An Estimated, New Keynesian Policy Model for Australia*

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Abstract

A two-block open economy model is estimated in this paper using Australian and U.S. data. Evaluation of the estimated model is carried out in relation to a simple closed economy alternative. Namely, we inspect the implied transmission mechanisms, and examine the relative out-of-sample forecasting performance of the closed and open economy models.

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1. Introduction

Dynamic Stochastic General Equilibrium (DSGE) models have become the workhorse of policy modeling and a popular tool for analyzing various features of national and world economies. Two broad strands in the literature can be identified. One strand works with microfounded medium-scale DSGE models, as e.g. Christiano *et al.* (2005) and Smets and Wouters (2003); the other strand favours more tractable 'policy-type' models such as, for example, McCallum and Nelson (2000) and Svensson (2000). We follow the second strand of the literature in this paper and estimate an open economy New Keynesian Policy Model (NKPM) for Australia. To our knowledge only a few papers have tried to estimate these types of models for Australia, among them being the studies by Dennis (2003), Leu (2004), Justiniano and Preston (2004), Lubik and Teo (2005), and Lubik and Schorfheide (*forthcoming*). Leu (2004) estimates a purely forward-looking model of rather low empirical relevance. Dennis (2003), on the other hand, restrains himself to a model that is driven largely by an empirical fit, and thus distances himself from a relevant microfounded motivation. Lubik and Teo, and Lubik and Schorfheide work with a group of countries and one-block open economy DSGE models and only Lubik and Teo report detailed results for Australia. Justiniano and Preston, on the other hand, consider a two-block open economy DSGE model and report detailed results for a group of developed open economies including Australia. We would like to follow up on the existing work by taking an alternative route and consider a two-block open economy NKPM for Australia.

Our motivation for taking this alternative route comes from the convenience encapsulated in the NKPM setup. Namely, these type of models are based on 'implicit' microfoundations in the sense that their 'semi-reduced' structural forms are not restrictive on the complexity of the underlying microfoundations. For instance, the hybrid New Keynesian IS curve, describing the dynamics of the output gap by means of the expected future output gap and the past output gap, can be derived as a result of consumption habit formation or costly adjustment of capital stock, or both, without being explicit about the implied cross-equation coefficient restrictions concerning the structural equations of the model. Also, the DSGE models may require estimation of unobserved variables, as e.g. in Lubik and Shorfheide (*forthcoming*) and Justiniano and Preston (2004), which, on one hand, may help the model to fit the data better, but, on the other hand, can obscure identification of the model parameters and use up some of the information available in the data.

In this paper we take as a reference point the New Keynesian Policy Model proposed by Svensson (2000) which consists of a domestic and world economy. The world economy, approximated by the U.S. in this paper (see also Justiniano and Preston, 2004), is modeled in a structural way so as to better identify foreign structural shocks and model their transmission into the domestic (Australian) economy. Justiniano and Preston (2004) also find that treating the foreign block as unobserved can lead to instability of the open economy's parameter estimates. Having such a two-block setup, we then focus on whether this open economy model adds additional insights into the functioning of the Australian economy. This is gauged in relation to a simple closed economy benchmark. Evaluation of the estimated open and closed economy models is carried out by inspecting the models' implied transmission mechanisms and examining their relative out-of-sample forecasting performance.

Our findings can be summarized as follows. The implied transmission mechanism of the two models differ significantly, and the open economy model seems to outperform the closed economy model in terms of the out-of-sample forecast up to six quarters ahead. We thus find that it is important to consider an open economy and possibly two-block economy setup when analysing an optimal monetary policy in Australia.

2. Model

In this section we outline a New Keynesian Policy Model capturing some of the basic characteristics of a small open economy. This includes the transmission of foreign shocks into the domestic economy. We use a two-block setup to analyze interactions between the Australian and the U.S. economies, and to identify and label the foreign shocks. We do not go through the microfounded motivation of the employed model as it is similar to the New Keynesian models developed and used by Monacelli (2003), Bergin (2003), Clarida *et al.* (2001 and 2002), McCallum and Nelson (2000), Obstfeld and Rogoff (2000) or Svensson (2000). However, we provide an interested reader with references that elaborate on the motivation behind our setup. The small open economy part of the model can be mapped into a reduced-form VAR including inflation, π_t, an output gap, y_t, a short-term nominal interest rate, r_t, and a real exchange rate, q_t.

The equation characterizing inflation dynamics takes on the following form:

$$\pi_t = \rho_\pi \mathbb{E}_t [\pi_{t+1}] + (1 - \rho_\pi) \pi_{t-1} + \lambda y_t + e_{AS,t} \tag{1}$$

where t denotes time, $\mathbb{E}_t$ the expectation of a variable conditional on the information set available to agents at time t and $e_{AS,t}$ is a stationary but autocorrelated supply shock, properties of which will be discussed below. Equation (1) describes the hybrid New Keynesian Phillips Curve (NKPC) which states that inflation depends on the expected inflation one-period ahead, the one-period lagged inflation and the current output gap with the respective weights given by ρ_π and λ. The hybrid NKPC arises as a consequence of the Calvo-type pricing mechanism with a partial indexation to last period's inflation. Namely, firms that are not allowed to re-optimize their prices in a given period index their prices according to last period's inflation and the inflation target (steady-state inflation). For an explicit derivation of the hybrid NKPC from first principles see e.g. Clarida *et al.* (2002), Christiano *et al.* (2005) or Smets and Wouters (2003). The empirical usefulness of the hybrid NKPC is also advocated by Gali and Getler (1999) and Cho and Moreno (*forthcoming*).

The output gap dynamics is described by the following equation of motion:

$$y_t = \rho_y \mathbb{E}_t [y_{t+1}] + \left(1 - \rho_y\right) y_{t-1} - \delta_1 (r_{t-4} - \mathbb{E}_{t-4} [\pi_{t-3}]) + \delta_2 (q_{t-1}) + e_{IS,t} \tag{2}$$

The output gap thus depends on its expected value one-period ahead and its lagged value where the relative impact is given by ρ_y. Further, the output gap is influenced by changes in the lagged real interest rate and the real exchange rate. The forward-looking term is due to households' inter-temporal optimizing behavior and the lagged term arises as a result of internal or external consumption habit formation or a costly adjustment of the capital stock (see e.g. Clarida *et al.*, 2002; Christiano *et al.*, 2005; and Smets and Wouters, 2003). The presence of the real exchange rate (the terms of trade), q_t, in the output gap (IS) equation represents the only transmission channel of foreign shocks into the domestic economy that we consider in this paper. For motivation of the open economy IS equation see Monacelli (2003), Clarida *et al.* (2001), McCallum and Nelson (2000), Obstfeld and Rogoff (2000) and Svensson (2000). In addition, we allow the IS shock to follow an AR(1) process.

The monetary policy rule completes the closed economy part of the New Keynesian models. Clarida *et al.* (2001) and Svensson (2002) argue that a Talor-type monetary policy (MP) rule is optimal even for an open economy in a sense that it is not significantly inferior to more open-economy tailored policy rules regarding stabilization of major macroeconomic variables and is reasonably robust to different model structures. We use a forward-looking version of the Taylor rule to emphasize the forward-looking perspective of the Reserve Bank of Australia (RBA) when adjusting its MP instrument:

$$r_t = \rho_r r_{t-1} + (1 - \rho_r) \left(\psi_1 \mathbb{E}_t \left[\pi_{t+1} \right] + \psi_2 y_t \right) + e_{MP,t} \tag{3}$$

The monetary authority thus responds to expected inflation one period ahead and the current output gap while adhering to a certain degree of inertia. The shock to monetary policy is assumed to be a white-noise process as it is common in the literature (see e.g. Smets and Wouters, 2003; or Del Negro *et al.*, 2005).

To close the open-economy block of our model we include real uncovered interest parity (UIP). The usual UIP condition is stated as an identity over the log of the nominal exchange rate and interest rates, where the exchange rate is expressed as the ratio of domestic to foreign currency units. Equation (4) describes the real exchange rate where $*$ denotes a foreign variable.

$$q_t = \mathbb{E}_t \left[q_{t+1}\right] - \left(r_t + \mathbb{E}_t \left[\pi_{t+1}\right]\right) + \left(r_t^* - \mathbb{E}_t \left[\pi_{t+1}^*\right]\right) + e_{ER,t} \tag{4}$$

We add an autocorrelated risk premium to Equation (1) in order to match some empirical properties of this relationship as UIP appears to hold at rather longer-horizons of 1-2 years (see e.g. Chin and Meredith, 2003; and Nelson and Young-Kyu, 2001).

The U.S. block of the model bears a similar structure to the small open economy counterpart with the exception that we do not allow for an impact of the domestic economy upon the foreign block. More specifically, we shut down the impact of the real exchange rate in the big economy's IS curve so that the foreign block describing the U.S. economy is similar to the model considered by Cho and Moreno (*forthcoming*).

The full structure of the model including the shocks is described below:

$$
\begin{aligned}
y_t &= \rho_y \mathbb{E}_t\left[y_{t+1}\right] + \left(1-\rho_y\right) y_{t-1} - \delta_1\left(r_{t-4} - \mathbb{E}_{t-4}\left[\pi_{t-3}\right]\right) + \delta_2(q_{t-1}) + e_{IS,t} \\
\pi_t &= \rho_\pi \mathbb{E}_t\left[\pi_{t+1}\right] + \left(1-\rho_\pi\right)\pi_{t-1} + \lambda y_t + e_{AS,t} \\
r_t &= \rho_r r_{t-1} + \left(1-\rho_r\right)\left(\psi_1 \mathbb{E}_t\left[\pi_{t+1}\right] + \psi_2 y_t\right) + e_{MP,t} \\
q_t &= \mathbb{E}_t\left[q_{t+1}\right] - \left(r_t + \mathbb{E}_t\left[\pi_{t+1}\right]\right) + \left(r_t^* - \mathbb{E}_t\left[\pi_{t+1}^*\right]\right) + e_{UIP,t} \qquad (5) \\
r_t^* &= \rho_r^F r_{t-1}^* + \left(1-\rho_r^F\right)\left(\psi_1^F \mathbb{E}_t\left[\pi_{t+1}^*\right] + \psi_2^F y_t^*\right) + e_{MP,t}^* \\
\pi_t^* &= \rho_\pi^F \mathbb{E}_t\left[\pi_{t+1}^*\right] + \left(1-\rho_\pi^F\right)\pi_{t-1}^* + \lambda^F y_t^* + e_{AS,t}^* \\
y_t^* &= \rho_y^F \mathbb{E}_t\left[y_{t+1}^*\right] + \left(1-\rho_y^F\right) y_{t-1}^* - \delta_1^F\left(r_{t-4}^* - \mathbb{E}_{t-4}\left[\pi_{t-3}^*\right]\right) + e_{IS,t}^*
\end{aligned}
$$

In general, both the domestic and the foreign shocks are assumed to follow AR(1) processes:

$$
\begin{aligned}
e_{X,t} &= \rho_X \; e_{X,t-1} + \varepsilon_{X,t} \qquad (6) \\
e_{X,t}^* &= \rho_X^F \; e_{X,t-1}^* + \varepsilon_{X,t}^*
\end{aligned}
$$

where $X = \{IS, AS, MP, UIP\}$ and we restrict $\rho_{MP} = \rho_{MP}^F = 0$. Further, the peak of the interest rate impact on the output gap is usually assumed to lag more than one year behind the interest rate adjustment. On the other hand, the effect of the exchange rate is thought to be much faster and almost immediate. We thus set the relative lags of the interest rate and exchange rate impacts in the IS curve to four and one respectively.

This lag selection corresponds to maximized log data densities using the whole model when the lag of the exchange rate impact was fixed to one and the lag of the impact of the interest rate was varied from 2 to 4. We thus leave more sophisticated selection of the relative lags of the interest rate and exchange rate effects on the output gap for future research.[1]

3. The Data

The data are obtained from the International Financial Statistics (IFS) published by the IMF and the Reserve Bank of Australia's (RBA's) website `www.rba.gov.au/statistics`. The real GDP series for Australia and the U.S. are obtained from the RBA's website and the IFS, respectively. The output gap series are constructed as a deviation of logs of the real GDP series from a linear trend (see also Justiniano and Preston, 2004) where we use the whole available samples, i.e. 1969Q4-2005Q2 for Australia and 1947Q1-2005Q2 for the U.S. The inflation series are constructed as the quarter-to-quarter annualized percentage changes in respective national CPI indexes taken from the IFS. The interest rate used for Australia is the 90-day Bank-Accepted-Bills (BAB) rate[2] and for the U.S.

[1] One may object to lagging the interest rate (IR) impact on the output gap four periods and require a shorter lag length, even though a one-year lag in the transmission of the monetary policy impact on the real economy is rather short itself. This may be due to evidence from VAR studies which typically find interest rate lagged two or three periods significant in explaining output dynamics. Nevertheless, these shorter lags of IR may reflect agents' expectations about future changes in monetary policy stance rather than the impact of a realized monetary policy adjustment. We have also tried lagging the interest rate impact by two periods and we obtained similar results with the exception of a smaller and less significant impact of the interest rate on the output gap.

[2] We use the BAB rate instead of the actual RBA's instrument, i.e. the cash rate, as the latter is readily available only from 1998. Also, the interest rates at the short end of the yield curve are usually highly correlated so the use of the BAB rate seems to be appropriate. The correlation between the

we use the quarterly Fed funds rate from the IFS. The real exchange rate is the log of the nominal end-of-period AUD/USD exchange rate deflated by logs of the corresponding national CPI indexes. All the data are demeaned prior to the estimation.

The estimated sample covers the post floating period of the Australian dollar, i.e. starting from the first quarter of 1984 to the second quarter of 2005, to eliminate a possible structural break in the transmission of foreign shocks into the Australian economy as a consequence of the switch to a new exchange rate regime after 1984. Alternatively, one could consider a sample period starting after the introduction of inflation targeting in Australia, however, this would further shorten the available sample.

4. Estimation

We use Bayesian methods to estimate and draw inferences on the model. In particular, we use the Metropolis-Hasting's (MH) algorithm to run the MCMC simulation based on our model and data set. For estimation, the model in (5) is first cast in the form of a canonical system according to Sims (2002):

$$\Gamma_0 \mathbf{x}_t = \Gamma_1 \mathbf{x}_{t-1} + \mathbf{C} + \Psi \mathbf{z}_t + \Pi \boldsymbol{\eta}_t \tag{7}$$

where $\mathbf{C}$ is a vector of zeros in our case, $\mathbf{z}_t$ is a vector of exogenously evolving, possibly autocorrelated structural shocks of the model in (5), and $\boldsymbol{\eta}_t$ is a vector of expectations

cash rate and the BAB rate appear to be 0.95.

errors, satisfying $\mathbb{E}_t\boldsymbol{\eta}_{t+1} = 0$. The latter vector is not given exogenously instead it is treated as determined within the model solution. The $k \times 1$ vector $\mathbf{x}_t$ contains the following *state* variables:

$$\mathbf{x}_t' = \begin{bmatrix} y_t, \mathbb{E}_t y_{t+1}, y_{t-1}, \pi_t, \mathbb{E}_t \pi_{t+1}, \pi_{t-1}, r_t, r_{t-1}, q_t, \mathbb{E}_t q_{t+1}, \\ r_t^*, r_{t-1}^*, \pi_t^*, \mathbb{E}_t \pi_{t+1}^*, \pi_{t-1}^*, y_t^*, \mathbb{E}_t y_{t+1}^*, y_{t-1}^* \end{bmatrix}'$$

and Γ_0 and Γ_1 are $k \times k$ coefficient matrices given by the structure of the model in (5). The canonical system of difference equations is then solved to obtain its state-space form using Sims' (2002) QZ algorithm.[3] In general, the solution takes the following form:

$$\mathbf{x}_t = \Theta_1 \mathbf{x}_{t-1} + \Theta_C \mathbf{C} + \Theta_z \mathbf{z}_t$$

where Θ_1, Θ_C and Θ_z are functions of the structural models parameters, i.e. the coefficient matrices of the canonical form in (7).

Second, we impose priors on the estimating model parameters to facilitate the Bayesian estimation and utilize some prior information from related studies. The priors are assumed to be independent across parameters and are listed in Tables (1) and (2). They were selected to be consistent with those of Smets and Wouters (2003), Del Negro *et al.* (2005), and An and Schorfheide (2005). Given the priors, $p(\theta)$ and the models structure, M_o, of (5), the posterior density of the model parameters can be expressed

[3] Instructive exposition of this method can also be found in Klein (1999).

as:

$$p\left(\theta|\mathbf{Y}^T, M_o\right) = \frac{p\left(\mathbf{Y}^T, M_o|\theta\right) p\left(\theta\right)}{\int p\left(\mathbf{Y}^T, M_o|\theta\right) p\left(\theta\right) d\theta}$$

where θ is the vector of model parameters and $\mathbf{Y}^T$ the data. From this we can write that:

$$p\left(\theta|\mathbf{Y}^T, M_o\right) \propto L\left(\theta|\mathbf{Y}^T, M_o\right) p\left(\theta\right)$$

where $L\left(\theta|\mathbf{Y}^T, M_o\right)$ is the likelihood conditional on the data $\mathbf{Y}^T$ and the model M_o. The Kalman filter is used to evaluate the log posterior distribution - the sum of the log likelihood and log priors - which is then maximized. The values of parameters at the estimated posterior mode, together with the corresponding Hessian matrix, are used to start the MCMC from which we obtain the entire posterior distributions of the model parameters. The MCMC is carried out using Metropolis-Hasting's sampling algorithm with random walk proposals. We run two chains of 200000 repetitions where the first 50 per cent of each chain is discarded as a burn-in sample.[4] The Markov chains converged successfully as documented by the multivariate convergence statistics reported in Figure (4) in the Appendix. The convergence criteria employed are those proposed by Brooks and Gelman (1998). Namely, we report the scalar distance measure the *maximum root statistic,* R^p, the determinants of within-sequence, $\det[W]$, and between-sequence variance, $\det[V]$, covariance matrices. The results from the MCMC simulation are

[4]We have achieved an acceptance rate of 0.248 and 0.275 for the two chains that we have run simultaneously.

reported in Table (1) and (2):

[TABLE 1 HERE]

We first discuss the results for the Australian and U.S. economies separately and then make some comparisons across the two economies.

4.1. The Australian Block

Starting with the IS curve, the estimate of ρ_y indicates that agents' demand in the Australian economy is far more forward-looking than backward-looking. Our estimate of the backward-looking coefficient, $\left(1-\rho_y\right)$, is thus lower than the one reported by Dennis (2003) of 0.75 using a modified version of the RBA's policy model, discussed in Beechey *el al.* (2000). This may be due to the fact that we allow the structural shocks to follow a MA process. Also, the RBA model includes actual inflation expectations extracted from financial markets. The estimated impact of the real interest rate on the output gap is similar to the one estimated by Dennis (2003) of 0.22, and about twice as large as the estimate of Leu (2004) of 0.112. The lag structure of both studies differ, though. We estimate the magnitude of the real exchange rate impact to be somewhat smaller than Leu's estimate of 1.601. Contrary to Dennis, we find that the coefficient estimate on the real interest rate, δ_1, is smaller in comparison to the coefficient estimate on the real exchange rate, δ_2, that Dennis estimates to be 0.10.

This may be due to Dennis' different sample, only up to 1998Q2, or the use of a more realistic lag structure in our model. We thus find that the interest rate (credit) channel is likely to be dominated by the real exchange rate channel in respect of both the magnitude and speed of its impact. This is consistent with conclusions of Suzuki (2004) who finds that Australian banks mitigate the effect of monetary contraction by borrowing overseas and keeping public securities as a buffer stock.[5]

In contrast to Leu (2004) who employs the traditional NKPC, i.e. excluding lagged inflation, we find that forward-looking behavior, characterized by ρ_π, plays a prominent role in our hybrid NKPC. The impact of demand pressures or marginal costs estimated by λ is smaller than Leu's estimate of 1.291, and higher than the estimate of Neiss and Nelson (2002) of 0.145. On the other hand, our estimate of λ falls within the range of estimates obtained by Gruen *et al.* (2002) of $0.187 - 0.608$. However, the latter study uses deviations of actual unemployment from its potential (effective) measure and conditions on further inflation factors.

The estimated monetary policy rule for Australia suggests that the RBA adheres to a certain degree of inertia although our estimate of ρ_r is somewhat lower to what one would expect given the results for other open economies. For instance, Giordani (2004) sets the degree of inertia to one and Justiniano and Preston (2005) estimated it to be about 0.8 when considering two-block models for the Canadian and U.S. economies.

[5] Svensson (2000) argues that a monetary authority should restrain itself from vigorous use of the exchange rate channel to stabilize inflation as it results in high variability of the remaining variables. However, we do not explicitly consider the direct exchange rate channel as Svensson (2000) does, so that this argument is somewhat confined.

Adolfson *et al.* (2005) estimated the persistence in the MP instrument to be about 0.87 when using an open economy specification for the euro area. Our estimate for Australia is thus rather small and is most likely a result of the switch to inflation targeting regime after which the interest rate dropped significantly, supposedly towards a new equilibrium level.[6] Our estimates thus contradict those of de Brouwer and Gilbert (2005) who find the inertia coefficient ranging between 0.83 and 0.94 when using GMM[7]. The coefficient estimate on the expected inflation, ψ_1, falls within the range considered by Svensson (2000) and estimated by de Brouwer and Gilbert (2005) of $1.53 - 2.36$. On the contrary, the estimate of Leu (2004) of 2.16 is somewhat higher but also consistent with de Brouwer and Gilbert's estimates. The estimated weight on the output gap suggests that the RBA follows flexible inflation targeting according to Svensson's (2000) classification. Our estimate of the weight the RBA puts on the output gap in its reaction function, ψ_2, is rather high compared to estimates for other open economies (see e.g. Giordani, 2004). However, it is in line with the most recent estimates for the Australian economy as reported by de Brouwer and Gilbert (2005) of $0.98 - 1.96$.[8]

[6] We have tried to dummy out this level shift but the optimal timing for the shift to a new equilibrium (mean) value is rather arbitrary as it does not start immediately with the introduction of inflation targeting. We thus prefer to stick to the original data.

[7] de Brouwer and Gilbert use the overnight cash rate as the policy instrument.

[8] de Brouwer and Gilbert's preferred measure of the output gap is the HP filtered GDP series which corresponds to the results reported in Table 2 and Table 3 in the row 'HP final'. Our results are close to their forward-looking version of the Taylor rule. de Brouwer and Gilbert estimate the coefficient on inflation to be similar across the backward- and forward-looking specifications and the output gap coefficient to be higher for the forward-looking specification.

4.2. The U.S. Block

When considering the estimated IS curve for the U.S., we find that the agent's forward-looking behavior, characterized by ρ_y^F, dominates the backward-looking behavior in determining the output gap. Our estimated impact of the forward-looking term is higher than that of Cho and Moreno (*forthcoming*) whose estimate is 0.5586. This may be due to the more recent sample that we use or the fact that we allow the IS shock to be autocorrelated. We also estimate the real interest rate impact on the output gap, δ_1^F, to be higher than that obtained by Cho and Moreno of 0.0045. This difference may be attributed to our more realistic lag structure which might consider the interest rate effect closer to its peak. Also Cho and Moreno annualize all the variables and express them as percentages, including the output gap.

Further, the inflation process seems to be much more forward-looking when comparing our estimate of the PC curve, ρ_π^F, with that of Cho and Moreno of 0.4850. The same argument as for the IS estimates may apply here as we allowed the shocks to be correlated and use a more recent data sample. The impact of demand pressures, or an increase in marginal costs, on inflation, λ^F, is significantly positive and somewhat higher than Cho and Moreno's estimate of 0.0011.

The inertia of the MP instrument, estimated by ρ_r^F, appear to be in the range of Cho and Moreno's estimate of 0.8458 where the degree of smoothing by the Federal Reserve Bank (FRB) seems to have risen recently. Our estimate of the weigh the FRB puts on expected inflation, ψ_1^F, is similar to Cho and Moreno's of 1.64. However, we estimate the weight the FRB puts on the output gap, ψ_2^F, to be much smaller compared to Cho and Moreno (0.6038). This may be attributed to our different data handling or suggests that the FRB responds to expected inflation and the output gap along the lines of rather strict inflation targeting.

[**TABLE 2 HERE**]

When considering the estimates of the degree to which the structural shocks are correlated in both economies, it appears that the Australian economy is subject to more persistent structural shocks in regards to inflation and the output gap. The serial correlation of the shock to output gap is estimated to be higher than the autocorrelation of the UIP shock. On the other hand, the domestic and foreign inflationary shocks and the real exchange rate shock are dominant in terms of magnitudes of their standard deviations.

To sum up, the open economy features of the model appear to be important in determining the variation in the main domestic macro variables even though we have considered only one channel through which the foreign shocks are transmitted into the domestic economy.

5. Model Evaluation

Evaluation of the DSGE models goes mainly along the lines of comparisons of marginal data densities, forecasting performance and inspection of implied transmission mechanisms, as in Giordani (2004), Adolfson *et al.* (2005) or Justiniano and Preston (2005). Most of the literature is moving away from using marginal likelihoods for model comparisons (see e.g. Del Negro *et al.*, 2004; Adolfson *et al.*, 2005; and Justiniano and Preston, 2005). We thus focus on evaluations of the forecasting performance of the model and inspection of its transmission mechanism relative to a closed-economy version of the model, i.e. using the Australian block only and shutting down the real exchange rate channel.

5.1. Transmission Mechanism

To investigate the transmission mechanism of the estimated model we derive its impulse responses and compare them to estimated impulse responses of a simple closed economy model. For estimation of the closed economy alternative for Australia the following model was used:

$$\begin{aligned} y_t &= \rho_y \mathbb{E}_t [y_{t+1}] + \left(1 - \rho_y\right) y_{t-1} - \delta_1 \left(r_{t-4} - \mathbb{E}_{t-4} [\pi_{t-3}]\right) + e_{IS,t} \\ \pi_t &= \rho_\pi \mathbb{E}_t [\pi_{t+1}] + (1 - \rho_\pi) \pi_{t-1} + \lambda y_t + e_{AS,t} \\ r_t &= \rho_r r_{t-1} + (1 - \rho_r) (\psi_1 \mathbb{E}_t [\pi_{t+1}] + \psi_2 y_t) + e_{MP,t} \end{aligned} \tag{8}$$

The estimates of the model in (8) are reported in Table (3):

[**TABLE 3 HERE**]

The general and surprising characteristic of the estimates in Table (3) is that they closely resemble those for the U.S. block provided in Table (1). Namely, the impact of the interest rate on the output gap, δ_1, dropped from 0.8 to 0.3, the impact of the demand pressures on the inflation, as captured by λ, dropped from 0.5 to 0.07, and the estimated weight the RBA puts on the output gap, ψ_2, has also declined from 1.97 to about 0.08. Relative magnitudes of the latter two coefficients suggest that the RBA would have had to apply rather strict inflation targeting which contradicts our original findings. Consideration or oversight of the open economy features, and explicit modelling of the foreign economy may thus explain the difference between our estimates and some previous estimates of the related models of the Australian economy.

At this point, one may want to see a comparison of the in-sample fit of the open and closed economy models based on the respective marginal data densities. This is not informative in this case as the open and closed economy models have different endogenous variables. The capability of the model to match the data is thus assessed based on out-of-sample forecasting performance (see below). For the moment, we proceed by inspecting the implied transmission mechanisms of the two models.

In this respect, consider the impact of the shocks from the open economy model on forecast variances of the model variables. The forecast variance decomposition for horizon s, where $s \to \infty$ is summarized in Table (4):

[**TABLE 4 HERE**]

We can infer that the biggest impact on the domestic variables of the model comes from the real exchange rate shock followed by the domestic IS and AS shocks and the foreign MP shock. The extraordinarily hight impact of the risk premium on the real economy arises as a consequence of not including the effect of the terms of trade explicitly in the model. Instead, we treat the terms of trade effect as unobserved and mixed with the risk premium effect. The terms of trade impact on the business cycle of a commodity exporting, open economy like Australia, is traditionally considered to be important. We will consider explicit modelling of the terms of trade in our future research.

The results in Table (4) indicate that the variation in output gap is mainly due to the UIP shock where the domestic IS and foreign MP shocks seem to deliver a significant amount of variation as well. The variation in inflation is almost exclusively attributable to the domestic AS shock. The domestic inflation is also affected by the UIP and foreign MP shocks but to a much lesser extent. The domestic interest rate variation is mostly brought about by the UIP and the foreign MP shocks. In addition, the domestic IS and AS shocks are responsible for about 10 per cent of the interest rate variation. Finally, the variance of the AUD/USD real exchange rate is largely owing to the UIP shocks but the domestic IS shock seems to be quite influential as well. The fact that we have considered only transmission of the foreign shocks through the real exchange rate's impact on the domestic output gap is likely to be responsible for the suppressed influence of the foreign IS shock on the domestic economy.

Next, consider the forecast variance decomposition for the variables of the closed economy model as reported in Table (5):

[**TABLE 5 HERE**]

We can conclude from Table (5) that the variance decomposition fully reflects the simple structure of the closed economy model. That is, 95% of variation in the output gap is due to the IS shock and the remaining 5 % comes from the MP shock. In the case of inflation, the AS shock explains almost all variation. It is interesting to note that as we move towards the two-block open economy setup most of the forecast variance in the output gap becomes attributable to external (foreign) shocks, viz., the risk premium (including the terms of trade shock) and the foreign MP shock. Together, the latter two shocks then explain about 90 percent of output gap's variation. We do not observe this shift towards external shocks in the case of inflation as 90% of the variation in inflation is still attributable to the domestic AS shock.[9] 80% of the interest rate variation is explained by the MP shock and 20% is owing to the AS shock in the closed economy

[9] This result may change as the direct effect of the real exchange rate on inflation is considered. We leave this for future research.

setup. This also changes when the foreign shocks are considered and variation in the domestic MP instrument then reacts to the risk premium (terms of trade) shock and the foreign MP shock.

To sum up, our inspection of the forecast variance decomposition suggests that the open economy setup is likely to produce a significantly different transmission mechanism to that implied my the closed economy model. The latter claim, however, calls for more precise investigation and we attempt to do this by comparing impulse responses of the domestic model variables to domestic shocks, as derived for the open and closed economy models. We use Bayesian inference to construct the 95 per cent confidence intervals for the estimated impulse responses. Results of these comparisons are captured in Figure (1):

[**FIGURE 1 HERE**]

We find that a negative supply shock (an unexpected rise in inflation) causes a decline in output, and a rise in inflation and interest rates in accord with the models' structure. As inflation and inflation expectations rise due to a positive AS shock the MP authority responds by increasing interest rates and output declines. Unexpected monetary tightening results in declining output, inflation and rising interest rates. This follows as increased interest rates cause a decrease in output and marginal cost so that inflationary pressures ease. Similarly, a positive demand shock tends to increase the output gap, inflation and the interest rate as increasing demand pressures impact positively on inflation, and the monetary authority increases interest rates in response to the positive output gap and increasing inflation expectations.

We can see that most of the time the impulse responses from the open and closed economy models differ significantly as the confidence intervals associated with each pair of impulse responses overlap only sparsely. Only in the case of the response of inflation to a domestic supply shock do the open and closed economy impulse responses appear to be similar. Further, the open economy responses to the domestic shocks are much stronger at impact.

The open economy features of the model are therefore important in order to improve the transmission mechanism of the model describing the Australian economy. Nevertheless, at this point we have just shown that the two models are different in terms of the implied transmission mechanism. A question remains of which of the two models forecasts better out of the sample and we investigate this issue in the next section.

For completeness, we report the impulse responses of the domestic variables to temporary foreign shocks, including the exchange rate shock, in Figure (2).

[**FIGURE 2 HERE**]

We find that a positive exchange rate shock increases inflation at impact. However, deflationary pressures follow as a result of monetary policy tightening, in reaction to increasing inflation, which also causes stronger than expected exchange rate appreciation. This reasoning is apparent in responses of the interest rate, which rises at the shock's impact, and output, which rises due to favorable export conditions and than falls as the real appreciation comes to an effect. A negative foreign supply shock makes inflation increase and output decrease. The dichotomous reaction of the monetary policy to this situation is reflected in the interest rate response. The interest rate thus initially declines accommodating the output decline and then increases as the inflation expectations rise. The domestic interest rate rises in reaction to foreign monetary policy tightening as the excessive depreciation of the domestic currency increases the output gap and inflation expectations. The domestic interest rises only mildly in response to a foreign IS shock. This is due to the low weight on the output gap in the foreign MP reaction function. More precisely, the foreign interest rates rise only slightly as the demand pressures in the foreign economy arise. This results in depreciation of the domestic currency and the domestic central bank reacts accordingly as the domestic output gap opens.

At last, we consider the response of the real exchange rate to all shocks in the model. The corresponding impulse responses are plotted in Figure (3):

[**FIGURE 3 HERE**]

The pattern of the exchange rate response to domestic or foreign supply shocks is similar but the magnitude of the response to a foreign AS shock is about twice as large as the response to the domestic AS shock. The responses show that the domestic currency first depreciates as the expected inflation makes the domestic real interest rate decline. The subsequent appreciation of the domestic currency is due to an increase in the domestic interest rate as the domestic central bank reacts to rising inflation expectations. Similarly, the unexpected domestic (foreign) MP tightening makes the domestic currency appreciate (depreciate). As the domestic currency's appreciation feeds through into the output gap, MP easing is required to close the output gap and the domestic currency depreciates. On the contrary to the foreign IS shock, which has only a marginal impact on the exchange rate, the domestic IS shock appears to have the second biggest impact on the exchange rate. The domestic currency appreciates strongly as demand pressures increase. The relative magnitudes of the exchange rate responses to the two IS shocks reflect the relative weights the foreign and domestic monetary authorities put on the output gap. Finally, the greatest portion of exchange rate variation is due to the UIP shock, i.e. the time-varying risk premium.

5.2. Out-of-Sample Forecasts

The relative forecasting performance of the estimated open and closed economy models is examined next. For this we recursively estimate the models described in (5) and (8) starting at quarter 1 of 2000. We estimate the models and carry out a h-step-ahead forecast where h is ranging from 1 to 6 quarters. We add one observation, re-estimate and forecast up to six steps ahead. This is repeated until the end of the sample. The forecasts obtained from the open and closed economy models are compared on the basis of their root-mean-square errors (RMSE's) by calculating the relative RMSE for each forecast horizon. Further, we compare the difference in the absolute forecast errors of the two models using the modified Diebold and Mariano (1995) statistic. We report the obtained values of the statistics and their significance, when appropriate, in Table (6).

[**TABLE 6 HERE**]

The reported relative RMSE's suggest that the open economy model forecasts the output gap and inflation better than the closed economy model at all horizons considered. Regarding the interest rate forecast, the closed economy model seems to perform better at shorter horizons up to one year after which the open economy model dominates. The differences in forecasting performance are however less decisive when the Diebold-Mariano's (DM) statistics are considered. The better performance of the open economy model in forecasting the output gap appears to be significant only for one and three step ahead forecasts. For the interest rate, there seems to be no significant difference in forecasts coming from the open or closed economy model. Nevertheless, inflation seems to be forecasted significantly better by means of the open economy model at all considered horizons. The relative forecasting performance of the two models thus suggests that the open economy features of the model are important for the Australian economy.

6. Conclusion

A two-block open economy DSGE model was estimated in this paper using Australian and U.S. data. The estimates emphasize the forward-looking nature of the inflation and output gap processes and the role of foreign shocks in the transmission mechanism of the Australian economy. Namely, the real exchange rate impact on the output gap is found to dominate the effect of the domestic interest rate in terms of its speed and magnitude. Further, rising demand pressures appear to significantly increase current inflation. Finally, the forward-looking Taylor rule estimated within our DSGE model suggests that the Reserve Bank of Australia follows flexible inflation targeting. We evaluated the estimated open economy DSGE model in relation to a simple closed economy alternative and found that the transmission mechanisms implied by the open and closed economy models differ significantly and that the open economy model outperforms the closed economy model when forecasting out of the sample.

Regarding future research we plan to consider more complete open economy structure with additional transmission channels of foreign shocks into the domestic economy and further enrich the model so that it better tracks the historical developments in Australian monetary policy, reflected in the data. This may involve estimation of the output gap within the DSGE model and introducing features that would allow the average inflation and interest rate to decrease over time.

Appendix

[**FIGURE 4 HERE**]

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Parameter	Prior				MH Posterior		
	Domain	Density	Mean	S.D.	Mean	5%	90%
ρ_y	$[0,1)$	*Beta*	0.60	0.20	0.8043	0.7083	0.8138
δ_1	$\mathbb{R}^+$	*Gamma*	0.20	0.05	0.1981	0.1812	0.2287
δ_2	$\mathbb{R}^+$	*Gamma*	0.30	0.10	1.0857	1.0951	1.1226
ρ_π	$[0,1)$	*Beta*	0.70	0.20	0.9690	0.9607	0.9851
λ	$\mathbb{R}^+$	*Gamma*	0.20	0.10	0.4764	0.3882	0.5733
ρ_r	$[0,1)$	*Beta*	0.80	0.10	0.6143	0.5820	0.6562
ψ_1	$\mathbb{R}^+$	*Gamma*	1.70	0.10	1.7241	1.7444	1.7861
ψ_2	$\mathbb{R}^+$	*Gamma*	0.125	0.10	1.8722	1.6557	1.9976
ρ_y^F	$[0,1)$	*Beta*	0.60	0.20	0.9892	0.9804	0.9939
δ^F	$\mathbb{R}^+$	*Gamma*	0.20	0.05	0.0339	0.0351	0.0411
ρ_π^F	$[0,1)$	*Beta*	0.70	0.20	0.9973	0.9962	0.9988
λ^F	$\mathbb{R}^+$	*Gamma*	0.20	0.10	0.1371	0.1270	0.1440
ρ_r^F	$[0,1)$	*Beta*	0.80	0.10	0.9280	0.9151	0.9311
ψ_1^F	$\mathbb{R}^+$	*Gamma*	1.70	0.10	1.6721	1.6290	1.7289
ψ_2^F	$\mathbb{R}^+$	*Gamma*	0.125	0.10	0.0593	0.0231	0.0886

TABLE 1: The column 'Max Posterior' reports the results from maximization of the log posterior and the column 'HM Posterior' posterior mean and associated percentiles from Metropolis-Hastings sampling

Parameter	Prior				MH Posterior		
	Domain	Density	Mean	S.D.	Mean	5%	90%
ρ_{IS}	$[0,1)$	*Beta*	0.50	0.10	0.7983	0.7955	0.7981
ρ_{AS}	$[0,1)$	*Beta*	0.75	0.10	0.1243	0.1073	0.1358
ρ_{UIP}	$[0,1)$	*Beta*	0.80	0.10	0.1358	0.1044	0.1542
ρ^F_{IS}	$[0,1)$	*Beta*	0.50	0.10	0.1285	0.0895	0.1204
ρ^F_{AS}	$[0,1)$	*Beta*	0.75	0.10	0.1155	0.1073	0.1157
σ_{IS}	$\mathbb{R}^+$	*InvGamma*	0.40	2.00	0.0924	0.0904	0.0945
σ_{AS}	$\mathbb{R}^+$	*InvGamma*	1.00	2.00	0.4281	0.4101	0.4371
σ_{MP}	$\mathbb{R}^+$	*InvGamma*	0.20	2.00	0.0328	0.0318	0.0347
σ_{UIP}	$\mathbb{R}^+$	*InvGamma*	1.00	2.00	0.4137	0.4146	0.4183
σ^F_{IS}	$\mathbb{R}^+$	*InvGamma*	0.40	2.00	0.0919	0.0915	0.0928
σ^F_{AS}	$\mathbb{R}^+$	*InvGamma*	1.00	2.00	0.4201	0.4152	0.4359
σ^F_{MP}	$\mathbb{R}^+$	*InvGamma*	0.20	2.00	0.0342	0.0313	0.0328

TABLE 2: The 'S.D.' column reports the degrees of freedom for the inverse gamma distribution. The column 'Max Posterior' reports the results from maximization of the log posterior and the column 'HM Posterior' posterior mean and associated percentiles from Metropolis-Hastings sampling

Parameter	Prior				MH Posterior		
	Domain	Density	Mean	S.D.	Mean	5%	90%
ρ_y	$[0,1)$	*Beta*	0.60	0.20	0.9593	0.9286	0.9872
δ_1	$\mathbb{R}^+$	*Gamma*	0.20	0.05	0.0362	0.0224	0.0484
ρ_π	$[0,1)$	*Beta*	0.70	0.20	0.9530	0.9193	0.9877
λ	$\mathbb{R}^+$	*Gamma*	0.20	0.10	0.0824	0.0206	0.1423
ρ_r	$[0,1)$	*Beta*	0.80	0.10	0.8660	0.8660	0.9307
ψ_1	$\mathbb{R}^+$	*Gamma*	1.70	0.10	1.7181	1.5533	1.8812
ψ_2	$\mathbb{R}^+$	*Gamma*	0.125	0.10	0.2517	0.0032	0.5431
ρ_{IS}	$[0,1)$	*Beta*	0.50	0.10	0.1389	0.0818	0.1980
ρ_{AS}	$[0,1)$	*Beta*	0.75	0.10	0.1542	0.1074	0.1985
σ_{IS}	$\mathbb{R}^+$	*InvGamma*	0.40	2.00	0.0906	0.0905	0.0907
σ_{AS}	$\mathbb{R}^+$	*InvGamma*	1.00	2.00	0.4118	0.4107	0.4138
σ_{MP}	$\mathbb{R}^+$	*InvGamma*	0.20	2.00	0.0313	0.0313	0.0313

TABLE 3: The 'S.D.' column reports the degrees of freedom for the inverse gamma distribution. The column 'Max Posterior' reports the results from maximization of the log posterior and the column 'HM Posterior' posterior mean and associated percentiles from Metropolis-Hastings sampling

Variable\Shock	$\varepsilon_{IS,t}$	$\varepsilon_{AS,t}$	$\varepsilon_{MP,t}$	$\varepsilon_{UIP,t}$	$\varepsilon^F_{IS,t}$	$\varepsilon^F_{AS,t}$	$\varepsilon^F_{MP,t}$
y_t	8.95	1.00	0.88	84.38	0.00	1.01	3.77
π_t	0.34	91.64	0.13	5.26	0.00	0.15	2.47
r_t	4.22	4.46	0.34	57.77	0.01	1.52	31.68
q_t	22.78	0.67	0.42	73.54	0.00	1.15	1.44

TABLE 4: t+s forecast variance decomposition in model variables due to different structural shocks at a forecast horizon s, where s goes to infinity

Variable\Shock	$\varepsilon_{IS,t}$	$\varepsilon_{AS,t}$	$\varepsilon_{MP,t}$
y_t	94.02	0.63	5.35
π_t	0.03	99.84	0.12
r_t	0.13	20.70	79.17

TABLE 5: t+s forecast variance decomposition in model variables due to different structural shocks at a forecast horizon s, where s goes to infinity

Variable	output gap		inflation		interest rate	
Horizon	relRMSE	mod.DM	relRMSE	mod.DM	relRMSE	mod.DM
1	1.7318	1.5926*	2.4231	2.2004**	0.4970	1.1686
2	1.8446	0.4974	3.1402	1.3757*	0.5770	0.4947
3	1.8446	1.5301*	3.7171	1.9022**	0.7470	0.3604
4	2.8007	1.1576	4.1393	2.1046**	0.9246	0.0456
5	4.2525	1.1822	4.2761	2.1824**	1.2999	0.3640
6	2.6651	0.7005	3.874	2.0762**	1.6591	0.5935

TABLE 6: The 'relRMSE.' column reports the calculated relative RMSE of the closed and open economy models respectively. The column 'mod.DM' reports the Diebold-Mariano statistic related to the null hypothesis of equal absolute forecast errors for closed and open economy models.

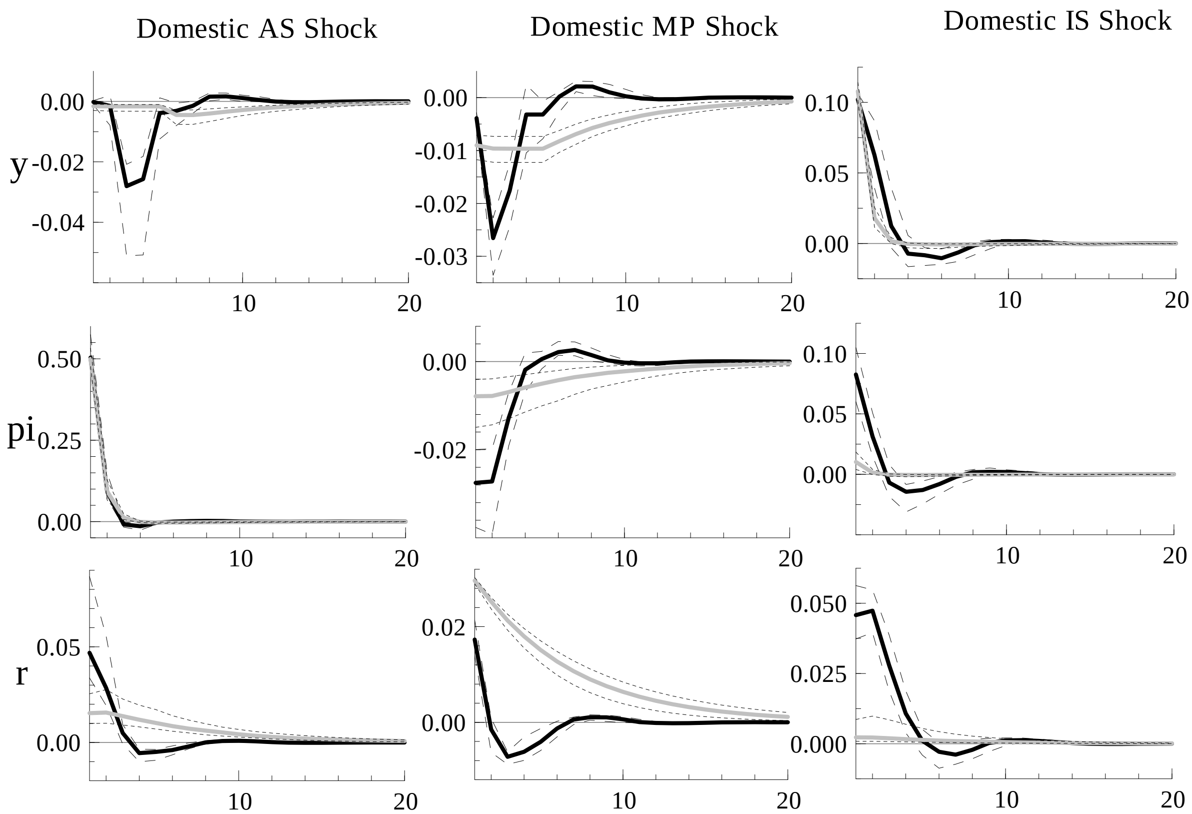

FIGURE 1: Impulse responses of domestic variables to domestic shocks estimated for closed (grey line) and open (black line) economy models. The dashed lines are the associated 95 % Bayesian confidence intervals.

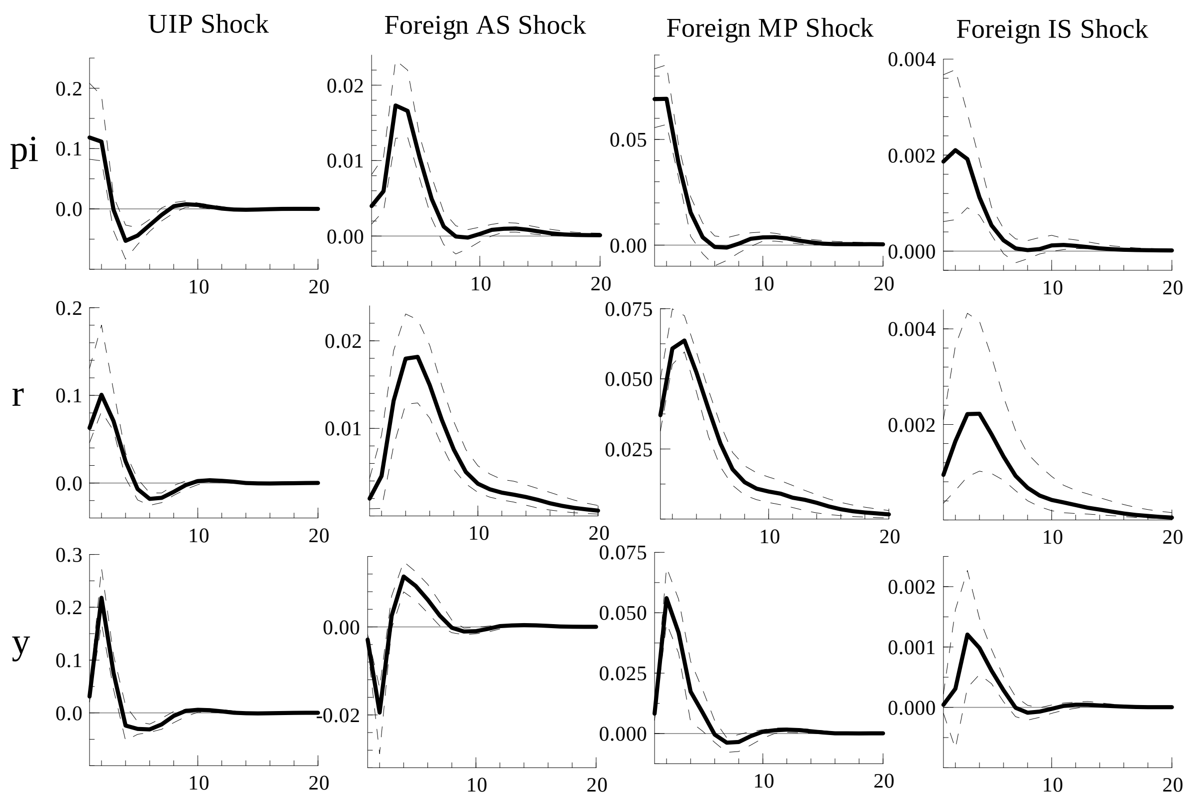

FIGURE 2: Impulse responses of domestic variables to foreign shocks, including the RER shock, from the open economy models. The dashed lines are the associated 95 % Bayesian confidence intervals.

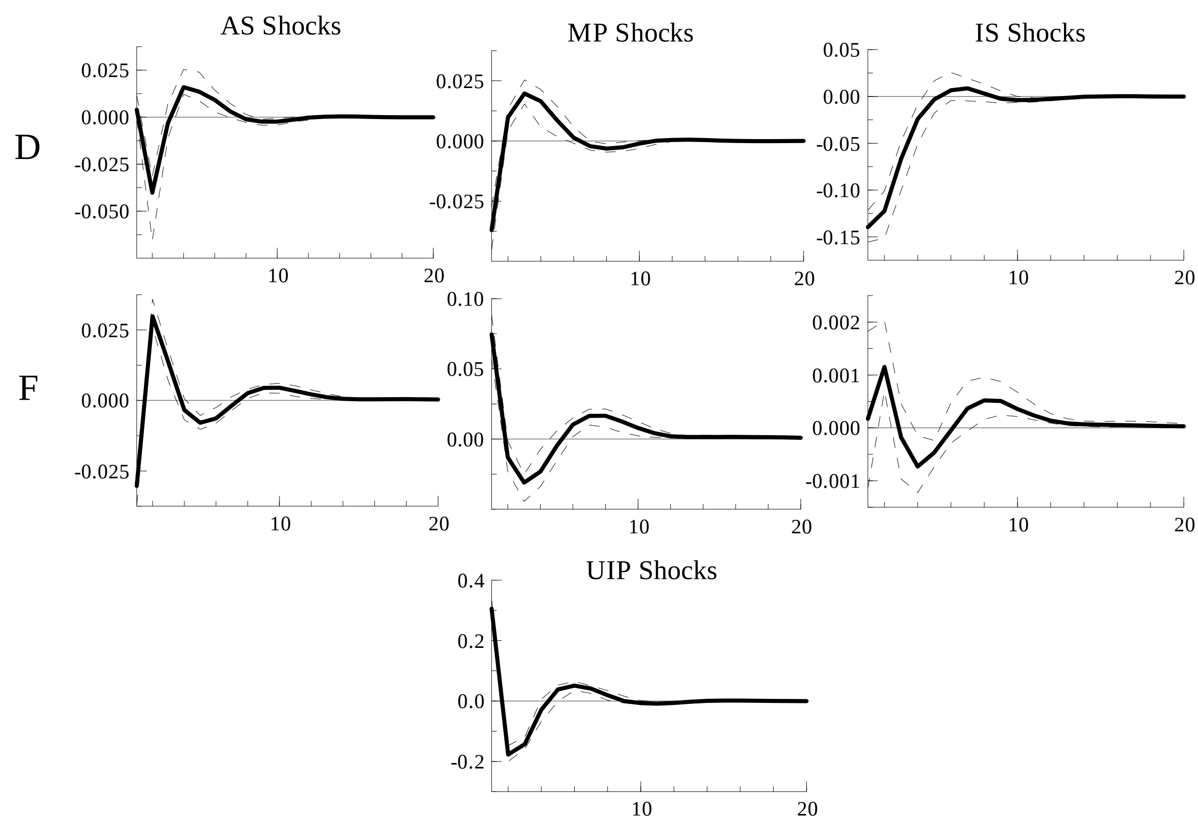

FIGURE 3: Impulse responses of the real exchange rate (RER) to all shocks in the open economy model. The dashed lines are the associated 95 % Bayesian confidence intervals. 'D' stands for domestic shocks, 'F' for foreign shocks and 'UIP' for the exchange rate shock.

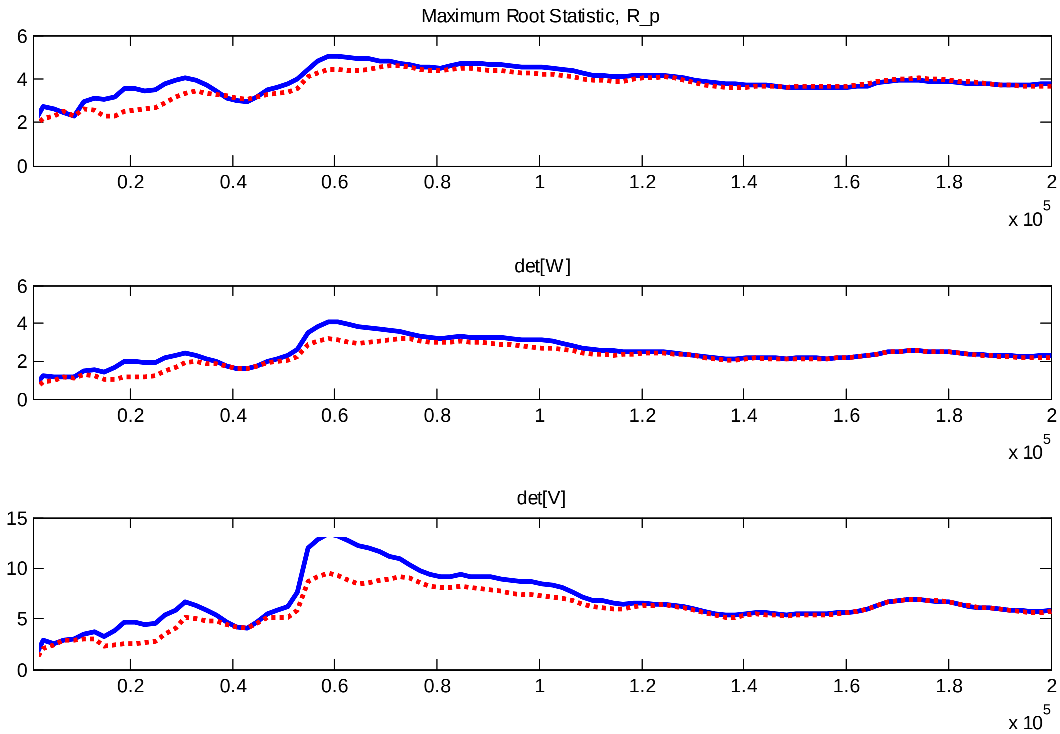

FIGURE 4: The covergence of iterates is monitored by the Maximum Root Statistic, the determinant of the Within-Sequence Covariance Matrix, det $[W]$, and the determinant of the Between-Sequence Variance, det $[V]$.