabilising the exchange rate is costly in terms of other macroeconomic objectives. Since section 2 finds relatively limited support for a forward-looking specification with low costs to mitigating exchange rate volatility, policymakers should infer that exchange rate stabilisation is particularly costly for the case of Australia.

IV Conclusion

This paper explores the effectiveness of stabilising the real exchange rate under inflation targeting. Central banks may desire exchange rate stability – above and beyond the role of exchange rate movements in determining inflation – to fulfil legislated objectives, for reasons of political economy and to reduce uncertainty for the plans of firms and households within the economy.

We show that under a forward-looking new-Keynesian model, exchange rate volatility can be reduced with comparatively little cost in terms of the volatility of inflation and output, a fall in exchange rate volatility of about 13 per cent comes with an increase in the volatility of output, inflation and the interest rate of just over 6 per cent. The central bank must respond relatively aggressively to the real exchange rate to reduce volatility in the exchange rate.

When the forward-looking model is appended with correlated errors determined by the data, the costs to mitigating exchange rate volatility fall somewhat: a 4 per cent decrease in the standard deviation of the exchange rate is associated with a less than 1 per cent fall in macroeconomic volatility of the other variables in aggregate. This is partly because the standard deviation of inflation actually decreases.

An alternative backward-looking representation of the Australian economy, suggests higher costs to reducing exchange rate volatility: adding a small weight on exchange rate stabilisation, on average generates a 1.5 per cent fall in exchange rate volatility that comes with an average increase in loss of 1.6 per cent. These measures results in an inflation-equivalent measure of about 25 basis points of additional inflation in every period. In this model, the central bank needs to reduce interest rates relatively aggressively when the exchange rate is overvalued relative to trend, and respond less aggressively to output and inflation, to achieve lower exchange rate volatility.

Thus, within models that best fit Australian data there appears to be a large concomitant increases in macroeconomic volatility from mitigating exchange rate volatility. Inflation targeting central banks should proceed with caution when attempting to mitigate movements in the exchange rate. At the very least, central banks should have a strong understanding of how exchange rate volatility maps into some measure of social welfare if attempting to control exchange rate variability.

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A Data Appendix

Variable	Series	Source	Identifier
y_t	Gross Domestic Product	RBA website	GGDPCVGDP
π_t	Consumer Price Inflation	RBA website	GCPIAGQP
q_t	Real Exchange Rate	IFS	Q193L00REC.Q
i_t	Ninety Day Nominal Interest Rate	RBA website	FIRMMBAB90
y_t^*	US Gross Domestic Product	FRED II website	GDPC1
π_t^*	US Consumer Price Index	FRED II website	CPIAUCNS
i_t^*	Effective US Federal Funds Rate	FRED II website	FEDFUNDS

Notes: Reserve Bank of Australia (RBA) website: http://www.rba.gov.au/Statistics/. FRED II website: http://research.stlouisfed.org/fred2/. IFS: International Financial Statistics Database.