A New Keynesian Perspective of Monetary Policy in Australia

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Monetary Policy Implementation in Australia*

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Abstract

We estimate a SVAR for the Australian economy based on an open economy New Keynesian model. Deep structural parameters are identified by placing exclusion restrictions on the VAR residuals and the covariance matrix. Parameter estimates suggest that the New Keynesian specification fits Australian data well. Dynamic responses show no price and exchange rate puzzles and indicate that the Reserve Bank of Australia (RBA) has a short-run focus on stabilizing output fluctuations while maintaining a medium-run inflation target since 1984. The RBA responds decisively to aggregate demand and exchange rate shocks while passively allowing the economy to self-correct aggregate supply shock.

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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 the output gap, inflation, the exchange rate, and interest rates. One popular tool is structural vector autoregression (SVAR) which provides simulations of dynamic responses of macroeconomic variables to particular structural shocks. Using an appropriate monetary policy instrument, SVAR models can be used to gauge the adequacy of a 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 (e.g., Hall, 1995). In recent Australian literature, Brischetto and Voss (1999) adopt the contemporaneous structural relationships proposed by Kim and Roubini (2000). Huh (1999) bases the identifying assumptions on a static Mundell-Fleming model with impositions of short-run and long-run restrictions. Dungey and Pagan (2000) develop a block-recursive structural model with eleven variables. This paper extends the identification scheme for the Australian economy by appealing to a fully specified macroeconomic model that explicitly accounts for the forward-looking behavior exhibited by economic agents.

A small open economy New Keynesian macroeconomic model is employed to analyze monetary policy in Australia, which carefully specifies the interactions between the exogenous structural shocks and the behavior of the monetary authority and private agents. The New Keynesian approach has received much attention in recent times due to its emphasis on the behavior of intertemporally optimizing agents and the incorporation of nominal rigidities. Aggregate relationships commonly used in the framework are derived from dynamic general equilibrium models, where the monetary authority and private agents are assumed to be rational and forward-looking. The structural model comprises a dynamic aggregate demand (IS) equation based on representative agent utility maximization in a small open economy, an aggregate supply (AS) equation based on Calvo’s (1983) staggered price setting model (or a New Keynesian Phillips curve), the uncovered interest rate parity, and a forward-looking monetary policy rule.

We estimate a SVAR model by appending the contemporaneous structure motivated 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. To identify the SVAR model under rational expectations, we
estimate ‘deep’ 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 and hence the result is not subject to the Lucas critique. Taking advantage of the feature offered by the SVAR methodology, deep structural parameters in this model are identified by imposing restrictions on the VAR residuals and the covariance matrix, while leaving the lag dynamics unrestricted. Dhrymes and Thomakos (1998) employ a similar procedure for imposing exclusion restrictions on a small open economy model. Their study differs from this paper in three respects: The open economy structural model is not based on intertemporal optimization; the method for solving rational expectations is different; and no exclusion restrictions are imposed on the exogenous variables.

Two questions are at the heart of this paper: ‘How well does the New Keynesian specification fit the Australian data?’ and ‘How does the New Keynesian SVAR model characterize monetary policy in Australia?’ To answer the first question, the relevance of the New Keynesian model is examined by obtaining and interpreting parameter estimates for the four structural equations. The dynamic responses of the macroeconomic variables subject to an exogenously generated monetary policy shock are also checked to see if they match a priori theoretical predictions. In answering the second question, the dynamic responses of interest rates to exogenous output gap, inflation, and exchange rate shocks are inspected. These impulse response functions allow us to observe and describe how monetary policy reacts endogenously to macroeconomic shocks based on the New Keynesian framework.

The SVAR model is estimated by full-information maximum likelihood (FIML). We find that the New Keynesian SVAR model fits the Australian data well. Results that are comparable with other single-equation studies are obtained by using the full-system estimation, which has the advantage of allowing for interactions among different agents in the economy, i.e., consumers, firms, and the monetary authority. The coefficient estimates suggest that inflation dynamics in Australia are backward-looking, which agrees with Gruen et al.’s (1999) finding. The estimated monetary policy rule indicates that the RBA has been stabilizing inflation and output fluctuations since 1984. Interestingly, the coefficient for the output gap suggests that the RBA responds with a somewhat larger weight to the real economy relative to the target inflation. de Brouwer and Gilbert (2005) estimate interest rate setting rules for Australia and find that the estimated coefficient for output fluctuations is larger in value when the sample period

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1This term appeared in Lucas and Sargent (1981).
2The main aim of their paper is to examine the empirical appropriateness of forward-looking and backward-looking expectations.
starts from 1984 than when the sample period starts from 1991 corresponding to the adoption of an implicit inflation target. While maintaining price stability is the underlying goal of monetary policy, the management of business cycle fluctuations is an equally important task in the RBA’s objective function. The importance of monitoring the real side of the economy has not diminished with the advent of inflation targeting in the early 1990s. This is consistent with the Australian inflation targeting framework which allows flexibility for the RBA to respond to business cycle fluctuations in the short run while not jeopardizing the task of maintaining the inflation target in the medium run.

We simulate for dynamic responses of the macroeconomic variables subject to an exogenous monetary tightening. In the short run, an exogenous monetary tightening has significant contractionary effects on the output gap and inflation. The relatively higher domestic interest rate pressures the exchange rate to appreciate on impact. Depreciation in the exchange rate follows in ensuing periods which leads to overshooting. After reaching its peak of depreciation, the exchange rate continuously appreciates and approaches its initial value in the medium run. 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 Keynesian model for the Australian economy.

The impulse response functions for an exchange rate shock and for an aggregate demand shock highlight the attention given to exchange rate fluctuations by the monetary authority in the short run. The RBA tightens quickly and decisively to stabilize output and inflation given 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 real output through the expenditure-switching effect and inflation through the pass-through effect. When an aggregate demand shock hits the economy, this causes a large and sustained nominal exchange rate appreciation. The forward-looking monetary authority cuts interest rate immediately to staunch the extent of current and future contraction in output and fall in inflation brought about by the sustained appreciation. The exchange rate is thus the major factor in correcting the aggregate demand shock, and the RBA appears to act to control the movement of the exchange rate.

In the face of an exogenous aggregate supply (or inflation) shock, contraction in output, rise in inflation, and exchange rate depreciation are observed in the short run. The impulse response functions suggest that the RBA takes an inactive role, allowing the economy to self-correct the temporary aggregate supply disturbance. We observe that the initial exchange rate depreciation is helpful in stabilizing output in the short run while inflation continues to fall and becomes stable in the medium run.
This paper is organized as follows: Section 2 reviews the SVAR literature on monetary policy. Section 3 lays out the New Keynesian specification of a small open economy. In section 4 we discuss the rational expectations identification scheme. Section 5 describes the Australian data used in estimation and 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 6 concludes.

2. Literature review

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 arranged the contemporaneous macroeconomic relationships according to the Wold causal chain. In Sims (1986) and Leeper and Gordon (1992), money supply innovations are modeled as unanticipated monetary policy shocks, and the results show anomalous positive responses 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.3

Using a series of measures, Bernanke and Blinder (1992) conclude that the federal funds rate is a good indicator of U.S. monetary policy. Their finding gives support to using nominal interest rates as an assumed instrument for examining monetary policy. Sims (1992) compares the simulated dynamic responses to money supply and interest rate innovations; the interest rate was the preferred policy instrument because it eliminates the liquidity puzzle and a monetary tightening consistently curtails the real economic activity. But a rise in the interest rate leads to an increase in prices and an impact depreciation in the nominal exchange rate.

Sims (1992) explains that the observed ‘price and exchange rate puzzles’ reflect the endogenous behavior of monetary policy reacting to future inflation. The monetary authority moves in a pre-emptive fashion to dampen imminent inflationary pressures signaled by movements in commodity prices, hence reducing actual increase in future prices. Private agents observe the pre-emptive policy measure and adjust their actions

3See Reichenstein (1987) for a review on single-equation studies of the liquidity effect.
accordingly, which results in the nominal exchange rate depreciation. To be more
concrete, Sims re-estimates the structural system without the 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. The
exchange rate and commodity prices are therefore significant information variables that
influence the endogenous behavior of the interest rate.

But the fact that the empirical puzzles are not completely resolved points to other
aspects of the identifying assumptions that need to be addressed. Zha (1997) argues that
the popular Cholesky structure precludes important simultaneous feedbacks. In a
recursive model, the interest rate is not contemporaneously related to monetary
aggregates, although the reverse contemporaneous relationship is permitted (see, for
example, Leeper and Gordon, 1992 and Gordon and Leeper, 1994). This sets up a
perfectly inelastic money supply function with respect to the interest rate, which is
highly unrealistic as most monetary authorities target interest rates by directly
intervening in overnight cash markets; this simultaneity needs to be modeled to produce
sensible policy analysis. Furthermore, the interest rate is ordered prior to all other
macroeconomic variables so there is no contemporaneous influence coming from prices,
exchange rates, and commodity prices (e.g., Sims, 1992). This is also unsatisfactory
since monetary authorities in small open economies are likely to respond quickly to
exchange rate fluctuations because of their potentially inflationary effect. If those
variables are relevant to the monetary authority’s information set, they need to be
included in the variable list to account for the simultaneous feedback.

In closed economy studies, Gali (1992) estimates an IS-LM-AS model which
separates the money demand and money supply equations; the impulse response
functions indicate the absence of liquidity and price puzzles. Other authors (e.g.,
Eichenbaum, 1992; Gordon and Leeper, 1994; Strongin, 1995; and Bernanke and Mihov,
1998) emphasize the need to model 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 monetary policy.\(^4\)

In open economy studies, Cushman and Zha (1997) model the money demand and
money supply equations to separate the behavior of the private sector and the monetary
authority. In the money supply equation, the interest rate responds contemporaneously
to exchange rates, money stock (M1), a foreign interest rate, and commodity prices. The
structural identification scheme includes an explicit trade sector. Kim and Roubini

\(^4\)In Pagan and Robertson (1998), the liquidity effect reported in Gali (1992) and Gordon and Leeper (1994)
is reassessed with an eye to robustness. Although the paper concludes favorably the superiority of
structural models over recursive models in correctly identifying the sign of the liquidity effect, the size of
the effect is shown to be either weak or imprecisely estimated.
(2000) eschew from a trade sector in their identification scheme. They exclude the foreign interest rate from the interest rate rule on the ground that the monetary authority is more sensitive to exchange rate fluctuations than foreign interest rate fluctuations. All empirical puzzles are absent in both studies.

In Australian SVAR models, Brischetto and Voss (1999) and Dungey and Pagan (2000) obtain sensible results without monetary aggregates and oil prices that feature prominently in the literature. Brischetto and Voss adopt the Kim-Roubini identification scheme but find it necessary to include the foreign interest rate in the monetary policy equation; its exclusion yields a rise in output and prices, and an impact depreciation of the nominal exchange rate in the event of an unanticipated monetary 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 changes in gross national expenditure. Oil prices are omitted on the ground that interest rates and exchange rates are competent predictors of future inflation with oil prices adding little information. The absence of monetary aggregates avoids the problem associated with money demand instability.\(^5\) The application of a New Keynesian macroeconomic model specification to the Australian economy is supported as money typically plays no role and the monetary authority is forward-looking by generating model-consistent expectations about the future states of the economy.

2.2. Treatments of the foreign sector

When the SVAR model is extended to small open economy studies, some foreign variables are included to reflect 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 the system. In Brischetto and Voss (1999) and Kim and Roubini (2000), the external sector is represented by oil prices and the federal funds rate. None of the domestic variables enters the oil price and federal funds rate equations contemporaneously. However, there is still delayed feedback through the lag values of the domestic variables.

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

\(^5\)In Australia, the relationship between monetary aggregates and the nominal GDP broke down in the 1980s due to financial deregulation. Using cointegration tests, de Brouwer et al. (1993) cannot establish a stable long-run relationship between money, income and interest rates.
on the structural system.

In previous identification schemes, foreign variables are placed in the endogenous variable vector. Exogeneity of foreign variables is represented by either contemporaneous exogeneity or block-exogeneity. Dhrymes and Thomakos (1998) treat SVAR as a special case of simultaneous equations estimation. They base the SVAR model on a structural open economy macroeconomic model. Contemporaneous exclusions and normalizations imposed on the contemporaneous system for both domestic and foreign variables come from the structural relationships in the open economy macroeconomic model. The contemporaneous system of the structural model may be written as

$$\Gamma_0 y_t = \Lambda_0 z_t + \epsilon_t, \quad (1)$$

where $y_t$ is the vector of endogenous (domestic) variables with $\Gamma_0$ containing the contemporaneous parameters, $z_t$ is the vector of exogenous (generally foreign) variables with $\Lambda_0$ containing the contemporaneous parameters, and $\epsilon_t$ is the vector of structural disturbances. Short run dynamics are added for SVAR estimation and the dynamic structural system is

$$\Gamma(L)y_t = \Lambda(L)z_t + \epsilon_t, \quad (2)$$

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

3. Theoretical Model

We describe a small open economy New Keynesian model that is consistent with the underlying behavior of intertemporally optimizing agents. Aggregate relationships used for analyzing the Australian economy are derived from dynamic general equilibrium setting, where agents are assumed to be rational and forward-looking. The set of macroeconomic relations are characterized by the following system of equations: an IS equation, an AS equation (or a Phillips curve), the uncovered interest rate parity, and a forward-looking monetary policy rule.

3.1. IS Equation

The derivation of an 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 maximizes the expected present discounted value of a lifetime utility function involving consumption and real money balances
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 composite consumption variable that appears in (3) is an index which is constructed as a Dixit-Stiglitz aggregate

$$C_i = \left[ \int_{0}^{1} C_z^{-\gamma/\theta} dz \right]^{-\theta/\theta-1},$$

where $C_{zt}$ denotes the household’s period $t$ consumption of good $z$ and $\theta > 1$ governs the price elasticity of demand for each differentiated good. The corresponding aggregate price index is

$$P_t = \left[ \int_{0}^{1} P_z^{-\gamma/\theta} dz \right]^{-\theta/\theta-1},$$

where $P_{zt}$ 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 specializes in production using the following constant elasticity of substitution (CES) technology involving labor and the imported intermediate good

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

with $\alpha \in (0,1]$ and $\nu \in (-\infty, \infty)$. In (6), $Y_t$ is the current level of output, $A_t$ is an exogenous technology shock entering all households’ production functions, $N_t$ is the amount of labor hired by the household, and $IM_t$ is the quantity of the foreign-produced good purchased by the household which is used as an input in production. Each household is a monopolistic producer that chooses the own product selling price $P_{zt}$ while taking the aggregate price level $P_t$, the nominal exchange rate $S_t$, and the foreign price level $P_t^*$ as given. $S_t$ is expressed as the domestic currency per unit of the 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 $(P_{zt}/S_t)$. 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 characterizing a small open economy at home.
Labor 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 labor 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 $t+1$; where $r_t$ stands for the domestic real interest rate. 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 $(1+\kappa_t)^{-1}(1+r^*_t)^{-1}$; where $r^*_t$ is the foreign real interest rate and $\kappa_t$ stands for a random risk-premium term.

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

$$TR_t = \frac{M_t - M_{t-1}}{P_t}.$$  \hfill (7)

The budget constraint for the household in real terms is

$$\frac{P_t D_t}{P_t} + \frac{P_t E_t}{P_t} + \frac{W_t N_t^s}{P_t} + TR_t + \frac{M_{t-1}}{P_t} + B_t + Q_t B^*_t$$

$$= C_t + \frac{W_t N_t^s}{P_t} + \frac{M_{t-1}}{P_t} + Q_t I_t + \frac{B^*_{t+1}}{(1+r^*_t)^{-1}}$$, \hfill (8)

where $W_t$ is the nominal wage, $Q_t \equiv (S_t P^*_t/P_t)$ is the real exchange rate, and $N_t^s$ denotes labor supply.

Let $\xi_t$ denote the Lagrange multiplier on constraint (6) and $\lambda_t$ the multiplier on constraint (8), the household’s first-order conditions with respect to $C_t$, $B_{t+1}$, $B^*_{t+1}$, $N_t$, and $I_t$ are\(^6,7\)

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\(^6\)The first-order condition with respect to $M_t$ is not presented since money plays no role in the New Keynesian model. The optimal condition for money demand can be derived, however, by combining the first-order condition for $M_t$

$$\frac{M_t}{P_t} \left[ (1+r_t)^{-1} \right] + \lambda_t E_t \left[ (1+r_t)^{-1} \right] = 0,$$

with (10). Therefore the money demand equation is

$$M_t/P_t = \left[ C^{\mu_t} (1+i_t) \right]^{\nu_t},$$

which determines the amount of $M_t$ required to meet the target interest rate.

\(^7\)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 labor market, $N_t = N_t^s = 1$, must be satisfied.
\[ C_i^{-\lambda} - \lambda_i = 0, \]  
\[ \lambda_i = \beta (1 + r_i) E_i \lambda_{i+1}, \]  
\[ Q_i \lambda_i = \beta (1 + \kappa_r) (1 + r^*_i) E_i Q_{i+1} \lambda_{i+1}, \]  
\[ \left[ \begin{pmatrix} \lambda_i \\ \xi_i \end{pmatrix} \right]^{\gamma - \nu} = \alpha^{\gamma - \nu} A_{i+1}^{\gamma - \nu} \left( \frac{Y_i}{N_i} \right), \]  
\[ \left[ \begin{pmatrix} \lambda_i \\ \xi_i \end{pmatrix} \right]^{\gamma - \nu} = (1 - \alpha)^{\gamma - \nu} \left( \frac{Y_i}{IM_i} \right). \]

Substituting (10) into (9) and taking logs gives the optimal intertemporal allocation of consumption

\[ c_i = E_i c_{i+1} - \sigma \ln \beta - \sigma \ln (1 + r_i), \]  
or

\[ c_i = E_i c_{i+1} + d_0 - d_1 r_i, \]

where \( d_0 = -\sigma \ln \beta, \) \( d_1 = \sigma, \) and lowercase variables denote the logarithms of the uppercase variables.

Taking logs of (13) yields the following cost-minimizing import demand

\[ im_i = y_i - \left( \frac{1}{1 - \nu} \right) q_i - \left( \frac{1}{1 - \nu} \right) \ln \left( \frac{\lambda_i}{\xi_i} \right) + \left( \frac{1}{1 - \nu} \right) \ln (1 - \alpha), \]

or

\[ im_i = y_i - \varphi q_i + \mu, \]

where \( \varphi = 1/(1 - \nu) \) is the elasticity of substitution between imported raw materials and labor, and \( \mu = 1/(1 - \nu)[\ln(1 - \alpha) - \ln(\lambda_i/\xi_i)]. \) Symmetrically, the export demand function is assumed to be given by

\[ ex_i = y^*_i + \varphi^* q_i. \]

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

\[ \bar{y}_i = (1 - \delta) a_i + \delta \bar{m}_i, \]
with \( \delta = (1 - \alpha)(LM^s / Y^s) \), and \( Y^s \) denotes the steady-state values; \( Y_i \) is the natural level of output and \( im_i \) is the level of imports under price flexibility.

Under price flexibility, \( (\lambda / \xi) \) is a constant and equal to \( \theta (\theta - 1) \). Thus (17) implies that, by neglecting the constant intercept term \( \mu \), the value of \( im_i \), conditional on the value of the real exchange rate, is given by

\[
im_i = \bar{Y}_i - \phi q_i. \tag{20}\]

Then (19) and (20) together imply that

\[
\bar{Y}_i = a_i - \sigma q_i, \tag{21}\]

where \( \sigma = [\phi \delta (1 - \delta)] \). (21) indicates that the flexible price level of log output, \( \bar{Y}_i \), is a function of 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 abstract from government expenditure (with the government assumed to run a balanced budget in (7)) in the analysis. Then the goods market clearing condition is

\[
y_i = \omega_1 c_i + \omega_2 e_x, \tag{22}\]

where \( \omega_1 \) and \( \omega_2 \) are steady-state ratios of consumption and exports to output respectively. Define output gap as the difference between actual output and potential output, i.e., \( x_t = y_t - \bar{Y}_t \). Substituting (15) and (18) into (22) and using the definition for output gap with (21) yields

\[
x_t = \alpha_0 + E_r x_{t+1} - \alpha_1 (i_t - E_r \pi_{t+1}) + \alpha_2 (s_t + p^*_t - p_t) + \epsilon^*_t, \tag{23}\]

where \( \alpha_0 = d_c \omega_1 \), \( \alpha_1 = d_i \omega_1 \), \( \alpha_2 = \sigma + \omega_2 \phi^* \), and \( \epsilon^*_t = E_{t} \bar{Y}_{t+1} - a_t + \omega_1 (y^*_t - E_x \pi_{t+1}) \).

The real interest rate is defined by \( r_t = i_t - E_r \pi_{t+1} \), where \( i_t \) is the nominal interest rate and \( \pi_{t+1} = p_{t+1} - p_t \) is the period \( t+1 \) inflation rate; and the real exchange rate is defined by \( q_t = s_t + p^*_t - p_t \).

Eq. (23) is a forward-looking open economy IS curve that describes the aggregate demand of the economy; where \( \epsilon^*_t \) is interpreted as an aggregate demand shock to the economy. The main difference from the traditional IS curve is the dependence of current

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8The labor market clearing condition, \( N_t = 1 \), applies for all \( t \) at the natural level of output; this implies that \( n_t = 0 \).
9Eq. (12) indicates that, under price flexibility, the aggregate markup, given by \( \lambda / \xi \), is constant and equal to \( \theta (\theta - 1) \). The derivation is shown in the Appendix.
10McCallum and Nelson (1999b) show that, for the U.S., there is a weak relationship between the capital stock and output at business-cycle frequencies.
output level on expected future output level. This additional term, $E_{t}x_{t+1}$, raises current output level when expectations of the future output level is higher, because individuals desire to achieve a balanced consumption portfolio. Individuals anticipate a higher level of consumption next period due to higher expected output, which induces consumers to spend more today to smooth out the consumption path. The real interest rate effect on current output is negative, reflecting the intertemporal substitution of consumption. A rise in the value of the real exchange rate, i.e. a real depreciation, is expected to boost current output through the 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 optimizing behavior 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

$$\pi_t = \beta_0 + \beta_1 E_t \pi_{t+1} + \beta_2 x_t + \epsilon_t^\pi. \quad (24)$$

In each period, a fraction of monopolistically competitive firms is allowed to adjust their prices according to a constant probability $(1 - \omega)$; the expected interval between price adjustments is $1/(1 - \omega)$. So probability $\omega$ measures the degree of price rigidity in the economy. Each firm sets the price optimally by minimizing 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-maximizing price in the absence of any restrictions associated with price adjustment. $\epsilon_t^\pi$ is a random disturbance that captures the determinants of the optimal price other than the aggregate output and price level. A higher $\epsilon_t^\pi$ prompts the firms to adjust upwards the actual prices to minimize the adjustment cost, therefore $\epsilon_t^\pi$ 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 models is the inclusion of the uncovered interest parity. Define the foreign real interest rate as $r_t^* = \hat{i}_t^* - E_t \pi_{t+1}$, where $\hat{i}_t^*$ is the foreign nominal interest rate and $\pi_{t+1}^* = p_{t+1}^* - p_t^*$ is the foreign inflation rate. The following uncovered interest parity holds as a first-order approximation when (10) and (11) are combined

$$s_t = E_t s_{t+1} - (i_t - \hat{i}_t^*) + \epsilon_t^\pi. \quad (25)$$

The time-varying risk premium $\epsilon_t^\pi = \kappa_t$ reflects temporary and persistent departures
from the uncovered interest parity.

3.4. Forward-Looking Monetary Policy Rule

Lastly the model is completed with the inclusion of a forward-looking monetary policy rule

\[ i_t = \gamma_0 + \pi_t + \gamma_1 (E_t \pi_{t+1} - \pi^T) + \gamma_2 x_t + \varepsilon'_t, \]  

where \( \pi^T \) is the target inflation rate and \( \varepsilon'_t \) represents the monetary policy shock. Taylor (1993) proposes a simple feedback interest-rate setting rule, where the monetary authority is assumed to respond to observed inflation and output fluctuations in the economy. Due to long and variable policy lags, monetary policy is inherently forward-looking and forecasts of future economic conditions are used to formulate current policy actions. Therefore our specification of monetary policy follows closely the forward-looking rule that is outlined in Clarida et al. (1998, 1999, 2000). The monetary authority is assumed to respond to expected future inflation deviations from its target value and contemporaneous output deviations from its trend value. When there is a positive inflation and/or output deviation from their respective target values, (26) calls for the monetary authority to adjust the nominal interest rate more than one-for-one so that the real interest rate \((i_t - \pi_t)\) rises sufficiently to close the positive gap. Therefore we would expect \( \gamma_1, \gamma_2 > 0 \) if the monetary authority pursues a stabilization policy with respect to inflation and output fluctuations. On the other hand, \( \gamma_1, \gamma_2 < 0 \) indicate that the monetary authority moves to accommodate any inflation and output fluctuations.

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 the government announces policy changes, economic agents update their expectations in anticipation of the new environment they face, which are embedded in the structural model. Since changes in expectations about the future affect current economic behavior, the estimated structural relations are poor guides for policy evaluation under the new regime. Hence 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’ optimizing behavior 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 optimization problem; these cross-equation restrictions identify the structural parameters in the model.11

Alternatively, SVAR models typically consist of a contemporaneous system of broadly defined behavioral relationships with unrestricted short-run lag dynamics. Instead of using lag restrictions to identify structural parameters, this paper adapts the rational expectations identification scheme of Keating (1990) to a New Keynesian open economy which takes full advantage of the features in a SVAR model. The contemporaneous structural model described by (23) through (26) is converted into a corresponding 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

A closed economy New Keynesian model

We begin the demonstration of how to identify a SVAR model under rational expectations with a closed economy version of the New Keynesian model (see, for example, Clarida et al., 1999)12

\[ x_t = \alpha_0 + E_t x_{t+1} - \alpha_1 (i_t - E_t \pi_{t+1}) + \varepsilon_t^x, \]  
\[ \pi_t = \beta_0 + \beta_1 E_t \pi_{t+1} + \beta_2 x_t + \varepsilon_t^\pi, \]  
\[ i_t = \gamma_0 + \pi_t + \gamma_1 \left( E_t \pi_{t+1} - \pi^T \right) + \gamma_2 x_t + \varepsilon_t^i. \]

The identification scheme is based on converting the contemporaneous structural system into an innovations representation that consists of structural disturbances and VAR innovations, by subtracting from each variable the expectation at time \( t-1 \) of that variable conditioned on all available past information.

---

11 In structural rational expectations models, the cross-equation restrictions typically result in over-identification.

12 By adding a real exchange rate term in (27) and the uncovered interest rate parity equation to the closed economy model, we return to the open economy New Keynesian model in section 3. This first step helps to facilitate explanations on how the identification scheme is adapted for an open economy model.
\[ e_t^* = (x_t - E_{t-1}x_t) - (E_tx_{t+1} - E_{t-1}x_{t+1}) + \alpha_1 (i_t - E_{t-1}i_t) - \alpha_1 (E_t\pi_{t+1} - E_{t-1}\pi_{t+1}) \]
\[ = e_t^* - (E_tx_{t+1} - E_{t-1}x_{t+1}) + \alpha_t e_t^1 - \alpha_1 (E_t\pi_{t+1} - E_{t-1}\pi_{t+1}), \] (30)

\[ e_t^* = (\pi_t - E_{t-1}\pi_t) - \beta_1 (E_t\pi_{t+1} - E_{t-1}\pi_{t+1}) - \beta_2 (x_t - E_{t-1}x_t) \]
\[ = e_t^* - \beta_1 (E_t\pi_{t+1} - E_{t-1}\pi_{t+1}) - \beta_2 e_t^1, \] (31)

\[ e_t^i = (i_t - E_{t-1}i_t) - (\pi_t - E_{t-1}\pi_t) - \gamma_1 (E_t\pi_{t+1} - E_{t-1}\pi_{t+1}) - \gamma_2 (x_t - E_{t-1}x_t) \]
\[ = e_t^i - e_t^* - \gamma_1 (E_t\pi_{t+1} - E_{t-1}\pi_{t+1}) - \gamma_2 e_t^1, \] (32)

where \((x_t-E_{t-1}x_t)\), \((\pi_t-E_{t-1}\pi_t)\), and \((i_t-E_{t-1}i_t)\) are the current values of the output gap, inflation, and the interest rate VAR innovations, respectively.

In (30) through (32), each structural disturbance is additionally related to one or both of the expectations revision processes of the output gap and inflation, i.e., \((E_tx_{t+1}-E_{t-1}x_{t+1})\) and \((E_t\pi_{t+1}-E_{t-1}\pi_{t+1})\). To calculate these two terms we first write the reduced-form VAR in stacked form\(^{13}\)
\[
Y_t = AY_{t-1} + Qe_t, \quad (33)
\]
or equivalently
\[
\begin{bmatrix}
y_t \\
y_{t-1} \\
y_{t-2} \\
\vdots \\
y_{t-q+1}
\end{bmatrix}
= \begin{bmatrix}
A_1 & A_2 & \ldots & A_q \\
I_n & 0_n & \ldots & 0_n \\
0_n & I_n & \ldots & 0_n \\
\vdots & \vdots & \ddots & \vdots \\
0_n & 0_n & \ldots & I_n 
\end{bmatrix}
\begin{bmatrix}
y_{t-1} \\
y_{t-2} \\
\vdots \\
y_{t-q+1}
\end{bmatrix}
+ \begin{bmatrix}
0_n \\
0_n \\
\vdots \\
0_n
\end{bmatrix} e_t, \quad (34)
\]
where \(q\) denotes the lag order of endogenous variables, \(I_n\) and \(0_n\) are \((n \times n)\) identity and zero matrices respectively, and \(n = 3\) is the number of endogenous variables.

The \(j\)-step conditional expectation of (33) is
\[
E_{y_{t+j}} = (A)^j Y_t. \quad (35)
\]

Two vectors of length \(nq\) are created to locate the forecasted variables
\[
r_t' = (1,0,0,\ldots,0) \text{ for the output gap},
\]
\[
r_\pi' = (0,1,0,\ldots,0) \text{ for inflation.} \quad (36)
\]

The expected future values of the output gap and inflation one period ahead, \(j = 1\), are derived by premultiplying (35) by the vectors defined in (36)
\[
E_t x_{t+1} = r_t' A Y_t,
\]
\[
E_t \pi_{t+1} = r_\pi' A Y_t. \quad (37)
\]

\(^{13}\)Constants and deterministic variables are ignored since they do not affect expectations revisions.
Hence the expectations revision processes are the differences between (37) and its own expected value at time $t-1$, which by using (33), are

$$E_t x_{t+1} - E_{t-1} x_{t+1} = r_t' A \left( Y_t - E_{t-1} Y_t \right)$$
$$= r_t' \text{AQe}_t,$$  

(38)

$$E_t \pi_{t+1} - E_{t-1} \pi_{t+1} = r_t' A \left( Y_t - E_{t-1} Y_t \right)$$
$$= r_t' \text{AQe}_t.$$

Inserting (38) into the system of VAR innovations described by (30) through (32) yields

$$e_t^x = e_t^x - r_t' \text{AQe}_t + \alpha_t \left( e_t^i - r_t' \text{AQe}_t \right),$$  

(39)

$$e_t^\pi = e_t^\pi - \beta_t r_t' \text{AQe}_t - \beta_t e_t^x,$$  

(40)

$$e_t^i = e_t^i - e_t^\pi - \gamma_t r_t' \text{AQe}_t - \gamma_t e_t^x,$$  

(41)

where the forward-looking behavior embedded in (39) through (41) suggests non-linear restrictions across the coefficients of each contemporaneous structural equation. Economic agents, i.e., consumers, firms, and the monetary authority, are assumed to incorporate all relevant innovations in forecasting future expected values of endogenous variables.

*An open economy New Keynesian model*

We first convert the contemporaneous structural equations of the open economy New Keynesian model represented by (23) through (26) in terms of structural disturbances and VAR innovations. In the process of conversion, innovations to the exogenous variables (i.e., foreign prices and interest rates) become factors inside the system of VAR innovations to the four endogenous variables; hence the following innovations representation contains only endogenous variable innovations

$$e_t^x = e_t^x - \left( E_t x_{t+1} - E_{t-1} x_{t+1} \right) + \alpha_t e_t^i - \alpha_1 \left( E_t \pi_{t+1} - E_{t-1} \pi_{t+1} \right) - \alpha_2 \left( e_t^i - e_t^\pi / 400 \right),$$  

(42)

$$e_t^\pi = e_t^\pi - \beta_t \left( E_t \pi_{t+1} - E_{t-1} \pi_{t+1} \right) - \beta_t e_t^x,$$  

(43)

$$e_t^i = e_t^i - \left( E_t s_{t+1} - E_{t-1} s_{t+1} \right) + e_t^i,$$  

(44)

$$e_t^i = e_t^i - e_t^\pi - \gamma_t \left( E_t \pi_{t+1} - E_{t-1} \pi_{t+1} \right) - \gamma_t e_t^x,$$  

(45)

where the domestic price innovation is equal to domestic inflation innovation over
Economic agents are required to update their future expectations on the output gap, inflation, and the 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 \((E_t s_{t+1} - E_{t-1} s_{t+1})\). In the closed economy model all observable innovations contribute to the revision of future expectations. Since the exogenous variable innovations are subsumed within the innovations representation in (42) through (45), we can effectively calculate the expectations revision processes through the VAR stacked form (33), \(Y_t = A Y_{t-1} + Q \varepsilon_t\). With \(n = 4\), the following vectors of length \(nq\) are created
\[
\begin{align*}
r'_s &= (1,0,0,\ldots,0) \\
r'_x &= (0,1,0,\ldots,0) \\
r'_r &= (0,0,1,\ldots,0)
\end{align*}
\]
(46)

The expectations revision processes are defined as
\[
\begin{align*}
(E_t x_{t+1} - E_{t-1} x_{t+1}) &= r'_x A Q e_t \\
(E_t \pi_{t+1} - E_{t-1} \pi_{t+1}) &= r'_\pi A Q e_t \\
(E_t s_{t+1} - E_{t-1} s_{t+1}) &= r'_r A Q e_t
\end{align*}
\]
(47)

Apply the definitions in (47) to the innovations system
\[
\begin{align*}
\varepsilon'_t &= e'_t - r'_x A Q e_t + \alpha_1 (e'_t - r'_x A Q e_t) - \alpha_2 (e'_t - e'_t / 400) \\
\varepsilon'_\pi &= e'_\pi - \beta_1 r'_\pi A Q e_t - \beta_2 e'_\pi \\
\varepsilon'_r &= e'_r - r'_r A Q e_t + \varepsilon'_t \\
\varepsilon'_s &= e'_s - r'_s A Q e_t - \gamma_1 r'_s A Q e_t - \gamma_2 e'_s
\end{align*}
\]
(48) \(49) \(50) \(51)

4.3. Full information maximum likelihood estimation (FIML)

We write the dynamic open economy structural model in matrix form
\[
\Gamma_0 y_t = \Gamma_1 y_{t-1} + \cdots + \Gamma_q y_{t-q} + \Lambda_0 z_t + \Lambda_1 z_{t-1} + \cdots + \Lambda_k z_{t-k} + \varepsilon_t, \quad \varepsilon_t \sim (0, D),
\]
(52)

where \(y_t = (x_t, \pi_t, s_t, i_t)'\) is the vector of endogenous variables and \(z_t = (p_t, i_t)'\) is the vector of exogenous variables, \(\Gamma_i\) and \(\Lambda_k\) are coefficient matrices for the endogenous and exogenous variables with lag order \(q\) and \(k\) respectively, the vector \(\varepsilon_t = (e'_t, e'_\pi, e'_r, e'_s)'\) contains the structural disturbances, \(0\) is a (4×1) vector of zeros, and \(D\) is a (4×4) diagonal variance-covariance matrix.

Premultiply (52) by \(\Gamma_0^{-1}\) yields the reduced-form VAR

---

14Because quarterly inflation is calculated on an annualized basis, so the connection between inflation and prices is \(\pi_t = 400(p_t - p_{t-1})\). The inflation innovation is derived by subtracting \(E_{t-1} \pi_t\) away from \(\pi_t\), i.e., \(\pi_t - E_{t-1} \pi_t = 400(p_t - E_{t-1} p_t)\), and therefore we obtain \(e'_\pi = e'_\pi / 400\).
\[ y_t = A_i y_{t-1} + \cdots + A_q y_{t-q} + B_{0} z_t + B_{1} z_{t-1} + \cdots + B_{k} z_{t-k} + e_t, \quad e_t \sim (0, \Omega), \]  
(53)

where \( A_i = \Gamma_0^{-1} \Gamma_i, \quad i = 1, \ldots, q \), \( B_j = \Gamma_0^{-1} \Lambda_j, \quad j = 0, 1, \ldots, k \), \( e_t = \Gamma_0^{-1} e_t \), and \( \Omega = \Gamma_0^{-1} D \Gamma_0^{-1}' \).

The estimation proceeds in two steps. Step 1 involves estimating the reduced-form VAR specified by (53). Parameter estimates contained in \( A \) and the rational expectations restrictions dictated by (48) through (51) are imposed on \( \Gamma_0 \); further exclusion restrictions placed on the contemporaneous exogenous variables are in \( \Lambda_0 \). The lagged dynamics are unrestricted and we estimate the structural system (52) using FIML with the assumption of normality in the structural disturbances. The structural parameters are obtained by maximizing the following log-likelihood function

\[
L = \sum_{t=1}^{T} \left[ -\frac{n}{2} \ln(2\pi) - \frac{1}{2} \ln \left| \Gamma_0^{-1} D \Gamma_0^{-1}' \right| - \frac{1}{2} e_t' D^{-1} e_t \right].
\]  
(54)

5. Data and empirical results

The SVAR model is estimated with Australian quarterly data from 1984Q1 to 2001Q4 with a total of 72 observations. Domestic variables include the output gap, the consumer price index, the SA/SUS bilateral exchange rate, and the official cash rate; the U.S. consumer price index and the federal funds rate make up the foreign sector of the model. The principal macroeconomic data series are presented in the Data Appendix. Given the financial market deregulation introduced by the Australian government in the early 1980s, the commencement of the sample period in 1984 avoids possible structural breaks in the data.

5.1. Diagnostic tests on the underlying VAR

Estimation of SVAR models are 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 structural estimators can be utilized with good faith. The maximum lag order associated with the VAR reduced form is generalized to four lags for the endogenous variables and two lags for the exogenous variables, i.e., VAR(4,2).\(^{16}\)

\(^{15}\)The Australian output gap is computed by using the Hodrick-Prescott filter with the smoothness parameter set to 1600.

\(^{16}\)Given the data is quarterly and its small sample size, the upper bound was initially set at 4 lags for both the endogenous and exogenous variables. However, the interest rate equation in VAR(4,4) failed to reject the null of no serial correlation. We thus proceeded to test down the order of exogenous variable lags by using the Schwarz Bayesian Criterion (SBC). We settled with VAR(4,2) (since it had the smallest SBC statistic) out of the following test results: VAR(4,4) = -292.78, VAR(4,3) = -295.53, and VAR(4,2) =
Keating (2000) terms this approach ‘asymmetric VAR’ which permits greater flexibility in specifying the dynamics. Hence, (53) is estimated as a VAR(4,2) with a constant and three seasonal dummies for each endogenous variable equation. Table 1 shows that the underlying VAR reduced form satisfies the null hypotheses of no serial correlation, no heteroskedasticity, and normality in the residuals.

[----- Insert Table 1 here -----]

5.2. Structural model specification

In addition to the contemporaneous parameters in $\Gamma_0$ and $\Lambda_0$, and the lagged parameters in $\Gamma_1, \ldots, \Gamma_4, \Lambda_1,$ and $\Lambda_2$, each endogenous variable equation in (52) also has a constant and three seasonal dummies. The total number of parameters in the structural model (52) is 106, which can be broken down into $4 \times 1 = 4$ constants, $4 \times 3 = 12$ seasonal dummies, $4 \times 4 \times 4 = 64$ lagged parameters for the four endogenous variables, $4 \times 2 \times 2 = 16$ lagged parameters for the two exogenous variables, 6 contemporaneous parameters in $\Gamma_0$ and $\Lambda_0$, and 4 variances in $D$. In the underlying VAR (53), the total number of reduced-form parameters is 114, which can be broken down into $4 \times 1 = 4$ constants, $4 \times 3 = 12$ seasonal dummies, $4 \times 4 \times 4 = 64$ lagged parameters for the four endogenous variables, $4 \times 2 \times 2 = 16$ lagged parameters for the two exogenous variables, 8 contemporaneous parameters in $B_0$, and 4 variances and 6 covariances in $\Omega$. Therefore, there are $114 - 106 = 8$ over-identifying restrictions. The likelihood-ratio (LR) test yields a statistic of 31.96. This statistic is asymptotically distributed as a $\chi^2$-variate with 8 degrees of freedom and the 5% critical value is 15.51. The test result rejects the null hypothesis that the restricted (structural) model comes from the same asymptotic distribution of the unrestricted (underlying VAR) model.

Cho and Moreno (2006) and Garratt et al. (2003) showed 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 35.82 indicating that the LR test adjusted for small sample does not reject the over-identifying restrictions implied by the economic theory.\(^{17}\)

5.3. Contemporaneous parameter estimates

The FIML estimates of the contemporaneous parameters in (48) through (51) are shown in Table 2. Asymptotic standard errors are obtained as the inverse of the Hessian

\[^{17}\text{We bootstrapped 1000 times to map out a small sample distribution of the LR statistic.}\]
matrix. The parameter estimates all possess the correct signs. For the IS equation, $\alpha_1$ and $\alpha_2$ are both significantly different from zero that indicate a reduction in the real interest rate and a depreciating real exchange rate both stimulate aggregate demand.

[----- Insert Table 2 here -----]

For the AS equation, $\beta_1$ represents the subjective discount factor of a representative forward-looking firm and $\beta_2$ captures the importance of the output gap in driving the inflation dynamics. In the recent empirical literature on the estimation of the New Keynesian Phillips curve (NKPC), a number of studies estimated a ‘hybrid’ NKPC model, which incorporates, in addition to the forward-looking component, lags of inflation not implied by the standard model with rational expectations. Our estimation of the open economy dynamic structural model (52) is consistent with the hybrid model approach as lagged inflation is included in the SVAR specification. The relevant coefficients (and their $p$-values) are $\beta_1 = 0.35 (0.13)$ for $E_t \pi_{t+1}$, $0.61 (0.00)$ for $\pi_{t-1}$, $0.03 (0.90)$ for $\pi_{t-2}$, $0.13 (0.52)$ for $\pi_{t-3}$, and $0.06 (0.75)$ for $\pi_{t-4}$. The coefficients suggest that private agents place a larger weight on past inflation than on expected future inflation.\(^{18}\)

This result agrees with Gruen et al. (1999) who also find that inflation expectations in Australia are mainly backward-looking. Two overseas studies that come to similar conclusions are Fuhrer and Moore (1995) who find that the NKPC (Eq. (24)) with purely forward-looking dynamics inadequately accounts for the degree of inflation persistence in the post-war U.S. data, and Fuhrer (1997) confirms that the presence of the forward-looking component in explaining inflation is not required empirically. Other studies have obtained an estimated $\beta_1$ of more than 0.5 which indicates that the forward-looking component is the dominant explanatory variable, e.g., Gali and Gertler (1999) for the U.S. and Gali et al. (2001) for the Euro area report a high value for $\beta_1$ of more than 0.75; this implies that the majority of the firms are forward-looking price-setters. Jondeau and Le Bihan (2005) estimate a hybrid NKPC that includes leads and lags of inflation for the U.S. and the Euro area. They find that the fraction of backward-looking price-setters increases and the fit to the data improves when the number of leads and lags of inflation increases. Across the six countries they examined, both the backward-looking and forward-looking components are statistically significant and take on almost equal weights. Therefore, at least for the U.S. and European inflation dynamics, a hybrid model fits the data better than a pure NKPC or a pure backward-looking model. Roberts (2001) demonstrates similar results for the U.S., he argues that additional lags are necessary to represent the simple autoregressive rules of

\(^{18}\)Since $\beta_1$ is not statistically significant from zero, the implication is actually that inflation expectations in Australia are purely backward-looking.
thumb that private agents use to forecast inflation.

There are two potential sources mentioned in the literature that try to explain the conflicting empirical results on inflation dynamics. First, Galí and Gertler (1999), among others, argue that the relevant forcing variable in the forward-looking Phillips curve should be the marginal cost and not the output gap. Because a profit-maximizing firm, for example operating in the Calvo (1983) staggered pricing world, is constrained by an exogenously given frequency of price adjustment, or adjustment costs. The firm will set prices as a function of their expectations concerning future costs. Second, the disparity in the results for inflation dynamics may be due to different lead and lag structures of the hybrid model, as shown in Fuhrer and Moore (1995) and Fuhrer (1997). In their extensive investigation, Jondeau and Le Bihan (2005) obtain mixed results for the preferred forcing variable. For a NKPC model with three leads and lags, marginal cost is the preferred forcing variable for the U.S. and U.K.; and the output gap is the preferred forcing variable for Germany, Italy, and the Euro area. The positive and significant estimate we obtain for $\beta_2$ suggests that the output gap is an important forcing variable for the inflation dynamics in Australia.

From the monetary policy rule, the estimated coefficient of $\gamma_1 = 2.16$ suggests that a rise in expected annual inflation of 1%, holding constant output gap, induces the monetary authority to raise the real interest rate by 215 basis points; and $\gamma_2 = 2.40$ suggests that, holding constant expected inflation, a 1% rise in the output gap induces the monetary authority to increase the real interest rate by 240 basis points. Both point estimates from the monetary policy rule are significantly different from zero and they indicate that the RBA implemented policy measures to counter inflation and output fluctuations since 1984. This result is consistent with the interest rate rule estimations in de Brouwer and Gilbert (2005). The estimated interest rate sensitivities indicate that the RBA responds to output fluctuations with greater intensity than inflation fluctuations. This may reflect the fact that the sample period covers the 1980s which was a decade of higher inflation and monetary policy did not attain a high level of credibility with the public and financial markets in a newly deregulated environment. Australian monetary policy moved from a monetary targeting framework to a ‘checklist’ approach with disappointing result in the fight against inflation. The lack of trust and confidence in the evolving state of monetary policy meant that the monetary authority could not lock in inflation expectations. Therefore monetary policy measures had to be much more aggressive to inflation fluctuations, and more so to output fluctuations because of their chain effects on inflation, to achieve the desired outcome.

Actual and predicted values of the endogenous variables are presented in Figure 1. The graphs show that in-sample fitted values of the estimated structural equations track the actual data very well.
5.4. Impulse response functions

Impulse response functions for the four structural shocks: interest rate, exchange rate, aggregate demand, and aggregate supply shocks are shown in Figures 2 to 5. The size of each structural shock is one standard deviation of the estimated value; where the dynamic responses of the output gap, inflation, and the interest rate are measured in percentage point. The dynamic responses of the exchange rate are in logs and multiplied by 100, so that its impulse response functions approximate percentage changes. We also show 90% confidence intervals which are based on Runkle’s (1987) bootstrapping procedure with 5000 simulations. In most cases, the confidence intervals indicate that the dynamic responses are statistically significant in the short run (within the first year of the initial shock). All responses show mean-reversion which reflects the stationary properties of the structural model.

**Interest rate shock**

Figure 2 shows the effect of an unexpected monetary tightening of 0.01% that leads to a significant decrease 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; hence there are none of the price and exchange rate puzzles that have been recorded in other work, e.g., Eichenbaum and Evans (1995) and Grilli and Roubini (1995). Significant contractions in the output gap lasts for two quarters and the inflation rate falls significantly for four quarters. In the short run, the initial tightening monetary policy stance is loosened after one quarter to staunch the deflationary pressure and output contraction. After two years of monetary expansion the policy is reversed to stabilize output. In the medium run, inflation responds to monetary policy tightening returning to its target value.

The dynamic behavior of the exchange rate complies with the prediction of uncovered interest parity that a positive innovation in the domestic interest rate relative to the foreign interest rate is associated with subsequent gradual depreciation of the domestic currency after the impact appreciation. We observe that the exchange rate embarks on a depreciating path after the first quarter; where overshooting occurs and the exchange rate reaches a peak in quarter 7. The exchange rate then continuously appreciates where its medium-run value approaches its initial level. Confidence intervals indicate that fluctuations in the exchange rate are significant between quarters 5 and 10.

Our over-depreciation result differs from the finding in Eichenbaum and Evans (1995) and Grilli and Roubini (1995) that a positive interest rate differential in favor of domestic assets is associated with persistent appreciation of the domestic currency up to
two years after the initial impact. Dynamic responses of the exchange rate are thus consistent with the contractionary effect a negative monetary policy shock generates in traditional theoretical analysis.

[----- Insert Figure 2 here -----]

**Exchange rate shock**

A positive exchange rate shock is shown in Figure 3; a one standard deviation exchange rate shock is equivalent to a depreciation of 0.88%. This immediately causes a significant expansion in the output gap by 0.02% and a rise in inflation by 0.1%. Monetary policy is tightened by 0.62% to counter the imminent inflationary pressure. In the short run, 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 variable in the interest rate rule, Taylor (2001) argues that the exchange rate affects output through the expenditure-switching effect and inflation through the pass-through effect. 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 AS equation. Initial monetary policy tightening was successful in reversing the path of the exchange rate, which in turn depresses the level of economic activity and inflation. In the medium run, the monetary authority eases its policy stance to reflate the economy with the aid of a depreciating exchange rate.

[----- Insert Figure 3 here -----]

**Aggregate demand shock**

In figure 4, 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. Subsequent dynamic responses are dominated by the persistent appreciation in the exchange rate,\(^\text{19}\) and the confidence intervals show that the appreciation is significant up to quarter 9. The large and immediate appreciation creates sustained deflationary pressure in the economy for the next 9 quarters after the initial impact of the aggregate demand shock and also causes output to contract after 5 quarters of expansion. The forward-looking monetary authority tries to lessen the future contractionary impact on the economy by reacting aggressively to the large appreciation and deflationary pressure with a cut in the interest rate almost immediately. Thus the

\(^{19}\text{This is consistent with the results in Fisher (1996) who investigates movements in the Australian nominal and real exchange rates.}\)
exchange rate behaves as the major factor in correcting aggregate demand shocks, and the monetary authority appears to act to control the extent of the exchange rate adjustment. After 5 quarters the exchange rate starts to depreciate which helps to expand output and builds up reflationary pressure in the economy. The impulse response function for the interest rate suggests that the monetary authority has maintained a relatively loose monetary policy stance to reduce the negative output gap. In the medium run, the interest rate is returned to its neutral value, corresponding with inflation having converged to its target value.

[----- Insert Figure 4 here -----]

_Aggregate supply shock_

The dynamic effects of an unexpected positive aggregate supply shock are shown in Figure 5. The immediate responses of a fall in the output gap by 0.38%, an increase in inflation by 0.4%, and a depreciation in the nominal exchange rate by 0.3% match closely to what would be expected from an adverse supply shock, e.g., the negative impact of drought on farm output, which forces firms to raise prices. Given the transitory nature of the shock, the impulse response function for the interest rate suggests that the monetary authority should wait and allow the economy to self-correct the adverse aggregate supply shock. In the short run we observe that the initial nominal depreciation is helpful in stabilizing output while inflation continues to fall over time and eventually stabilize in the medium run.

[----- Insert Figure 5 here -----]

5.5. _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 forecast error variance 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 variability in output gap. This shock accounts for around 63% of the forecast error variance at short horizons and 65% at long horizons. Interest rate 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 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 the 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 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 shock in accounting for fluctuations in the interest rate. The forecast error variance in the interest rate is dominated by the 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, the aggregate demand shock becomes relatively important in its contribution; explaining 14.7% of the variability at the 40 quarter horizon.

[----- Insert Table 3 here -----]

6. Conclusions

A SVAR model for the Australian economy covering the period 1984 to 2001 is estimated, where the contemporaneous structural relationships are derived from an open economy New Keynesian model. Since the New Keynesian model is based on intertemporally optimizing agents who are rational and forward-looking, the identification of the SVAR model under rational expectations requires exclusion restrictions to be placed on the VAR residuals and the covariance matrix.

The SVAR model is estimated by full-information maximum likelihood that accounts for full interactions between consumers, firms and the monetary authority operating in the economy. Contemporaneous parameter estimates from the structural equations and simulated dynamic responses to an exogenous monetary tightening indicate that the New Keynesian SVAR model gives an adequate fit to the Australian data. The
parameter estimates are largely consistent in magnitudes and signs with other studies in the literature. From the IS curve, we find that a reduced real interest rate and a depreciating real exchange rate boost the level of current output. Looking at the New Keynesian Phillips curve, the estimated coefficients for the subjective discount factor and the lagged inflation rates support the notion that a large fraction of firms is backward-looking in setting prices. The output gap is found to be a significant and important forcing variable in driving the Australian inflation dynamics. The estimated coefficients from the monetary policy rule suggest that the RBA has dual policy objectives of maintaining price stability and managing the business cycle since 1984. In responding to inflation and output movements away from their target values, the RBA adjusts nominal interest rates more than one-for-one so that real interest rates move sufficiently to stabilize fluctuations in inflation and output. Interestingly, the estimated coefficient on output gap suggests a somewhat larger responsive weight for the RBA in tackling the real economy relative to maintaining the inflation target. Since the sample period covers the 1980s which was a period of much higher inflation rates and low monetary policy credibility, the parameter estimates reflect the intensity and aggressiveness that were required from monetary policy measures to achieve the desired outcome.

Dynamic responses of the macroeconomic variables to an exogenous monetary tightening were simulated to check for the price and exchange rate puzzles. In the short run, an exogenous rise in the interest rate has significant contractionary effects on output and inflation. The relatively higher domestic interest rate induces the exchange rate to appreciate on impact. This short-run effect is supplemented by information from the forecast error variance which shows that the interest rate shock explains 32% of output gap fluctuations, 53% of inflation fluctuations, and 24% of exchange rate fluctuations at the one quarter horizon. The exchange rate depreciates immediately after the initial appreciation, however, reaching a peak level of depreciation before appreciating continuously to approach its initial level in the medium run. There is no sign of a price or exchange rate puzzle, which further endorses the relevance of the New Keynesian model for the Australian economy.

The impulse response functions for an exchange rate shock and for an aggregate demand shock highlight the sensitivity the monetary authority displays towards exchange rate fluctuations in the short run. The RBA reacts swiftly by raising the interest rate to stabilize output and inflation in the face of 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 the expenditure-switching effect and on inflation through the pass-through effect. The forecast error variance shows that the exchange
rate shock explains 99.95% of interest rate fluctuations in the immediate short run. When the economy experiences a positive aggregate demand shock, this causes a large and sustained nominal exchange rate appreciation. The forecast error variance indicates that real shocks explain 67% of exchange rate fluctuations and remain dominant at 57% at long horizons. The forward-looking monetary authority cuts the interest rate almost immediately with the purpose of lessening the current and future adverse impact on output and inflation brought about by the sustained appreciation. Thus this result suggests consistency with a favorable aggregate demand shock that increases the demand for Australia’s exports, which pushes up the value of the currency. Therefore the RBA appears to control the movement of the exchange rate as a corrective instrument to stabilize the economy.

When an exogenous inflation shock hits the economy, we observe a contraction in output, a rise in inflation, and nominal exchange rate depreciation in the short run. One recent example in Australia was the adverse impact of drought on farm output which forces firms to raise their prices. The impulse response functions suggest that the RBA takes an inactive role of allowing the economy to self-correct the temporary aggregate supply disturbance. We observe that the initial nominal depreciation is helpful in stabilizing output in the short run while inflation continues to fall and stabilize in the medium run.
References


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Hall, S., 1995, Macroeconomics and a bit more reality, Economic Journal 105, 974-988.
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Appendix: Derivation of the aggregate markup under price flexibility (footnote 9)

Each monopolistically competitive firm satisfies the domestic demand represented by

\[ D_{zt} = \left( \frac{P_{zt}}{P_{t}} \right)^{\theta} D_{t}, \quad (A.1) \]

where \( D_{zt} \) is the domestic demand for good \( z \).

Foreigners’ demand for the households’ exports is assumed to be given by

\[ EX_{zt} = \left( \frac{P_{zt}}{P_{t}} \right)^{\theta} EX_{t}, \quad (A.2) \]

where \( EX_{zt} \) is the export demand for good \( z \).

Since the total demand for domestic goods comes from these two sources, \( Y_{t} = D_{t} + EX_{t} \), the aggregate demand faced by each household is

\[ Y_{zt} = \left( \frac{P_{zt}}{P_{t}} \right)^{\theta} Y_{t}, \quad (A.3) \]

where \( Y_{zt} \) is the aggregate demand for good \( z \).

In Calvo’s (1983) world of staggered price setting, firms that are allowed to reset their price are randomly selected by the probability \((1-\omega)\); while the remaining firms that are not allowed to adjust their price are assigned with probability \(\omega\). While each firm supplies a differentiated product, they are identical in having the same production technology and facing the same demand curve, with the exception that they set their current prices at different dates in the past according to the random probability \((1-\omega)\). However, all firms adjusting in period \( t \) face the same problem and therefore they will set the same price. Let \( X_{t} \) denote the price set by firms that receive the signal allowing them to change price. The firm’s problem in period \( t \) is to maximize the expected discounted value of current and future profits

\[
\max \ E_{t} \sum_{j=0}^{\infty} (\omega \beta)^{j} \left[ X_{t} \left( \frac{X_{t}}{P_{t+j}} \right)^{\theta} Y_{t+j} - W_{t+j} N_{t+j} - S_{t+j} P_{t+j}^{*} IM_{t+j} \right], \quad (A.4)
\]

subject to

\[
\left( \frac{X_{t}}{P_{t+j}} \right)^{\theta} Y_{t+j} \leq \left[ \alpha \left( A_{t+j} N_{t+j} \right)^{\nu} + (1-\alpha) \left( IM_{t+j} \right)^{\nu} \right]^{\frac{1}{\nu}}, \quad (A.5)
\]

where the price of the intermediate imported good, \( S_{t+j} P_{t+j}^{*} \), is expressed in terms of the domestic currency value.

Let \( \zeta \) denote the multiplier on constraint (A.5), the Lagrangian function
corresponding to the above program is

\[
L = E_t \sum_{j=0}^{\infty} (\omega \beta)^j \left[ X_t \left( \frac{X_t}{P_t} \right)^{-\theta} Y_{t+j} - W_{t+j} N_{t+j} - S_{t+j} P_{t+j}^* IM_{t+j} \right] + E_t \sum_{j=0}^{\infty} (\omega \beta)^j \left[ \alpha \left( A_{t+j} N_{t+j} \right)^\nu + \left( 1 - \alpha \right) \left( IM_{t+j} \right)^\nu \right]^{\frac{1}{\nu}} - \left( \frac{X_t}{P_{t+j}} \right)^{-\theta} Y_{t+j} \right].
\]

Each term is weighted by the discount factor \( \beta^j \) and the probability \( \omega^j \) that the price set in period \( t \) is still unchanged in period \( t+j \).

The first-order condition with respect to labor \( N_t \) is

\[
\xi_{t+j} = \frac{W_{t+j} N_{t+j}}{\alpha \left( A_{t+j} N_{t+j} \right)^\nu \left( Y_{t+j} \right)^{1-\nu}}.
\]

(A.6)

The multiplier \( \xi_{t+j} \) can be seen as the nominal marginal cost in period \( t+j \).

We now solve for the first-order condition with respect to prices \( X_t \)

\[
X_t = \left( \frac{\theta}{\theta - 1} \right) E_t \left[ \sum_{j=0}^{\infty} (\omega \beta)^j W_{t+j} N_{t+j} \right] \left[ \sum_{j=0}^{\infty} (\omega \beta)^j \alpha \left( A_{t+j} N_{t+j} \right)^\nu \left( Y_{t+j} \right)^{1-\nu} \right].
\]

(A.7)

In the flexible-price equilibrium, all firms are able to adjust their prices every period, i.e., \( \omega = 0 \), (A.7) becomes

\[
\bar{X}_t = \left( \frac{\theta}{\theta - 1} \right) \frac{W_t N_t}{\alpha \left( A_t N_t \right)^\nu \left( Y_t \right)^{1-\nu}}.
\]

(A.8)

Eq. (A.8) states that, when prices are perfectly flexible, each firm sets a price \( \bar{X}_t \) equal to a markup \( (\theta \theta - 1) \) above the nominal marginal cost. Rearrange (12) in terms of \( (\lambda_t / \xi_t) \) and equate to (A.8) shows that

\[
\frac{\lambda_t}{\xi_t} = \frac{\alpha \left( A_t N_t \right)^\nu \left( Y_t \right)^{1-\nu}}{W_t N_t} X_t = \frac{\theta}{\theta - 1}.
\]

(A.9)

So under price flexibility, the aggregate markup given by (\( \lambda_t / \xi_t \)), is constant and equal to \( (\theta \theta - 1) \).
Data appendix

**Australian Output Gap**

**Australian Inflation Rate**

**$A/$US Bilateral Exchange Rate**

**Australian Cash Rate**

**US Consumer Price Index**

**US Federal Funds Rate**
### Tables

#### Table 1: Reduced-form diagnostics

<table>
<thead>
<tr>
<th>Diagnostic Tests</th>
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<th>$\pi_t$</th>
<th>$s_t$</th>
<th>$i_t$</th>
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<td>(0.62)</td>
<td>(0.40)</td>
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<td>(0.61)</td>
<td>(0.19)</td>
<td>(0.33)</td>
<td>(0.57)</td>
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**Notes:** P-values are in parentheses. The diagnostic tests are: the Jarque-Bera normality test, an $F$-test for fourth-order ARCH effects based on regression of squared residuals on lagged squared residuals, and an $F$-test for serial correlation based on regression of residuals on initial regressors and four lagged residuals. The $F$-test is a modified Lagrange multiplier (LM) test.

#### Table 2: Contemporaneous structural estimates

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<th>$\beta_2$</th>
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**Note:** P-values are in parentheses.
Table 3: Forecast error variance decomposition

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Notes: IR denotes the interest rate shock; ER denotes the exchange rate shock; AD denotes the aggregate demand shock; and AS denotes the aggregate supply shock.
Figures

Figure 1: Historical values vs. in-sample predicted values
Figure 2: Impulse response functions to a one standard deviation interest rate shock
Figure 3: Impulse response functions to a one standard deviation exchange rate shock
Figure 4: Impulse response functions to a one standard deviation aggregate demand shock
Figure 5: Impulse response functions to a one standard deviation aggregate supply shock
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