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A New Keynesian Perspective of Monetary Policy Implementation in Australia

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ABSTRACT

We estimate a structural VAR (SVAR) for the Australian economy based on an open economy New Keynesian macro model. The identification of the rational expectations SVAR is achieved by placing exclusion restrictions on the VAR residuals and the covariance matrix. The full information maximum likelihood parameter estimates of the model suggest that the New Keynesian specification fits the Australian data well, and the Reserve Bank of Australia (RBA) has a short-run focus on stabilising the output fluctuations while maintaining a medium-run inflation target since 1984. We simulate the dynamic responses of the output gap, inflation, exchange rate, and interest rate to an exogenous monetary policy shock. The results are clear of the price and exchange rate puzzles, which further supports the relevance of the New Keynesian model to the Australian economy. The impulse response functions for an exchange rate shock and for an aggregate demand shock suggest that the RBA is primarily concerned about the effects of the exchange rate fluctuations on inflation and output in the short run.

JEL CLASSIFICATION:
KEYWORDS:

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CONTENTS

1. Introduction

The conduct and impact of monetary policy both in a closed and an open economy framework have received immense attention in the literature. While there is consensus that monetary policy has a significant influence on the real economy in the short run, there is much debate on the quantitative effects on the dynamics of output gap, inflation, exchange rate, interest rate, etc. One popular tool is structural vector autoregression (SVAR) which provides simulations of dynamic responses of macro variables to particular structural shocks. Using an appropriate monetary policy instrument, SVAR models can be used to gauge the adequacy of the theoretical model to an unexpected monetary policy shock.

Generally SVAR models are identified with a set of restrictions that are broadly consistent with economic theory. The identifying assumptions are checked against sensible dynamic responses (Hall (1995)). In recent Australian literature, Brischetto and Voss (1999) adopt the contemporaneous structural relationships proposed by Kim and Roubini (2000). Dungey and Pagan (2000) develop a block-recursive structural model with eleven variables. None of these papers identify SVAR models from a fully specified macro model, and so this paper attempts a remedy using a particular macro model.[1,2]

A small open economy New Keynesian macro model is employed to analyse monetary policy in Australia, carefully specifying the interactions between the exogenous structural shocks and the behaviour of both the monetary authority and private agents. The New Keynesian approach has received much attention in recent times due to its emphasis on the behaviour of intertemporally optimising agents and the incorporation of nominal rigidities. The aggregate relationships commonly used in the framework are derived from dynamic general equilibrium models. The monetary authority

[1] Some examples that apply this strategy to other datasets are Gali (1992), Dhrymes and Thomakos (1998), Garratt et al (1998), and Leeper and Zha (2000).

[2] Huh (1999) identifies a SVAR model from a static Mundell-Fleming model for Australia, however, the study imposes short-run and long-run restrictions. We focus only on short-run restrictions in this paper.

and private agents are both assumed to be rational and forward-looking. The structural model comprises a dynamic aggregate demand (IS) equation based on representative agent utility maximisation, an aggregate supply (AS) equation based on Calvo's (1983) staggered price setting, uncovered interest rate parity, and a forward-looking monetary policy rule.

We estimate a SVAR model by appending the contemporaneous structure implied by the New Keynesian model with unrestricted short-run dynamics. The monetary authority and private agents are assumed to face the same information set in forming future expectations on any macro variables. To identify the SVAR model under rational expectations, we estimate "deep"[3] structural parameters using the methodology proposed by Keating (1990). Deep structural parameters come from utility functions and technological constraints of economic agents in the economy. Their identification is desirable because they are invariant to shifts in policy. Instead of relying on cross-equation restrictions that often render an overly restrictive lag dynamics, the identification of deep structural parameters in this model requires restrictions to be placed on the VAR residuals and the covariance matrix; while leaving the lag dynamics unrestricted. Dhrymes and Thomakos (1998) follow a similar procedure using exclusion restrictions on a small open economy model.[4] The paper differs from ours in three respects: the open economy structural model is not based on intertemporal optimisation, the method for solving rational expectations is different, and no other restrictions are imposed on the exogenous variables.

The SVAR model is estimated by full-information maximum likelihood. The New Keynesian SVAR model allows us to evaluate whether the intertemporal optimising structure with nominal rigidities fits the Australian data well. The relevance of the New Keynesian model is further examined by checking whether the dynamic responses of the macro variables match a priori theoretical predictions.

We find that the New Keynesian SVAR model fits the Australian data quite well. We are able to obtain similar results compared with other single-equation studies while the full-system estimation has the advantage of allowing for interactions among the different economic agents: consumers, firms and the monetary authority. The parameter estimates indicate that the inflation dynamics in Australia are mainly backward-looking, which is in line with Gruen et al's (1999) finding. The monetary policy rule suggests that the RBA has been stabilising inflation and output fluctuations since 1984. Interestingly, the coefficient on output gap suggests that the RBA places a somewhat larger weight on tackling the real economy than pursuing the target inflation.

We simulate the dynamic responses of the macro variables subject to an exogenous monetary tightening. In the short run, we find that an exogenous monetary tightening has significantly contractionary effects on the output gap and inflation. The relatively higher domestic interest rate pressures the exchange rate to appreciate on impact. The exchange rate depreciates immediately after the initial appreciation, however, we observe over-depreciation which results in the medium-run value staying above its initial level. This is in contrast to the persistent appreciation documented by Eichenbaum and Evans (1995) and Grilli and Roubini (1995). The absence of the price and exchange rate puzzles lends further support to the relevance of the New Keynsian model to the Australian economy.

The impulse response functions for an exchange rate shock and for an aggregate demand shock both highlight the importance of the exchange rate fluctuations to the monetary authority in the short run. The RBA reacts swiftly and strongly to an exchange rate depreciation shock even though the nominal exchange rate is not an explicit consideration in the monetary policy rule. Large exchange rate fluctuations may have detrimental effects indirectly on the real output through expenditure-switching effect and on the inflation through pass-through effect. When the economy experiences an aggregate demand shock, this causes a large and sustained nominal exchange rate appreciation. The RBA seems to focus mainly on controlling the exchange rate adjustment. The exchange rate thus acts as an instrument to correct the output gap fluctuations in the short run and has a stabilising effect on the inflation fluctuations in the medium run.

[3] This term appears in Lucas and Sargent (1981).

[4] The main aim of their paper is to examine the empirical appropriateness of forward-looking and backward-looking expectations.

The paper is organised as follows. Section 2 discusses related literature. Section 3 lays out the New Keynesian specification of the macroeconomy. In section 4 we discuss the rational expectations identification scheme. Section 5 describes the Australian data used in estimation. Section 6 presents the empirical results. First we show the preliminary diagnostic tests of the underlying VAR. Second we perform a bootstrapping exercise to ascertain the small sample likelihood ratio (LR) test statistic. Third the structural estimates and the fit of predicted variable values to actual values are examined. Fourth we look at the dynamic responses and finally report the forecast error variance decomposition. Section 7 concludes.

2. Related Literature

2.1 *Identification of Monetary Policy by SVAR Models*

The empirical SVAR literature on the transmission mechanism of monetary policy has evolved around various kinds of identifying assumptions that yield dynamic responses comparable to theoretical predictions. Early studies rely on the contemporaneous macro relationships being ordered according to the Wold causal chain. In Sims (1986) and Leeper and Gordon (1992) money supply innovations are modelled as unanticipated monetary policy shocks, and the results show an anomaly of a positive response from nominal interest rates to an expansion in monetary aggregates. This liquidity effect puzzle directly contravenes the widespread view that the short-term interest rate is the primary channel through which the monetary policy transmission mechanism works in the short-run.[5]

Using a series of measures, Bernanke and Blinder (1992) conclude that the federal funds rate is a good indicator of US monetary policy. This lends some support towards regarding nominal interest rates more relevant than monetary aggregates for understanding monetary policy. Sims (1986) re-estimates the SVAR model by using positive interest rate innovations to represent monetary policy tightening, and the result shows the anticipated contraction in monetary aggregates. The price level behaves strangely, however, as it rises in response to positive interest rate innovations. Sims (1992) subsequently expands the number of countries and the variable list to include the exchange rate and commodity price index, since monetary authorities might track them for signs of future inflationary pressure. A similar comparison of the generated dynamic responses is made between the money supply and interest rate innovations. The interest rate emerges as the preferred indicator of monetary policy stance because it eliminates the liquidity puzzle and monetary tightening still consistently curtails the real economic activity. Such monetary tightening, however, leads to the same anomalous price response and an anomalous impact depreciation of the nominal exchange rate.

Sims (1992) argues that the observed price and exchange rate puzzles reflect the endogenous behaviour of monetary policy reacting to future inflation. The monetary authority moves in a pre-emptive fashion to dampen any imminent inflationary pressures signalled by the movements in commodity prices, hence diminishing the magnitude of increase in prices. Private agents observe the pre-emptive policy measure and adjust their actions accordingly, which results in the nominal exchange rate depreciation. To be more concrete, Sims re-estimates the structural system without exchange rate and commodity prices, and shows that the effect of the price puzzle is consistently larger across countries than the effect that is observed when both variables are included. This leads to the conclusion that the exchange rate and commodity prices are significant information variables that influence the endogenous behaviour of the interest rates. But the fact that the empirical puzzles are not completely resolved points to other aspects of the identifying assumptions that need to be examined. Zha (1997) argues that the popular Cholesky structure precludes important simultaneous feedbacks. In explaining the liquidity puzzle, the interest rate does not have a contemporaneous impact on monetary aggregates, although a feedback is permitted (Leeper and Gordon (1992) and Gordon and Leeper (1994)). This sets up a perfectly inelastic money supply function with respect to interest rate. This is highly unrealistic as most monetary authorities target the interest rate by directly intervening in overnight cash markets, such simultaneity must be allowed to produce sensible policy analysis. Further, in these models, the

[5] See Reichenstein (1987) for a review on single-equation studies of the liquidity effect.

interest rate is ordered prior to all other macro variables which means there is no contemporaneous influence coming from prices, exchange rate, and commodity prices (Sims (1992)). This is also unsatisfactory since monetary authorities in small open economies are likely to respond quickly to exchange rate fluctuations. If those variables are relevant to the monetary authority's information set, they should be included in the variable list; the simultaneous feedback must also be introduced.

For the closed economy, Gali (1992) estimates an IS-LM-AS model which distinguishes between the money demand and supply equations. The study finds no sign of liquidity and price puzzles. Other authors (Eichenbaum (1992), Gordon and Leeper (1994), Bernanke and Mihov (1995), Strongin (1995)) emphasise the need to model the demand and supply of the reserves market, where the monetary authority has the most direct control. They suggest using narrow monetary aggregates (such as non-borrowed reserves) to proxy for the monetary policy.

In open economy studies, Cushman and Zha (1997) model the money demand and supply equations separately, thus distinguishing between the behaviour of the private sector and the monetary authority. In the money supply equation, the interest rate responds contemporaneously to the exchange rate, money stock (M1), foreign interest rate, and commodity prices. The structural identification scheme includes an explicit trade sector. Kim and Roubini (2000) follow the same line of identification scheme without the trade sector. In the monetary policy reaction rule, they exclude the foreign interest rate on the ground that the monetary authority is more sensitive towards exchange rate fluctuations than foreign interest rate fluctuations. All puzzles disappear in both studies.

In Australia, Brischetto and Voss (1999) and Dungey and Pagan (2000) both obtain sensible results even though they exclude monetary aggregates and oil prices in the structural model. Brischetto and Voss adopt the Kim-Roubini identification scheme but find it necessary to include the foreign interest rate in the monetary policy equation. This is because the exclusion of foreign interest rate yields a rise in output and price, and an impact depreciation of the nominal exchange rate in the event of an unanticipated interest rate tightening. In contrast Dungey and Pagan define a Taylor-rule type of monetary policy equation in which the interest rate responds contemporaneously to changes in inflation and gross national expenditure. The omission of oil prices is justified on the grounds that the interest rate and exchange rate seem to be competent predictors of future inflation with oil prices adding very little information. The absence of monetary aggregates in the model helps to avoid problems associated with money demand instability.[6] This lends support to the New Keynesian specification where money plays no role and the monetary authority is forward-looking by generating model-consistent future expectations.

2.2 *Treatments of Foreign Sector*

When the SVAR model is extended to small open economy studies, some foreign variables are included to reflect the interactions between the domestic and world economies. The usual assumption is that the domestic economy has no influence on the external sector, hence foreign variables are treated as exogenous to domestic variables. In Brischetto and Voss (1999) and Kim and Roubini (2000), the external sector is represented by the oil prices and federal funds rate. None of the domestic variables enters into the oil price and federal funds rate equations contemporaneously. However, there is still delayed feedback through the lag values of the domestic variables.

Cushman and Zha (1997) and Dungey and Pagan (2000) both assume the foreign sector is block-exogenous to the domestic sector. The rationale stems from the assumption that small open economies have no influence on the rest of the world. Hence, there are no contemporaneous and lagged domestic variables in the foreign block. The Kim-Roubini identification scheme allows for delayed feedback between domestic and foreign variables; that link is completely severed when block-exogeneity is imposed on the structural system.

In the previous two identification schemes, foreign variables are part of the endogenous variable vector. The feature of exogeneity is manifested

[6] In Australia, the relationship between monetary aggregates and nominal output broke down in the 1980s. Using cointegration tests, de Brouwer et al (1993) conclude that a stable long-run relationship between money, income and interest rates is elusive.

through the presence of either contemporaneous exogeneity or block exogeneity. Dhrymes and Thomakos (1998) treat SVAR as a special case of simultaneous equations estimation. The authors base the SVAR model on an explicit open economy macro model. The contemporaneous exclusions and normalisations placed on the contemporaneous system for both the domestic and foreign variables are dictated by the structural relationships in the macro model. The structural model may be written as:

$$\Gamma_0 y_t = \Lambda_0 z_t + \varepsilon_t \tag{1}$$

where y_t is the vector of endogenous (domestic) variables with Γ_0 containing the contemporaneous parameters,[7] z_t is the vector of exogenous (generally foreign) variables with Λ_0 containing the contemporaneous parameters, and ε_t is the vector of structural disturbances. Short run dynamics are appended for SVAR estimation and the dynamic structural system is

$$\Gamma(L) y_t = \Lambda(L) z_t + \varepsilon_t \tag{2}$$

where $\Gamma(L) = \Gamma_0 - \Gamma_1 L - \cdots - \Gamma_q L^q$ and $\Lambda(L) = \Lambda_0 + \Lambda_1 L + \cdots + \Lambda_k L^k$.

3. Theoretical Model

We describe a small open economy New Keynesian model for analysing the Australian economy. The aggregate relationships commonly used are derived from dynamic general equilibrium models, with agents assumed to be rational and forward-looking. The set of macroeconomic relations are characterised by the following system of equations: the IS equation, the AS equation, uncovered interest rate parity, and a forward-looking monetary policy rule.

3.1 *IS Equation*

The derivation of the open economy IS equation is based on the aggregate demand specification described in McCallum and Nelson (1999a, 2000). A small open economy is populated by a continuum of households over (0,1). In an infinite horizon setting, a representative household maximises a lifetime utility function involving consumption and real money balances:

$$E_t \sum_{j=0}^{\infty} \beta^j \left[\left(\frac{\sigma}{\sigma - 1} \right) C_{t+j}^{\sigma-1/\sigma} + \left(\frac{1}{1-\gamma} \right) \left(\frac{M_{t+j}}{P_{t+j}} \right)^{1-\gamma} \right] \tag{3}$$

with $\sigma > 0$, $\gamma > 0$, $\sigma \neq 1$, $\gamma \neq 1$, and $\beta \in (0,1)$. Each household consumes solely domestically produced goods that are differentiated from each other. The consumption variable that appears in (3) is an index which is constructed as a Dixit-Stiglitz aggregate:

$$C_t = \left[\int_0^1 C_t(z)^{\theta - 1/\theta} dz \right]^{\theta/\theta-1} \tag{4}$$

where $C_t(z)$ denotes the household's period t consumption of good z and $\theta > 1$. The corresponding aggregate price index is

$$P_t = \left[\int_0^1 P_t(z)^{1-\theta} dz \right]^{1/1-\theta} \tag{5}$$

where $P_t(z)$ denotes the price of good z. M_t/P_t is the end-of-period real money holdings and E_t represents the expectations formed on the basis of available information in period t.

The representative household specialises in production using the following CES technology involving labour and imported intermediate goods:

$$Y_t = \left[\alpha \left(A_t N_t \right)^{\upsilon} + \left(1 - \alpha \right) \left(IM_t \right)^{\upsilon} \right]^{1/\upsilon} \tag{6}$$

with $\alpha \in (0,1]$ and $\upsilon \in (-\infty, \infty)$. In equation (6), Y_t is the current level of output,[8] A_t is an exogenous technology shock entering all households' production functions, N_t is the amount of labour hired by the household, and IM_t is the quantity of foreign-produced good purchased by the household which is used as an input in production. Each household is a monopolistic producer that chooses its good's price $P_t(z)$ while taking the aggregate price

[7] y_t is utilised in this paper in two ways: it is defined as a vector of endogenous variables in sections 2.2, 4.2.1, and 4.2.2; it is defined as the log of aggregate output in section 3.1.

[8] Y_t is utilised in in this paper in two ways: it is defined as the level of current period aggregate output in section 3.1; it is defined as a stacked coefficient matrix in sections 4.2.1 and 4.2.2.

level P_t, the nominal exchange rate S_t, and the foreign price level P_t^* as given. S_t is expressed as domestic currency per unit of foreign currency and P_t^* can be regarded as the foreign-currency price of a single foreign good. The household faces demand domestically and from the rest of the world (to which it exports its good) denoted by D_t and EX_t respectively. As the household may not price-discriminate between domestic and foreign buyers, the price it sells overseas is (P_t/S_t). The domestic economy's aggregate exports are assumed to form an insignificant portion of foreigners' consumption, and thus their weight in the foreign economy's aggregate price index is negligible. This is one way of characterising a small open economy at home.

Labour is immobile across countries and each household is endowed with one unit of potential work-time each period, which it supplies inelastically to the domestic labour market. Households in each country have access to a private security market where bonds are denominated in units of its own output. Domestic households may sell or purchase a domestic bond, denoted by B_t, for $(1+r_t)^{-1}$ units of output in period t, which is redeemed for one unit of domestic output in period t+1. r_t stands for the domestic real rate of interest. Foreigners sell or purchase only a bond denominated in their own output, denoted by B_{t+1}^*, which they may purchase for $(1+r_t^*)^{-1}$ units of foreign output and is redeemed for one unit of foreign output one period later. The domestic household can also purchase a foreign bond. The price that domestic households need to pay to purchase foreign bonds (expressed in foreign output units), however, is $(1+\kappa_t)^{-1}(1+r_t^*)^{-1}$. r_t^* and κ_t stand for the foreign real rate of interest and a random risk-premium term.

The home government runs a balanced budget and the seigniorage revenue is transferred to the household as a lump sum denoted by TR_t:

$$TR_t = \frac{M_t - M_{t-1}}{P_t} \tag{7}$$

The budget constraint for the household in real terms is

$$\begin{aligned} &\frac{P_t(z)D_t}{P_t} + \frac{P_t(z)EX_t}{P_t} + \frac{W_t N_t^s}{P_t} + TR_t + \frac{M_{t-1}}{P_t} + B_t + Q_t B_t^* \\ &= C_t + \frac{W_t N_t}{P_t} + \frac{M_t}{P_t} + Q_t IM_t + \frac{B_{t+1}}{1+r_t} + \frac{Q_t B_{t+1}^*}{(1+\kappa_t)(1+r_t^*)} \end{aligned} \tag{8}$$

where W_t is the nominal wage, $Q_t \equiv (S_t P_t^*/P_t)$ is the real exchange rate, N_t^s and N_t denote the labour supply and demand respectively.

Let ξ_t denote the Lagrange multiplier on constraint (6) and λ_t the multiplier on constraint (8). Then the household's first order conditions with respect to C_t, B_{t+1}, B_{t+1}^*, N_t, and IM_t are[9,10]

$$C_t^{-1/\sigma} - \lambda_t = 0 \tag{9}$$

$$\lambda_t = \beta(1+r_t)E_t\lambda_{t+1} \tag{10}$$

$$Q_t\lambda_t = \beta(1+\kappa_t)(1+r_t^*)E_t Q_{t+1}\lambda_{t+1} \tag{11}$$

$$\left[\left(\frac{\lambda_t}{\xi_t}\right)\left(\frac{W_t}{P_t}\right)\right]^{1/(1-\upsilon)} = \alpha^{1/(1-\upsilon)} A_t^{\upsilon/(1-\upsilon)}\left(\frac{Y_t}{N_t}\right) \tag{12}$$

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[9] We omit the presentation of the first order condition with respect to M_t since money plays no role in the New Keynesian macro model. The optimising money demand equation can be derived, however, by combining M_t's first order condition:

$$(M_t/P_t)^{-\gamma} + \lambda_t E_t\left[(1+r_t)^{-1}(P_t/P_{t+1}) - 1\right] = 0$$

with (10). Therefore the money demand equation is

$$M_t/P_t = \left[C_t^{1/\sigma}(1+i_t/i_t)\right]^{1/\gamma}$$

which simply determines the values of M_t that are needed to implement the interest-rate policy rule.

[10] The transversality conditions pertaining to the household accumulation of bonds and money are assumed to hold. In equilibrium, the market clearing conditions for the bond market, $B_{t+1} = 0$, and the labour market, $N_t = N_t^s = 1$, must be satisfied.

$$\left[\left(\frac{\lambda_t}{\xi_t}\right)Q_t\right]^{1/1-\upsilon} = (1-\alpha)^{1/1-\upsilon}\left(\frac{Y_t}{IM_t}\right) \tag{13}$$

Substituting (10) into (9) and taking logs give us the first order condition for consumption over time:

$$c_t = E_t c_{t+1} - \sigma \ln \beta - \sigma \ln(1+r_t) \tag{14}$$

or

$$c_t = E_t c_{t+1} + d_0 - d_1 r_t \tag{15}$$

where $d_0 = -\sigma \ln\beta$, $d_1 = \sigma$, and lowercase variables denote the logarithmic counterparts of the uppercase variables.

Taking logs of (13) renders the following cost-minimising import demand:

$$im_t = y_t - \left(\frac{1}{1-\upsilon}\right)q_t - \left(\frac{1}{1-\upsilon}\right)\ln\left(\frac{\lambda_t}{\xi_t}\right) + \left(\frac{1}{1-\upsilon}\right)\ln(1-\alpha) \tag{16}$$

or

$$im_t = y_t - \varphi q_t + \mu \tag{17}$$

where $\varphi = 1/(1-\upsilon)$ is the elasticity of substitution between imported raw materials and labour, and $\mu = 1/(1-\upsilon)[\ln(1-\alpha) - \ln(\lambda_t/\xi_t)]$. Symmetrically, we assume the export demand is given as:

$$ex_t = y_t^* + \varphi^* q_t \tag{18}$$

We now consider the flexible-price natural level of output. Taking a log-linear approximation of the home-country production function (6):

$$\bar{y}_t = (1-\delta)a_t + \delta i\bar{m}_t \tag{19}$$

with $\delta \equiv (1-\alpha)(I\bar{M}^{ss}/\bar{Y}^{ss})^{\upsilon}$, and ss denotes the steady-state values.[11] $\bar{y}_t$ is the natural level of output and $i\bar{m}_t$ is the level of imports under price flexibility.

[11] The labour market clearing condition, $N_t = 1$, applies for all t at the natural level of output. This implies that $n_t = 0$.

Under price flexibility, (λ_t/ξ_t) is a constant and equal to $\theta/(\theta-1)$.[12] Thus (17) implies that, neglecting the constant intercept term, the value of $i\bar{m}_t$, conditional on the value of the real exchange rate, is given by:

$$i\bar{m}_t = \bar{y}_t - \varphi q_t \tag{20}$$

Then (19) and (20) together imply that:

$$\bar{y}_t = a_t - \varpi q_t \tag{21}$$

where $\varpi = [\varphi\delta/(1-\delta)]$. Equation (21) indicates that the flexible price level of log output, $\bar{y}_t$, is a function of both the technology shock and the real exchange rate. With an imported intermediate good, a real exchange rate depreciation reduces the amount of imports and thus output.

As in McCallum and Nelson (1999a), we maintain the assumption that investment and capital are exogenous, and abstracting from government expenditure in the analysis. Then the goods market clearing condition is

$$y_t = \omega_1 c_t + \omega_2 ex_t \tag{22}$$

where ω_1 and ω_2 are steady-state ratios of consumption and exports to output respectively. Define output gap as the difference between actual output and potential output, $x_t = y_t - \bar{y}_t$. Substituting (15) and (18) into (22) and using the definition for output gap with (21) gives:

$$x_t = \alpha_0 + E_t x_{t+1} - \alpha_1(i_t - E_t\pi_{t+1}) + \alpha_2(s_t + p_t^* - p_t) + \varepsilon_t^x \tag{23}$$

with $\alpha_0 = d_0\omega_1$, $\alpha_1 = d_1\omega_1$, $\alpha_2 = \varpi + \omega_2\varphi^*$, and $\varepsilon_t^x = E_t\bar{y}_{t+1} - a_t + \omega_2(y_t^* - E_t ex_{t+1})$.

The real interest rate is represented by $r_t = i_t - E_t\pi_{t+1}$, where i_t is the nominal interest rate and $\pi_{t+1} = p_{t+1} - p_t$ is the inflation rate; the real exchange rate is represented by $q_t = s_t + p_t^* - p_t$.

Equation (23) is the forward-looking IS curve that describes the demand side of the economy. ε_t^x is interpreted as an aggregate demand shock to the

[12] Equations (12) and (13) indicate that, in a symmetric equilibrium and under price flexibility, the aggregate markup, given by (λ_t/ξ_t), is constant and equal to $(\theta/\theta-1)$.

economy. The main difference from the traditional IS curve is the dependence of current output level on expected future output level. This additional term, $E_t x_{t+1}$, raises current output level given a higher anticipated future output level, because individuals desire to achieve a balanced consumption portfolio. Individuals anticipate a higher level of consumption next period due to expected higher output, this induces consumers to spend more today to smooth out the consumption path. The real interest rate effect is negative on current output level as it reflects the intertemporal substitution of consumption. A rise in real exchange rate (i.e. a real depreciation) is expected to boost the current output via expenditure switching effect.

3.2 *AS Equation*

The main theme in the New Keynesian framework regarding price adjustment is to combine nominal rigidities and the optimising behaviour of firms that produce forward-looking dynamics of inflation. The New Keynesian Phillips curve derived from Calvo's (1983) staggered nominal price setting model is given by

$$\pi_t = \beta_0 + \beta_1 E_t \pi_{t+1} + \beta_2 x_t + \varepsilon_t^{\pi} \tag{24}$$

In Calvo (1983), monopolistically competitive firms are allowed to adjust their prices infrequently according to a random probability. Each firm sets the price optimally by minimising a quadratic loss function that depends on the difference between the firm's actual price in period t and its optimal price, where the latter price denotes the profit-maximising price in the absence of any restrictions associated with price adjustment. ε_t^{π} is a random disturbance that captures the determinants of the optimal price other than the aggregate output and price level. A higher ε_t^{π} prompts the firms to adjust upwards the actual prices to minimise the adjustment cost, therefore ε_t^{π} is interpreted as an inflation shock. A key difference with the standard Phillips curve is that expected future inflation, $E_t \pi_{t+1}$, enters additively as opposed to expected current inflation, $E_{t-1} \pi_t$.

3.3 *Uncovered Interest Parity*

A standard feature in most open economy macro models is the inclusion of the uncovered interest parity. Using the definitions of the real interest rate and its foreign counterpart,[13] the following uncovered interest parity holds as a first-order approximation when (10) and (11) are combined:

$$s_t = E_t s_{t+1} - (i_t - i_t^*) + \varepsilon_t^s \tag{25}$$

where $\varepsilon_t^s = \kappa_t$ is the time-varying risk-premium that reflects temporary and persistent departures from uncovered interest parity.

3.4 *Forward-Looking Monetary Policy*

Finally the model is completed with the inclusion of a monetary policy rule:

$$i_t = \gamma_0 + \pi_t + \gamma_1 (E_t \pi_{t+1} - \pi^T) + \gamma_2 x_t + \varepsilon_t^i \tag{26}$$

where π^T is the target inflation rate and ε_t^i represents the monetary policy shock. Taylor (1993) proposes a simple feedback interest-rate setting rule, where the central bank reacts to inflation deviation from its target rate and output gap in a "leaning-against-the-wind" manner. The specification follows closely a forward-looking version of the simple Taylor rule that was outlined in Clarida (2001). Under the rule described by equation (26), the central bank responds to expected inflation as opposed to lagged inflation.

4. Econometric Methodology

4.1 *Rational Expectations Econometrics*

The Lucas critique undermines traditional procedures for econometric policy evaluation that did not allow expectations to adjust to policy shifts. When government policy rule changes, economic agents do update their expectations subject to the new environment they face, which are embedded in the structural model. This means that the estimated structural relations are

[13] The foreign real interest rate is defined as: $r_t^* = i_t^* - E_t \pi_{t+1}^*$, where i_t^* is the foreign nominal interest rate and $\pi_{t+1}^* = p_{t+1}^* - p_t^*$ is the foreign inflation rate.

poor guides for policy evaluation under the new regime. The implication is that one should estimate structurally stable, deep parameters which have the advantage of being invariant to shifts in policy.

One response is to estimate a structural rational expectations model. Private agents' optimising behaviour is combined with the complete knowledge of the structural parameters of the economy and the underlying stochastic forcing processes. Solutions to the dynamic rational expectations models yield restrictions across equations arising from the assumption of rational expectations and the structure embedded in the optimisation problem. These cross-equation restrictions identify the structural parameters in the model.[14] In Cho and Moreno (2002), the cross-equation restrictions from the rational expectations solutions yield a highly restrictive lag structure–the implied reduced form is equivalent to a VAR of order one.

Alternatively, structural VAR models typically consist of a contemporaneous model of broadly defined behavioural relationships and unrestricted short-run lag dynamics. Instead of using lag restrictions to identify the structural parameters, this paper adopts Keating's (1990) rational expectations identification scheme which takes full advantage of the features in the structural VAR model. The contemporaneous structural model described by (23) through (26) is converted into an equivalent representation that comprises structural disturbances and reduced form innovations. Private agents form future expectations using observable innovations that result from the dynamic structure of the economy. Therefore, the identification of deep parameters comes from the VAR residuals and restrictions on the covariance matrix of the structural disturbances.

4.2 *SVAR Identification Incorporating Rational Expectations*

4.2.1 *Closed Economy Model*

We start with a canonical closed economy model as described in Clarida et al (1999) that focuses on the output gap, inflation, and interest rate:

$$x_t = \alpha_0 + E_t x_{t+1} - \alpha_1 (i_t - E_t \pi_{t+1}) + \varepsilon_t^x \tag{27}$$

$$\pi_t = \beta_0 + \beta_1 E_t \pi_{t+1} + \beta_2 x_t + \varepsilon_t^\pi \tag{28}$$

$$i_t = \gamma_0 + \pi_t + \gamma_1 (E_t \pi_{t+1} - \pi^T) + \gamma_2 x_t + \varepsilon_t^i \tag{29}$$

We add short-run dynamics to the contemporaneous structure described by (27) through (29) and rewrite the dynamic structural model in matrix form:

$$\Gamma_0 y_t = \Gamma_1 y_{t-1} + \cdots + \Gamma_q y_{t-q} + \varepsilon_t, \quad \varepsilon_t \sim (0, D) \tag{30}$$

where $y_t = (x_t, \pi_t, i_t)'$ contains the endogenous variables, Γ_i are the coefficient matrices where q denotes the lag order, $\varepsilon_t = (\varepsilon_t^x, \varepsilon_t^\pi, \varepsilon_t^i)'$ is the vector of structural disturbances, 0 denotes a 3×1 vector of zeros, and D is the 3×3 diagonal variance-covariance matrix.

Premultiply equation (30) by Γ_0^{-1} renders the reduced form VAR:

$$y_t = A_1 y_{t-1} + \cdots + A_q y_{t-q} + e_t, \quad e_t \sim (0, \Omega) \tag{31}$$

where

$A_i = \Gamma_0^{-1} \Gamma_i, \; i = 1, \ldots, q$

$e_t = \Gamma_0^{-1} \varepsilon_t$

and $\Omega = \Gamma_0^{-1} D \Gamma_0^{-1\prime}$.

To see how the expectations of future values of the variables are imposed in a SVAR model setting, we rewrite the system (30) in terms of structural disturbances and VAR innovations, i.e. $\varepsilon_t = \Gamma_0 e_t$, by subtracting from each variable the expectation at time t–1 of that variable conditioned on all available past information:

$$\varepsilon_t^x = (x_t - E_{t-1} x_t) - (E_t x_{t+1} - E_{t-1} x_{t+1}) + \alpha_1 (i_t - E_{t-1} i_t) - \alpha_1 (E_t \pi_{t+1} - E_{t-1} \pi_{t+1}) \tag{32}$$

$$\varepsilon_t^\pi = (\pi_t - E_{t-1} \pi_t) - \beta_1 (E_t \pi_{t+1} - E_{t-1} \pi_{t+1}) - \beta_2 (x_t - E_{t-1} x_t) \tag{33}$$

$$\varepsilon_t^i = (i_t - E_{t-1} i_t) - (\pi_t - E_{t-1} \pi_t) - \gamma_1 (E_t \pi_{t+1} - E_{t-1} \pi_{t+1}) - \gamma_2 (x_t - E_{t-1} x_t) \tag{34}$$

[14] In a structural rational expectations model, the cross-equation restrictions typically result in over-identifications.

In (32) through (34), the current values of output gap, inflation, and interest rate innovations are represented by $(x_t - E_{t-1}x_t)$, $(\pi_t - E_{t-1}\pi_t)$, and $(i_t - E_{t-1}i_t)$ respectively. However, each structural disturbance is additionally related to one or both of the expectations revision processes of the output gap and inflation, i.e. $(E_t x_{t+1} - E_{t-1}x_{t+1})$ and $(E_t \pi_{t+1} - E_{t-1}\pi_{t+1})$. These two terms need to be calculated before estimation. First, the VAR (31) is expressed in stacked form in order to facilitate calculations:[15]

$$Y_t = AY_{t-1} + Qe_t \tag{35}$$

or equivalently

$$\begin{bmatrix} y_t \\ y_{t-1} \\ y_{t-2} \\ \vdots \\ y_{t-p+1} \end{bmatrix} = \begin{bmatrix} A_1 & A_2 & \dots & \dots & A_p \\ I_n & 0_n & \dots & \dots & 0_n \\ 0_n & I_n & 0_n & \dots & 0_n \\ \vdots & \ddots & \ddots & \ddots & \vdots \\ 0_n & \dots & 0_n & I_n & 0_n \end{bmatrix} \begin{bmatrix} y_{t-1} \\ y_{t-2} \\ y_{t-3} \\ \vdots \\ y_{t-p} \end{bmatrix} + \begin{bmatrix} I_n \\ 0_n \\ 0_n \\ \vdots \\ 0_n \end{bmatrix} e_t \tag{36}$$

where I_n and 0_n are $n \times n$ identity and zero matrices respectively with $n = 3$ being the number of endogenous variables.

The j-step conditional expectation of (35) is

$$E_t Y_{t+j} = (A)^j Y_t \tag{37}$$

To select the variables that the private agents are forecasting, the following vectors of length nq are created:

$$\begin{aligned} r_x' &= (1,0,0,\dots,0) \text{ for output gap} \\ r_\pi' &= (0,1,0,\dots,0) \text{ for inflation rate} \end{aligned} \tag{38}$$

The expected future values of the output gap and inflation are derived by premultiplying (37) for $j = 1$ by the vectors defined in (38) respectively:

$$\begin{aligned} E_t x_{t+1} &= r_x' A Y_t \\ E_t \pi_{t+1} &= r_\pi' A Y_t \end{aligned} \tag{39}$$

[15] Constants and deterministic variables are ignored since they do not affect expectations revisions.

The expectations revision processes are therefore the differences between (39) and expected value of (39) at time t–1, which by using (35) are

$$\begin{aligned} E_t x_{t+1} - E_{t-1}x_{t+1} &= r_x' A(Y_t - E_{t-1}Y_t) \\ &= r_x' AQe_t \\ E_t \pi_{t+1} - E_{t-1}\pi_{t+1} &= r_\pi' A(Y_t - E_{t-1}Y_t) \\ &= r_\pi' AQe_t \end{aligned} \tag{40}$$

Inserting (40) into the system of innovations described by (32) through (34):

$$\varepsilon_t^x = e_t^x - r_x' AQe_t + \alpha_1(e_t^i - r_\pi' AQe_t) \tag{41}$$

$$\varepsilon_t^\pi = e_t^\pi - \beta_1 r_\pi' AQe_t - \beta_2 e_t^x \tag{42}$$

$$\varepsilon_t^i = e_t^i - e_t^\pi - \gamma_1 r_\pi' AQe_t - \gamma_2 e_t^x \tag{43}$$

Compared to traditional SVAR methodology, the forward-looking behaviour embedded in (41) through (43) suggests nonlinear restrictions across the coefficients of each contemporaneous structural equation. The implication of this procedure is that by not accounting for the forward-looking behaviour, agents are assumed not to incorporate all relevant innovations in forecasting future expected values of variables. Take (42) as an example, the forecast of future inflation needs to be based on all observable innovations in the economy. A Phillips curve specification for (42) without the forward-looking component, $E_t \pi_{t+1}$, excludes the necessary interest rate innovation from the information set.

4.2.2 *Open Economy Model*

We now apply the same SVAR identification scheme under rational expectations to the open economy model laid out in section 3. The dynamic open economy structural model in matrix form is

$$\Gamma_0 y_t = \Gamma_1 y_{t-1} + \dots + \Gamma_q y_{t-q} + \Lambda_0 z_t + \Lambda_1 z_{t-1} + \dots + \Lambda_k z_{t-k} + \varepsilon_t, \quad \varepsilon_t \sim (0, D) \tag{44}$$

where $y_t = (x_t, \pi_t, s_t, i_t)'$ with the nominal exchange rate added to the vector of endogenous variables; $z_t = (p_t^*, i_t^*)'$ is the vector of exogenous variables; Γ_i and Λ_j are coefficient matrices for the endogenous and exogenous variables with lag order q and k respectively, $\varepsilon_t = (\varepsilon_t^x, \varepsilon_t^\pi, \varepsilon_t^s, \varepsilon_t^i)'$ includes the structural disturbance to the exchange rate, 0 is now a 4×1 vector of zeros, and D is a 4×4 diagonal variance-covariance matrix.

The corresponding reduced form is

$$y_t = A_1 y_{t-1} + \cdots + A_q y_{t-q} + B_0 z_t + B_1 z_{t-1} + \cdots + B_k z_{t-k} + e_t, \quad e_t \sim (0, \Omega) \tag{45}$$

where

$$A_i = \Gamma_0^{-1}\Gamma_i, \; i = 1, \ldots, q$$

$$B_j = \Gamma_0^{-1}\Lambda_j, \; j = 0, 1, \ldots, k$$

$$e_t = \Gamma_0^{-1}\varepsilon_t$$

and $\Omega = \Gamma_0^{-1} D \Gamma_0^{-1\prime}$.

The underlying VAR in (45) comprises the four endogenous variables and includes the current and lagged values of each exogenous variable, along with lags of each endogenous variable. The contemporaneous relationships ((23) through (26)) are expressed in terms of structural disturbances and VAR innovations. In the process of conversion, the innovations to the exogenous variables become factors inside the system of VAR innovations to the endogenous variables, hence the innovations representation contains only endogenous variable innovations:

$$\varepsilon_t^x = e_t^x - (E_t x_{t+1} - E_{t-1} x_{t+1}) + \alpha_1 e_t^i - \alpha_1 (E_t \pi_{t+1} - E_{t-1}\pi_{t+1}) - \alpha_2 (e_t^s - e_t^\pi / 400) \tag{46}$$

$$\varepsilon_t^\pi = e_t^\pi - \beta_1 (E_t \pi_{t+1} - E_{t-1}\pi_{t+1}) - \beta_2 e_t^x \tag{47}$$

$$\varepsilon_t^s = e_t^s - (E_t s_{t+1} - E_{t-1} s_{t+1}) + e_t^i \tag{48}$$

$$\varepsilon_t^i = e_t^i - e_t^\pi - \gamma_1 (E_t \pi_{t+1} - E_{t-1}\pi_{t+1}) - \gamma_2 e_t^x \tag{49}$$

where the price innovation is equal to inflation innovation over 400.[16]

Private agents are required to update their future expectations on the output gap, inflation, and exchange rate, i.e. $(E_t x_{t+1} - E_{t-1} x_{t+1})$, $(E_t \pi_{t+1} - E_{t-1}\pi_{t+1})$, and $(E_t s_{t+1} - E_{t-1} s_{t+1})$. We saw in the closed economy example that all observable innovations contribute towards updating future expectations. Since the exogenous variable innovations are subsumed within the innovations representation ((46) through (49)), we can effectively calculate the expectations revision processes through the VAR stacked form in (35), i.e. $Y_t = AY_{t-1} + Qe_t$, where A is the stacked coefficient matrix obtained from equation (45). With n = 4, the following vectors of length nq are created:

$$\begin{aligned} r_x' &= (1, 0, 0, \ldots, 0) \text{ for output gap} \\ r_\pi' &= (0, 1, 0, \ldots, 0) \text{ for inflation rate} \\ r_s' &= (0, 0, 1, \ldots, 0) \text{ for exchange rate} \end{aligned} \tag{50}$$

The expectations revision processes are thus defined as:

$$\begin{aligned} (E_t x_{t+1} - E_{t-1} x_{t+1}) &= r_x' A Q e_t \\ (E_t \pi_{t+1} - E_{t-1}\pi_{t+1}) &= r_\pi' A Q e_t \\ (E_t s_{t+1} - E_{t-1} s_{t+1}) &= r_s' A Q e_t \end{aligned} \tag{51}$$

Apply the definitions in (51) to the innovations system ((46) through (49)):

$$\varepsilon_t^x = e_t^x - r_x' A Q e_t + \alpha_1 (e_t^i - r_\pi' A Q e_t) - \alpha_2 (e_t^s - e_t^\pi / 400) \tag{52}$$

$$\varepsilon_t^\pi = e_t^\pi - \beta_1 r_\pi' A Q e_t - \beta_2 e_t^x \tag{53}$$

$$\varepsilon_t^s = e_t^s - r_s' A Q e_t + e_t^i \tag{54}$$

$$\varepsilon_t^i = e_t^i - e_t^\pi - \gamma_1 r_\pi' A Q e_t - \gamma_2 e_t^x \tag{55}$$

4.3 *Full Information Maximum Likelihood Estimation (FIML)*

[16] Quarterly inflation is calculated on an annualised basis, and so $\pi_t = 400(p_t - p_{t-1})$. The inflation innovation is derived by subtracting $E_{t-1}\pi_t$ away from π_t, i.e. $\pi_t - E_{t-1}\pi_t = 400(p_t - E_{t-1}p_t)$. Therefore $e_t^p = e_t^\pi / 400$.

The estimation proceeds in two steps.[17] Step 1 involves estimating the reduced form VAR as specified by (45). The parameter estimates contained in A and the rational expectations restrictions dictated by (52) through (55) are imposed on Γ_0. We further place exclusion restrictions for the contemporaneous exogenous variables on Λ_0. The lagged dynamics are left unrestricted and we estimate the structural system (44) using FIML by assuming normality of the structural disturbances. The structural parameters are obtained by maximising the following log-likelihood function:

$$L = \sum_{t=1}^{T}[-\frac{n}{2}\ln(2\pi) - \frac{1}{2}\ln|\Gamma_0^{-1}D\Gamma_0^{-1\prime}| - \frac{1}{2}\varepsilon_t' D^{-1}\varepsilon_t] \tag{56}$$

5. Data

The model is estimated with Australian quarterly data from 1984Q1 to 2001Q4 with a total of 72 observations. Domestic variables include the output gap,[18] the consumer price index, the $A/$US exchange rate, and the official cash rate. The foreign variables are the US consumer price index and the federal funds rate. The data series for these variables are presented in Figure 1. The sample period chosen is more appropriate for Australia because of the structural changes, in particular financial market deregulation, that occurred during the early 1980s.

6. Empirical Results

6.1 *Diagnostic Tests on Underlying VAR*

The estimation of SVAR models are all preceded by the selection and testing of an underlying VAR. Spanos (1990) argues for the importance of checking the statistical adequacy of the reduced form before the structural estimators can be treated with good faith. We generalise the maximum order of lag associated with the traditional VAR framework to four lags for the endogenous variables and two lags for the exogenous variables,[19] i.e. VAR(4,2). Keating (2000) terms this approach as "asymmetric VAR" which permits greater flexibility in specifying the dynamics. We thus estimate (45) as a VAR(4,2) with the addition of a constant and three seasonal dummies for each endogenous variable equation. Table 1 shows that the underlying VAR structure satisfies the tests for serial correlation, heteroskedasticity, and normality.

6.2 *Structural Model Specification*

In addition to the contemporaneous parameters in Γ_0 and Λ_0, and the lagged parameters in $\Gamma_1,\ldots,\Gamma_4$, Λ_1, and Λ_2, each endogenous variable equation in (44) also contains a constant and three seasonal dummies. Therefore, the total number of parameters in the structural model (44) is 106, which can be broken down into 4×1 = 4 constants, 4×3 = 12 seasonal dummies, 4×4×4 = 64 lagged parameters for the four endogenous variables, 4×2×2 = 16 lagged parameters for the two exogenous variables, 6 contemporaneous parameters in Γ_0 and Λ_0, and 4 variances in D. In the underlying VAR (45), the total number of reduced-form parameters is 114, which can be broken down into 4×1 = 4 constants, 4×3 = 12 seasonal dummies, 4×4×4 = 64 lagged parameters for the four endogenous variables, 4×2×2 = 16 lagged parameters for the two exogenous variables, 8 contemporaneous parameters in B_0, and 4 variances and 6 covariances in Ω. Therefore, there are 114−106 = 8 over-identifying restrictions. The log-likelihood ratio (LR) test yields the statistic

[17] Deterministic variables such as constants and seasonal dummies are included in both the structural system and the reduced form.

[18] The output gap for Australia is computed using the Hodrick-Prescott filter with smoothness parameter equal 1600.

[19] Given the quarterly data and small sample size, we initially set the upper bound at 4 lags for both the endogenous and exogenous variables. However, the interest rate equation in VAR(4,4) fails the serial correlation test. We thus proceed to test down the order of exogenous variable lags using Schwarz Bayesian Criterion (SBC): VAR(4,4) = -292.78, VAR(4,3) = -295.53, and VAR(4,2) = -307.93.

of 31.96. The statistic is asymptotically distributed as a χ^2 variate with 8 degrees of freedom, and the 5% critical value is 15.51. This rejects the null hypothesis that the restricted (structural) model comes from the same asymptotic distribution as the unrestricted one (underlying VAR).

Garratt et al (1998) and Cho and Moreno (2002) show that asymptotic tests such as the LR test can be severely biased in small samples. Hence we conduct a non-parametric bootstrapping exercise to obtain the small sample critical value that takes into account the dimensions of the model and the relatively small sample of data. The simulated 5% critical value is 35.815 indicating that the LR test adjusted for small sample does not reject the over-identifying restrictions implied by the economic theory.[20]

6.3 *Contemporaneous Parameter Estimates*

The FIML estimates of the contemporaneous parameters in (52) through (55) are shown in Table 2. Asymptotic standard errors are obtained as the inverse of the Hessian matrix. The parameter estimates all possess the correct signs. In the IS equation, α_1 and α_2 are both significantly different from 0 and reflecting that a reduced real interest rate and a depreciating real exchange rate both stimulate the aggregate demand.

In the Phillips curve, β_1 represents the subjective discount factor of a representative forward-looking firm and β_2 captures the effect of output gap in driving the dynamics of inflation. Fuhrer and Moore (1995) find that the Phillips curve (24) with purely forward-looking dynamics inadequately accounts for the degree of inflation persistence in the post-war U.S. data. Gali and Gertler (1999) propose including lags of inflation not implied by the standard model with rational expectations to strengthen the fit of data. Our estimation of (44) is in line with their approach as we also include lagged inflation as part of the SVAR specification. The relevant coefficients are β_1 = 0.351, and 0.612, 0.027, 0.128, and 0.058 for π_{t-1}, π_{t-2}, π_{t-3}, and π_{t-4} respectively.[21] The coefficients suggest that the private agents place a larger weight on past inflation than on expected future inflation.[22] This is in line with Gruen et al (1999) who also find that the inflation expectations in Australia are mainly backward-looking. Our result is in contrast with some of the findings in overseas literature where β_1 is over 0.5 indicating that private agents are forward-looking (Gali and Gertler (1999) and Cho and Moreno (2002)). Jondeau and Le Bihan (2001) estimate a hybrid New Keynesian Phillips curve that includes leads and lags of inflation for the U.S. and Euro area. The authors find that the fraction of backward-looking price-setters increases and the fit of the data improves when the number of leads and lags of inflaton increases. Roberts (2001) demonstrates similar results for the U.S., he argues that the additional lags are necessary to represent the simple autoregressive rules of thumb that private agents use to forecast inflation. The positive and significant estimate of β_2 confirms the finding in Jondeau and Le Bihan (2001) that the output gap is important in explaining the dynamics of the inflation rate.

In the monetary policy rule, if the monetary authority pursues a stabilisation policy of inflation and output, we will expect that $\gamma_1 > 1$ and $\gamma_2 > 0$. On the other hand, $\gamma_1 < 1$ signals an accommodating policy to changes in inflation: From (26), if the monetary authority raises the nominal interest rate (i_t) in response to an expected rise in inflation, it does not increase it sufficiently to keep the real interest rate ($i_t - \pi_t$) from declining. The coefficient of γ_1 = 2.155 suggests that a rise in expected annual inflation of one percent, holding constant output gap, induces the monetary authority to raise the real interest rate by 115 basis points. The surprising result is γ_2 = 2.403, holding constant expected inflation, which suggests that a one percent rise in the output gap induces the monetary authority to increase the real interest rate by 140 basis points. Our point estimates of γ_1 and γ_2 from the monetary policy equation are both larger than 1 and significantly different from 0. These estimates suggest that the Reserve Bank of Australia responds to the real economy in addition to its inflation target with somewhat more weight. While

[20] We bootstrapped 1000 times to map out a small sample distribution of the LR statistics.

[21] The corresponding p-values for the lagged coefficients in the same order are 0.001, 0.902, 0.516, and 0.750.

[22] Since β_1 is not statistically significant from 0, the implication is actually that the inflation expectations in Australia are purely backward-looking.

γ_1 is similar to the estimates in Clarida et al (1998), γ_2 is higher to what is generally found in the literature.

6.4 *Impulse Response Functions*

Figures 3 to 6 present the impulse response functions to the four structural shocks: monetary policy, exchange rate, aggregate demand, and aggregate supply shocks. The size of each structural shock is one standard deviation of the estimated value. The dynamic responses of the output gap, inflation, and interest rate are measured in percentage point. The dynamic response of the exchange rate is in logs and multiplied by 100, so that its impulse response function approximates percentage changes. We also show 90% confidence intervals which are based on Runkle's (1987) boostrapping procedure with 5000 simulations. In most cases, we observe wide confidence intervals which indicate that the dynamic responses are not statistically significant. All of the responses show mean-reversion which reflect the stationary properties of the model.

Interest Rate Shocks

In Figure 3, the initial unexpected monetary tightening of 0.01% leads to a significant fall in the output gap by 0.27% and the inflation rate by 0.45% and the exchange rate appreciates significantly by 1.55% upon impact. There are no price and exchange rate puzzles. The significant contractionary effect lasts two quarters for the output gap and four quarters for the inflation. The exogenous rise in interest rate, however, is quickly reversed after one quarter due to the subsequent deflationary pressure and output gap contraction. The interest rate declines for several quarters before rising to respond to the expansion in output gap and the increase in inflation. The dynamic behaviour of the nominal exchange rate obeys the prediction of the uncovered interest parity that the positive innovation in domestic interest rates relative to foreign interest rates should be associated with subsequent gradual depreciation of domestic currency after the impact appreciation. We observe that the exchange rate depreciates straight away in the second quarter, however, over-depreciation ensues before the exchange rate reaches a peak in the seventh quarter. The exchange rate then continuously appreciates where its medium-run value stays above the initial level. The confidence intervals indicate that the fluctuations in the exchange rate are significant between quarters 5 and 10.

Our result differs from the finding in Eichenbaum and Evans (1995) and Grilli and Roubini (1995) that a positive interest rate differential in favour of domestic assets is associated with a persistent appreciation of domestic currency up to two years after the initial impact. The dynamic responses are thus consistent with the manner in which a negative monetary policy shock generates such contractionary effects in traditional theoretical analysis.

Exchange Rate Shocks

The exchange rate depreciation shock of 0.88% immediately causes a significant increase in the output gap by 0.02% and inflation by 0.1%. The interest rate is raised straight away by 0.62% to counter the imminent inflationary pressure. In the short run, the inflation rises significantly for two quarters and the cautious monetary policy reaction persists significantly for five quarters. Even though the exchange rate is not an explicit target in the reaction function, Taylor (1999) argues that the exchange rate effect works through the expenditure-switching effect to alter real GDP and the pass-through effect to alter the inflation rate. In the open economy New Keynesian model, an unexpected nominal exchange rate depreciation raises the output gap in the IS equation, which in turn causes inflation to rise through the Phillips curve. The high interest rate was successful in reversing the exchange rate, which in turn depresses economic activity and inflation. Over time as the monetary authority corrects its initial policy, the exchange rate depreciates which works favourably for the output gap and inflation.

Aggregate Demand Shocks

In figure 5, a positive aggregate demand shock leads to a significant increase in the output gap by 0.11% and inflation by 0.08%, and a significant exchange rate appreciation of 2.6% upon impact. The subsequent dynamic

responses are dominated by the persistent appreciation in the exchange rate,[23] and the confidence intervals show that the appreciation is significant up to quarter 9. This creates sustained deflationary pressure in the next nine quarters after impact that causes the output gap to contract. The monetary authority reacts aggressively to the large appreciation and deflationary pressure by lowering the interest rate almost immediately. Thus the exchange rate is the major factor in correcting aggregate demand shocks, and the monetary authority appears to act only to control the extent of the exchange rate adjustment. After five quarters the exchange rate starts to depreciate which expands the output gap and creates reflationary pressure in the economy.

Aggregate Supply Shocks

The dynamic effects of an unexpected positive aggregate supply shock are depicted in figure 6. The immediate responses of a fall in the output gap by 0.38% and an increase in the inflation rate by 0.4% match closely to what would be expected from an inflation shock due to pricing error. This leads to a small rise in the interest rate by 0.008% initially to counter the inflationary pressure. That is quickly reversed, however, after one quarter to boost the output gap. The exchange rate depreciates by 0.28% upon impact due to the adverse supply shock. The subsequent lowering of the interest rate prompts more depreciation which further helps the output gap through the IS equation. As the economy settles on a recovery path with rising output gap, the monetary authority then raises the interest rate to initiate an appreciation to bring down the inflation rate. In the short run, the confidence intervals confirm the contraction in output gap and the rise in inflation as significant. The exchange rate depreciates significantly in the first two quarters, however, the dynamic response of the interest rate is shown to be imprecisely estimated.

6.6 *Variance Decomposition*

An assessment of the relative importance of the four structural shocks at various horizons can be gained by examining the proportion of the variance of the forecast error which is accounted for by each of the shocks.

The top panel of table 3 displays the fraction of the forecast error variance in the output gap attributable to each structural shock at horizons up to 40 quarters. The aggregate supply shock is the major contributor to explaining the variability in output gap. This shock accounts for around 63% of the forecast error variance at short horizons and 65% at long horizons. Monetary policy shocks rank second in its relative contribution. At the 1 quarter horizon, it accounts for around 32% of the forecast error variance and declines to 22% in the long run. As in Huh (1999), the aggregate demand shock does not play a significant role in influencing output gap even in the short run.

The second panel reports the relative contribution of each structural shock in explaining the inflation rate. The interest rate shock explains the most of the short run forecast error variance and follow by the aggregate supply shock in second place. Both explain around 54% and 43% of the variability in the short run and steadily decline to 36% and 21% at the 40 quarter horizon respectively. On the other hand, the contribution of the aggregate demand shock becomes more important as the forecast horizon increases. At the horizon of 40 quarters, this shock accounts for 36% of the forecast error variance in inflation rate.

The third panel examines the relative importance of each structural shock in explaining the exchange rate. The aggregate demand shock is the most important factor which accounts for between 68% and 57% of forecast error variance in the exchange rate at all horizons. On the other hand, the interest rate shock accounts for, at most, 24% of the forecast error variance at all horizons. This confirms Fisher's (1996) finding that the real shocks are the major determinant of movements in the Australian nominal exchange rate.

Finally, the last panel looks at the relative contributions of each structural in accounting for fluctuations in interest rate. The forecast error variance in interest rate is dominated by exchange rate shock over all horizons. In the short run, the exchange rate shock explains 99.9% and 85.4% at the horizons of 1 and 4 quarters respectively. As the forecast horizon increases,

[23] This is consistent with Fisher (1996) who investigates movements in Australian nominal and real exchange rates.

the aggregate demand shock becomes somewhat important in its contribution. But it only explains 14.7% at the 40 quarter horizon.

7. Conclusions

We estimate a SVAR model for the Australian economy with contemporaneous structural relationships derived from an open economy New Keynesian model. Since the New Keynesian model is based on intertemporally optimising agents who are forward-looking, the identification of the SVAR model under rational expectations requires the exclusion restrictions to be placed on the VAR residuals and the covariance matrix.

The SVAR model is estimated by full-information maximum likelihood. The full-system estimation has the advantage of allowing for interactions among the different economic agents: consumers, firms and the monetary authority. We find that the New Keynesian SVAR model fits the Australian data quite well. The parameter estimates in the structural equations are largely consistent in magnitudes and signs with other findings in the literature. In the IS curve, we find that a reduced real interest rate and a depreciating real exchange rate both boost the current output level. The estimated coefficients for the subjective discount factor and the lagged inflation rates in the Phillips curve support that a large fraction of firms is backward-looking in setting prices. The output gap is found to be a significant variable in driving the inflation dynamics. The estimated coefficients in the monetary policy rule suggest that the RBA has been stabilising the output fluctuations in the short run while maintaining a medium-run inflation target since 1984. Interestingly, the coefficient on output gap suggests that the RBA places a somewhat larger weight on tackling the real economy than pursuing the target inflation.

We simulate the dynamic responses of the macro variables subject to an exogenous monetary tightening. The impulse response functions quantify the effects of the monetary policy shock on the dynamics of output gap, inflation, exchange rate, and interest rate. We can further check the reasonableness of the dynamic responses to assess the adequacy of the New Keynesian specification. In the short run, we find that an exogenous monetary tightening has significantly contractionary effects on the output gap and inflation. The relatively higher domestic interest rate pressures the exchange rate to appreciate on impact. This is supported by the forecast error variance which shows that the interest rate shock explains 32% of the output gap fluctuations, 53% of the inflation fluctuations, and 24% of the exchange rate fluctuations at the 1 quarter horizon. The exchange rate depreciates immediately after the initial appreciation, however, we observe over-depreciation which results in the medium-run value staying above its initial level. The absence of the price and exchange rate puzzles lends further support to the relevance of the New Keynsian model to the Australian economy.

The impulse response functions for an exchange rate shock and for an aggregate demand shock both highlight the importance of the exchange rate fluctuations to the monetary authority in the short run. The RBA reacts swiftly and strongly to an exchange rate depreciation shock even though the nominal exchange rate is not an explicit consideration in the monetary policy rule. Large exchange rate fluctuations may have detrimental effects indirectly on the real output through expenditure-switching effect and on the inflation through pass-through effect. The forecast error variance shows that the exchange rate shock explains 99.95% of the interest rate fluctuations in the immediate short run.

When the economy experiences an aggregate demand shock, this causes a large and sustained nominal exchange rate appreciation. This is confirmed by the forecast error variance that the real shocks explain 67% of the exchange rate fluctuations and remain dominant at 57% at long horizons. The RBA seems to focus mainly on controlling the exchange rate adjustment. The exchange rate thus acts as an instrument to correct the output gap and inflation fluctuations.

8. References

Bernanke, B.S. and A.S. Blinder (1992) "The Federal Funds Rate and the Channels of Monetary Transmission" *American Economic Review*, 82(4), pp. 901-21.

Bernanke, B.S. and I. Mihov (1998) "Measuring Monetary Policy" *Quarterly Journal of Economics*, 113(3), pp. 869-902.

Brischetto, A. and G. Voss (1999) "A Structural Vector Autoregression Model of Monetary Policy in Australia" *Reserve Bank of Australia Research Discussion Paper* 1999-11.

Calvo, G.A. (1983) "Staggered Prices in a Utility-Maximizing Framework" *Journal of Monetary Economics*, 12(3), pp. 383-98.

Cho, S. and A. Moreno (2002) "A Structural Estimation and Interpretation of the New Keynesian Macro Model" *Columbia University, mimeo*.

Clarida, R.H. (2001) "The Empirics of Monetary Policy Rules in Open Economies" *International Journal of Finance and Economics*, 6(4), pp. 315-23.

Clarida, R., J. Gali, and M. Gertler (1998) "Monetary Policy Rules in Practice: Some International Evidence" *European Economic Review*, 42(6), pp. 1033-67.

Clarida, R., J. Gali, and M. Gertler (1999) "The Science of Monetary Policy: A New Keynesian Perspective" *Journal of Economic Literature*, 37(4), pp. 1661-707.

Cushman, D.O. and T. Zha (1997) "Identifying Monetary Policy in a Small Open Economy under Flexible Exchange Rates" *Journal of Monetary Economics*, 39(3), pp. 433-48.

de Brouwer, G., I. Ng, and R. Subbaraman (1993) "The Demand for Money in Australia: New Tests on an Old Topic" *Reserve Bank of Australia Research Discussion Paper* 9314.

Dhrymes, P.J. and D.D. Thomakos (1998) "Structural VAR, MARMA, and Open Economy Models" *International Journal of Forecasting*, 14(2), pp. 187-98.

Dungey, M. and A. Pagan (2000) "A Structural VAR Model of the Australian Economy" *Economic Record*, 76(235), pp. 321-42.

Eichenbaum, M. (1992) "Interpreting the Macroeconomic Time Series Facts: The Effects of Monetary Policy: Comments" *European Economic Review*, 36(5), pp. 1001-11.

Eichenbaum, M. and C.L. Evans (1995) "Some Empirical Evidence on the Effects of Shocks to Monetary Policy on Exchange Rates" *Quarterly Journal of Economics*, 110(4), pp. 975-1009.

Fisher, L.A. (1996) "Sources of Exchange Rate and Price Level Fluctuations in Two Commodity Exporting Countries: Australia and New Zealand" *Economic Record*, 72(219), pp. 345-58.

Fuhrer, J. and G. Moore (1995) "Inflation Persistence" *Quarterly Journal of Economics*, 110(1), pp. 127-59.

Gali, J. (1992) "How Well Does the IS-LM Model Fit Postwar U.S. Data?" *Quarterly Journal of Economics*, 107(2), pp. 709-38.

Gali, J. and M. Gertler (1999) "Inflation Dynamics: A Structural Econometric Analysis" *Journal of Monetary Economics*, 44(2), pp. 195-222.

Garratt, A., K. Lee, M.H. Pesaran, and Y. Shin (1998) "A Long-Run Structural Macroeconometric Model of the UK" *University of Cambridge, mimeo*.

Gordon, D.B. and E.M. Leeper (1994) "The Dynamic Impacts of Monetary Policy: An Exercise in Tentative Identification" *Journal of Political Economy*, 102(6), pp. 1228-47.

Grilli, V. and N. Roubini (1995) "Liquidity and Exchange Rates: Puzzling Evidence From the G-7 Countries" *New York University, mimeo*.

Gruen, D., A. Pagan, and C. Thompson (1999) "The Phillips Curve in Australia" *Reserve Bank of Australia Research Discussion Paper* 1999-01.

Hall, S. (1995) "Macroeconomics and A Bit More Reality" *Economic Journal*, 105(431), pp. 974-88.

Hodrick, R.J. and E.C. Prescott (1980) "Postwar U.S. Business Cycles: An Empirical Investigation" *Journal of Money, Credit, and Banking*, 29(1), pp. 1-16.

Huh, H.-S. (1999) "How Well Does the Mundell-Fleming Model Fit Australian Data since the Collapse of Bretton Woods?" *Applied Economics*, 31(3), pp. 397-407.

Jondeau, E. and H. Le Bihan (2001) "Testing for a Forward-Looking Phillips Curve: Additional Evidence from European and US Data" *Universite Paris XII Val de Marne, mimeo*.

Keating, J.W. (1990) "Identifying VAR Models under Rational Expectations" *Journal of Monetary Economics*, 25(3), pp. 453-76.

Keating, J.W. (2000) "Macroeconomic Modeling with Asymmetric Vector Autoregressions" *Journal of Macroeconomics*, 22(1), pp. 1-28.

Kim, S. and N. Roubini (2000) "Exchange Rate Anomalies in the Industrial Countries: A Solution with a Structural VAR Approach" *Journal of Monetary Economics*, 45(3), pp. 561-86.

Leeper, E.M. and D.B. Gordon (1992) "In Search of the Liquidity Effect" *Journal of Monetary Economics*, 29(3), pp. 341-69.

Leeper, E.M. and T. Zha (2000) "Assessing Simple Policy Rules: A View from a Complete Macro Model" *Federal Reserve Bank of Atlanta Working Paper* 2000-19.

Lucas, R.E. and T.J. Sargent (1981) "After Keynesian Macroeconomics" in *Rational Expectations and Econometric Practice*. R.E. Lucas and T.J. Sargent eds. London: George Allen & Unwin, pp. 295-328.

McCallum, B.T. and E. Nelson (1999a) "Nominal Income Targeting in an Open-Economy Optimizing Model" *Journal of Monetary Economics*, 43(3), pp. 553-78.

McCallum, B.T. and E. Nelson (1999b) "An Optimizing IS-LM Specification for Monetary Policy and Business Cycle Analysis" *Journal of Money, Credit, and Banking*, 31(3), pp. 296-316.

McCallum, B.T. and E. Nelson (2000) "Monetary Policy for an Open Economy: An Alternative Framework with Optimizing Agents and Sticky Prices" *Oxford Review of Economic Policy*, 16(4), pp. 74-91.

Reichenstein, W. (1987) "The Impact of Money on Short Term Interest Rates" *Economic Enquiry*, 25(1), pp. 67-82.

Roberts, J.M. (2001) "How Well Does the New Keynesian Sticky-Price Model Fit the Data?" *Board of Governors of the Federal Reserve System, mimeo*.

Runkle, D.E. (1987) "Vector Autoregressions and Reality" *Journal of Business and Economic Statistics*, 5(4), pp. 437-42.

Sims, C.A. (1986) "Are Forecasting Models Usable for Policy Analysis?" *Federal Reserve Bank of Minneapolis Quarterly Review*, 10(1), pp. 2-16.

Sims, C.A. (1992) "Interpreting the Macroeconomic Time Series Facts: The Effects of Monetary Policy" *European Economic Review*, 36(5), pp. 975-1000.

Spanos, A. (1990) "The Simultaneous-Equations Model Revisited: Statistical Adequacy and Identification" *Journal of Econometrics*, 44(1-2), pp. 87-105.

Strongin, S. (1995) "The Identification of Monetary Policy Disturbances: Explaining the Liquidity Puzzle" *Journal of Monetary Economics*, 35(3), pp. 463-97.

Taylor, J.B. (1993) "Discretion versus Policy Rules in Practice" *Carnegie-Rochester Conference Series on Public Policy*, 39(0), pp. 195-214.

Taylor, J.B. (1999) "The Role of the Exchange Rate in Monetary Policy Rule" *Stanford University, mimeo*.

Zha, T. (1997) "Identifying Monetary Policy: A Primer" *Federal Reserve Bank of Atlanta Economic Review*, 82(2), pp. 26-43.

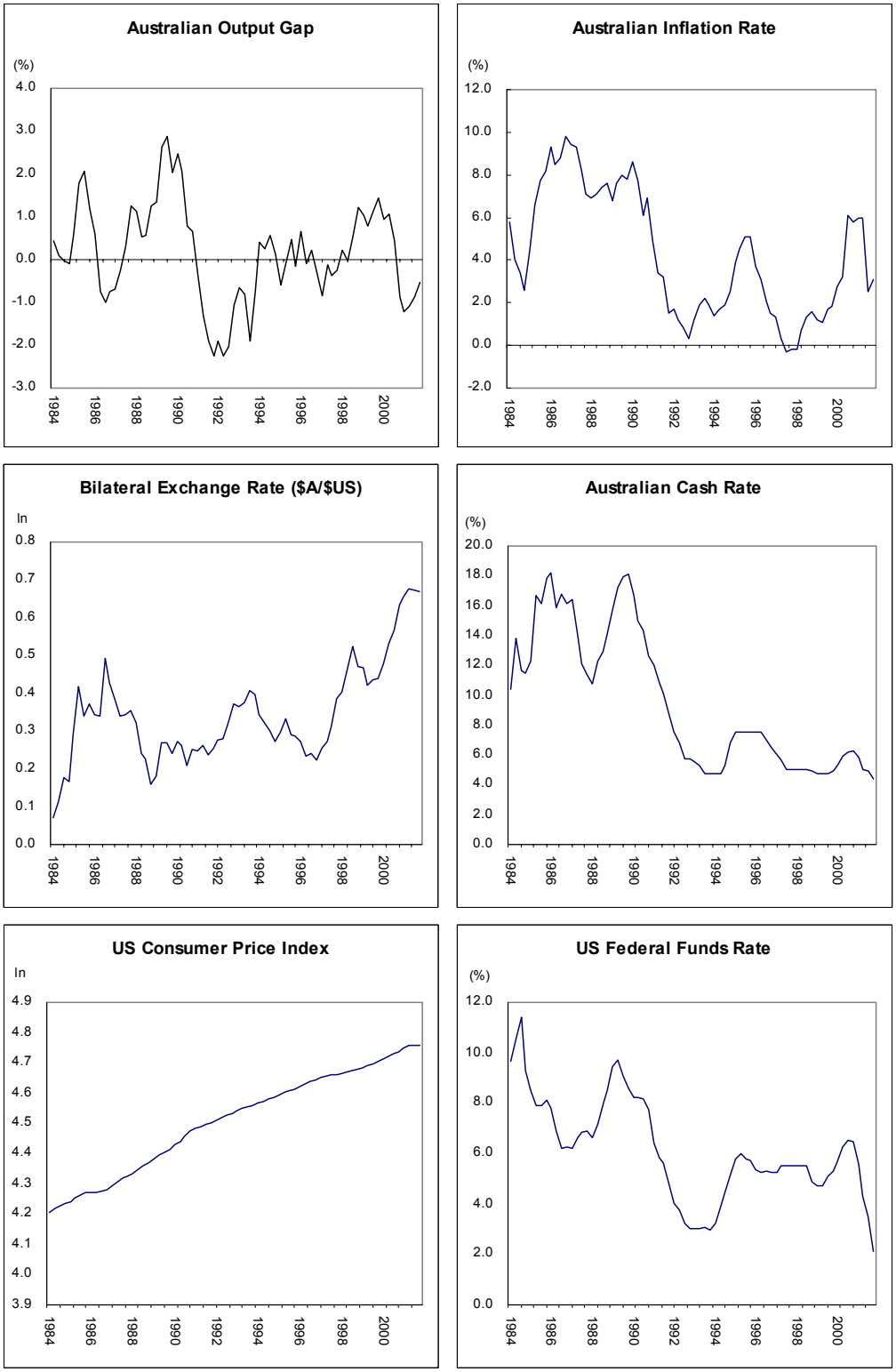

Figure 1: *Principal Macroeconomic Variables 1984Q1~2001Q4*

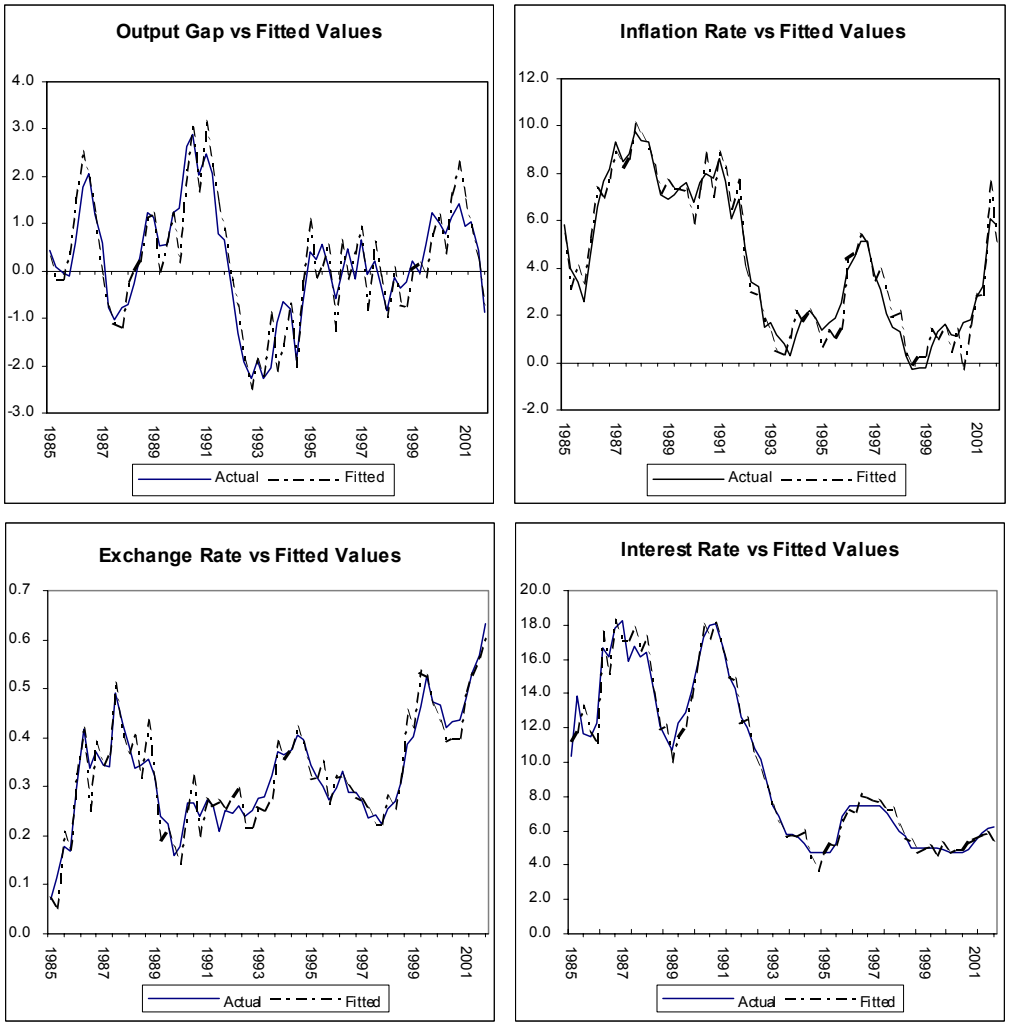

Figure 2: Historical Values vs. In-Sample Predicted Values

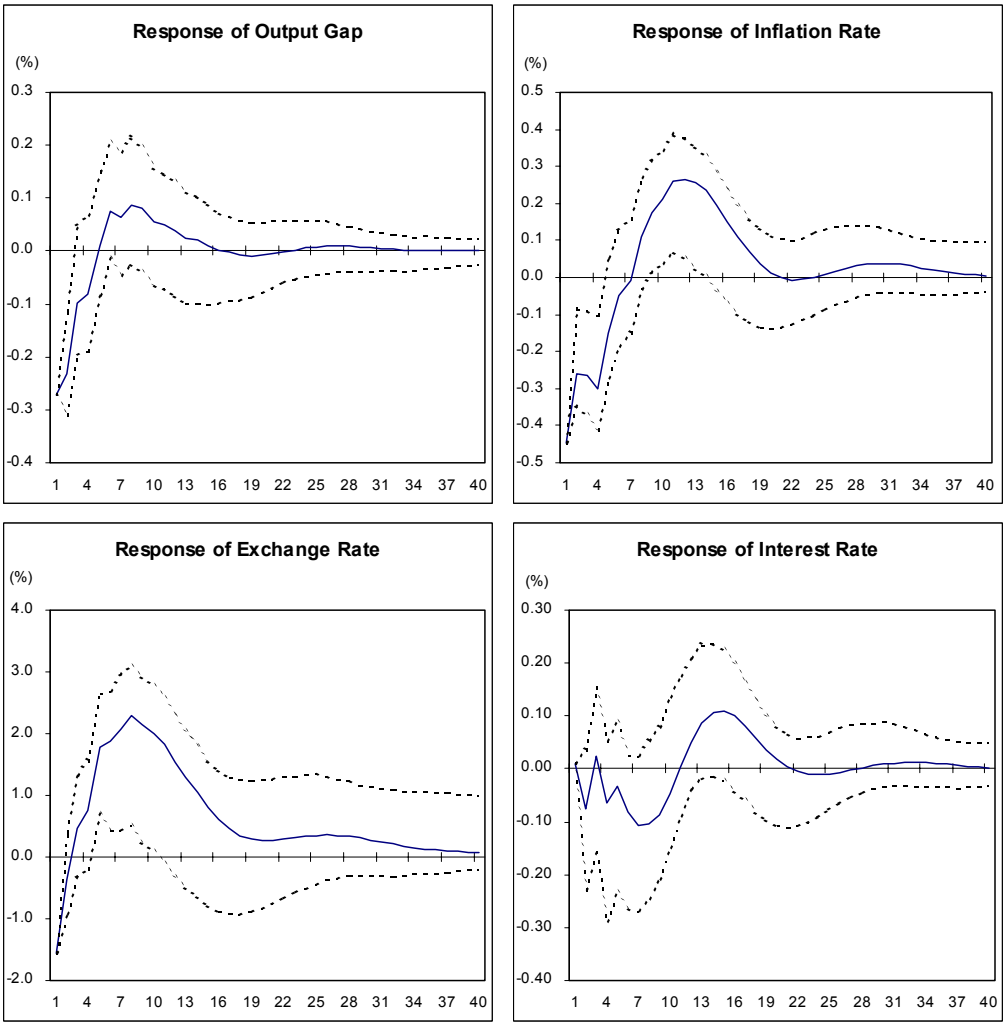

Figure 3: Impulse Response Functions to a One Standard Deviation Interest Rate Shock

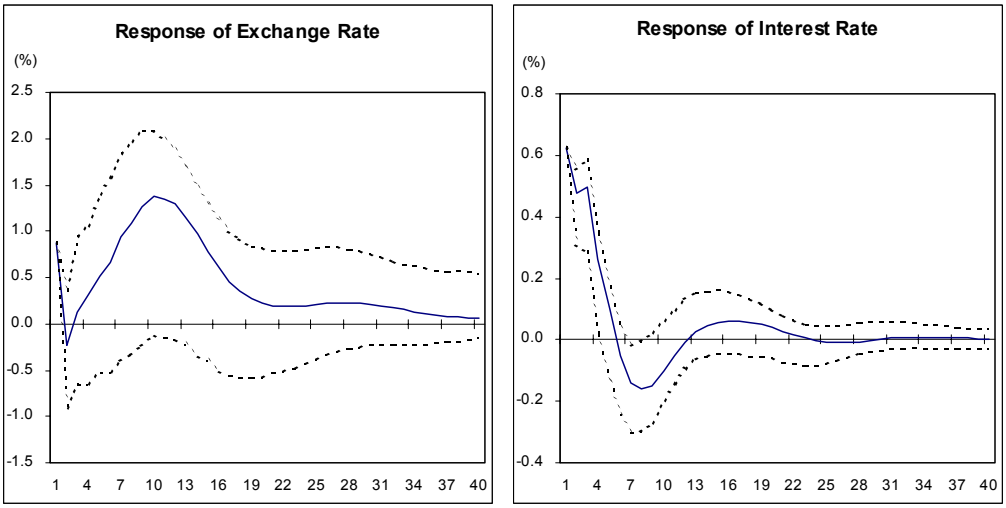

Figure 4: Impulse Response Functions to a One Standard Deviation Exchange Rate Shock

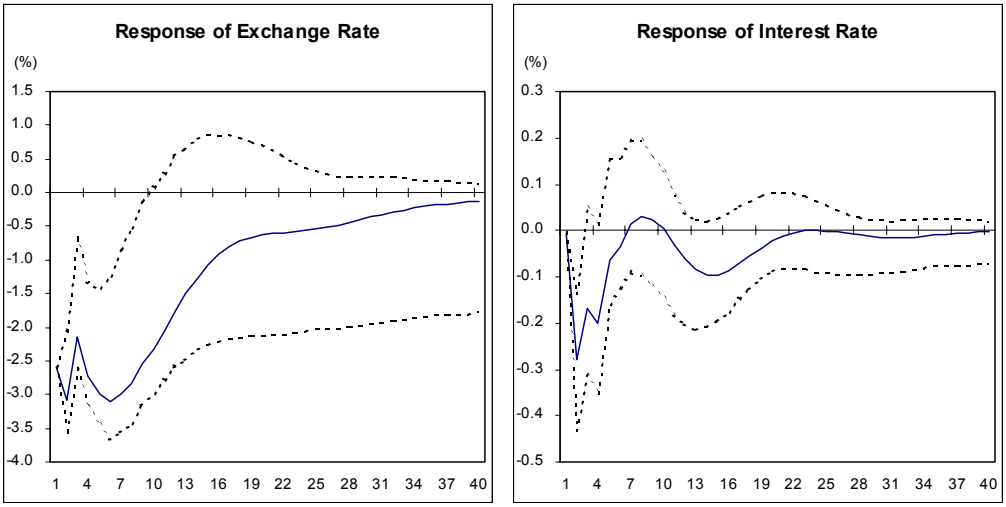

Figure 5: Impulse Response Functions to a One Standard Deviation Aggregate Demand Shock

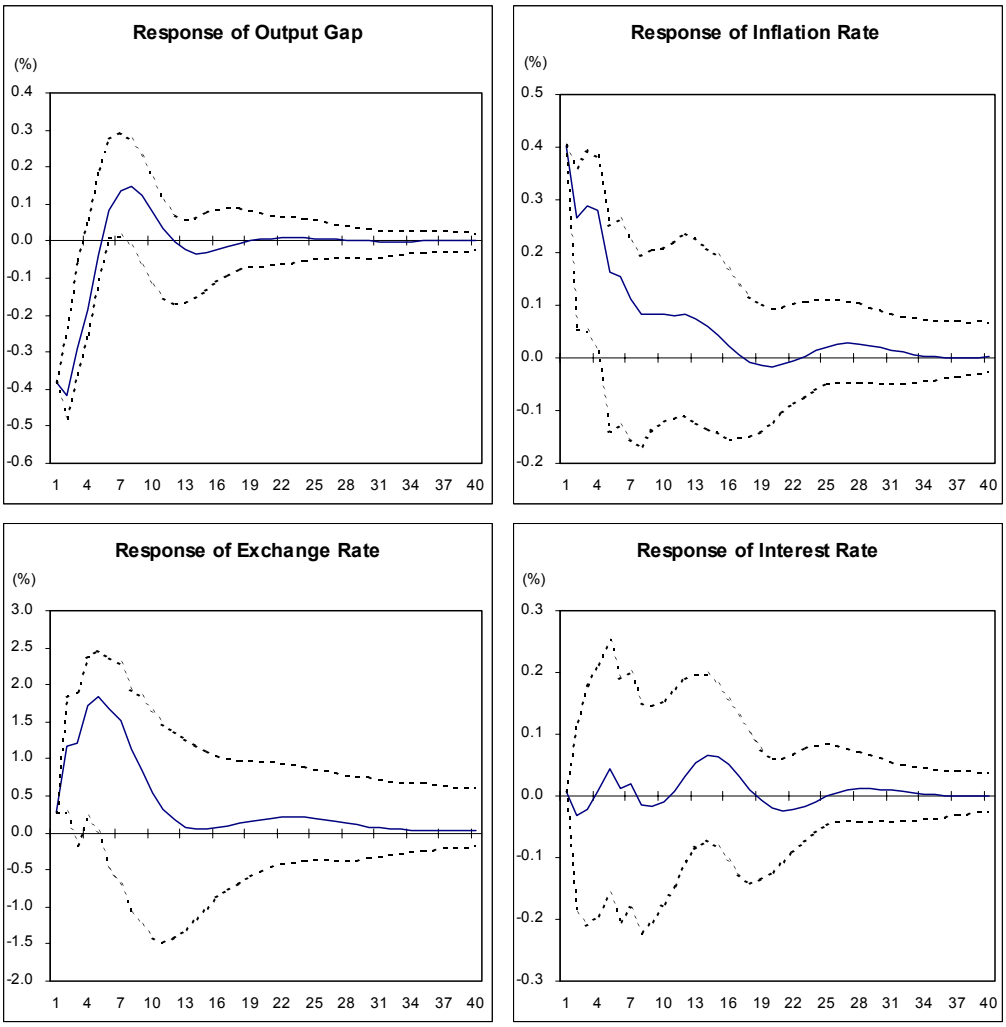

Figure 6: Impulse Response Functions to a One Standard Deviation Aggregate Supply Shock

Table 1: Reduced Form Diagnostics

Diagnostic Tests	*Equation*			
	x_t	π_t	s_t	i_t
Serial Correlation				
AR(1) $F(1,41)$	0.187	0.901	0.406	3.923
	(0.667)	(0.348)	(0.528)	(0.054)
AR(4) $F(4,38)$	1.346	1.485	0.571	1.715
	(0.271)	(0.226)	(0.685)	(0.167)
ARCH				
ARCH(1) $F(1,41)$	1.560	0.065	1.709	4.427
	(0.216)	(0.800)	(0.198)	(0.042)
ARCH(4) $F(4,38)$	0.453	0.671	1.037	1.020
	(0.770)	(0.616)	(0.401)	(0.410)
Normality				
Jarque-Bera $\chi^2(2)$	1.006	3.307	2.250	1.135
	(0.605)	(0.191)	(0.325)	(0.567)

Note: P-values are in parentheses.[24]

Table 2: Contemporaneous Structural Estimates ((23) through (26))

α_1	α_2	β_1	β_2	γ_1	γ_2
0.112	1.601	0.351	1.291	2.155	2.403
(0.002)	(0.000)	(0.131)	(0.026)	(0.003)	(0.005)

Note: P-values are in parentheses.

[24] The set of specification tests is conducted with Microfit 4.0.

Table 3: Forecast Error Variance Decomposition

Series	Number of Quarters	Structural Shocks			
		IR	ER	AD	AS
	1	32.07	0.12	4.87	62.94
	4	23.05	0.62	6.05	70.28
x	8	22.56	2.83	6.17	68.44
	12	22.47	3.83	7.87	65.83
	20	22.14	5.00	8.03	64.83
	40	22.15	5.03	8.12	64.70
	1	53.08	2.65	1.76	42.51
	4	40.58	6.12	16.02	37.28
π	8	32.21	4.94	30.83	32.02
	12	35.04	4.53	35.17	25.26
	20	35.82	8.48	35.23	20.47
	40	35.58	8.52	35.63	20.27
	1	23.99	7.70	67.53	0.77
	4	8.62	2.43	73.75	15.20
s	8	19.02	3.56	62.24	15.18
	12	23.46	7.39	57.56	11.58
	20	23.77	8.96	56.77	10.50
	40	23.77	9.02	56.86	10.35
	1	0.03	99.95	0.00	0.02
	4	0.98	85.39	13.48	0.15
i	8	3.49	82.23	12.90	0.38
	12	4.33	82.43	12.75	0.48
	20	7.78	76.02	14.66	1.54
	40	7.84	75.76	14.72	1.69

Note:
IR: interest rate shock
ER: exchange rate shock
AD: aggregate demand shock
AS: aggregate supply shock.