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The Role of International Shocks in Australia's Business Cycle

Philip Liu

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Author: ecpubs@rba.gov.au

Economic Publications: ecpubs@rba.gov.au

Abstract

This paper examines the sources of Australia's business cycle fluctuations. The cyclical component of GDP is extracted using the Beveridge-Nelson decomposition and a structural VAR model is identified using robust sign restrictions derived from a small open economy model. In contrast to previous VAR studies, international factors are found to contribute to over half of the output forecast errors, whereas demand shocks have relatively modest effects.

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THE ROLE OF INTERNATIONAL SHOCKS IN AUSTRALIA'S BUSINESS CYCLE

Philip Liu

1. Introduction

There is little consensus on the role played by the rest of the world in a small open economy's business cycle. In the case of Australia, Dungey (2002) estimates a structural vector autoregression (SVAR) model, which implies that international factors account for 32 per cent of output forecast errors over a one-year horizon, while domestic GDP shocks remain the dominant contributor. A SVAR model for Australia by Brischetto and Voss (1999) reveals that only around 5 per cent of output forecast errors stem from foreign factors. On the other hand, using an estimated new Keynesian dynamic stochastic general equilibrium (DSGE) model, Nimark (2007) concludes foreign shocks explain over 50 per cent of the variance in Australian output around its trend while domestic output shocks account for only 8 per cent. Using a different criteria, Dungey and Pagan (2000) simulate data from a SVAR model and find that recessions would have been less severe in the absence of foreign disturbances, while cumulated movements during the expansion phase would also have been smaller.

This paper argues that the different findings of the studies cited above can be understood as resulting from the difficulty of deciding how to appropriately identify the structural disturbances relevant to a small open economy. Traditional SVAR models employ zero-type restrictions, which may introduce substantial misspecifications that could lead to invalid inference. At the same time, identification of structural disturbances by means of cross-equation restrictions from a small DSGE model may be too stringent a method to capture the complex dynamics of the data-generating process. This paper contributes to this debate by developing a SVAR model of the Australian economy using robust sign restrictions derived from an estimated DSGE model. One key element of this approach is that it allows for a theoretically consistent view of the relationships between the set of macro variables without imposing the full DSGE structure or potentially invalid zero-type restrictions used in SVAR models.

Earlier sign restriction VAR studies focus mainly on identifying a subset of structural disturbances; examples include Faust (1998) and Uhlig (2005) who identify only monetary policy shocks. More recent studies by Canova and De Nicolo (2002) and Peersman (2005) apply the sign restriction methodology to identify all shocks in the VAR model. All these studies, however, are based on large economies with little discussion of the role of exchange rates. One exception is Farrant and Peersman (2006), who investigate the role of exchange rates in an open economy setting. However, the role of international factors is not explicitly discussed in that study.

The use of restrictions derived from a theoretical model to aid VAR estimation is not new. McKibbin, Pagan and Robertson (1998) use the McKibbin-Sachs Global (MSG2) model to restrict the long-run behaviour of a VAR, while the short-run features are left unrestricted. Dungey and Pagan (forthcoming) try to reconcile their earlier SVAR model with restrictions implied by a simple open economy DSGE model. Peersman and Straub (2004) use a calibrated real business cycle model to derive sign restrictions in order to identify technology shocks.

The starting point of this paper is to use the Beveridge-Nelson decomposition to extract the cyclical component of GDP, which will be used as a measure of Australia's business cycle. A slightly modified version of the small open economy model proposed in Monacelli (2005) and Galí and Monacelli (2005) is then estimated using maximum likelihood. The estimated model is used to determine a set of robust sign restrictions for the VAR analysis. The small open economy assumption is imposed on the VAR model by restricting the impact of domestic variables on foreign variables. The ultimate aim of the analysis is to map the set of statistical relationships estimated from the reduced-form VAR back into a set of structural disturbances for economic interpretation. To do this, an algorithm similar to that proposed by Canova and De Nicolo (2002) is used to trace out all possible orthogonal vector moving average (VMA) representations of the VAR that are consistent with the sign restrictions derived from the estimated DSGE model. Since there is not enough information to uniquely identify a set of structural disturbances, the median impulse approach suggested in Fry and Pagan (2005) is used to summarise the results.

The analysis reveals several interesting results. First, the Beveridge-Nelson decomposition produces a plausible measure of Australia's output fluctuations.

The characteristics of the cyclical behaviour match previous business cycle studies using factor models such as Gillitzer, Kearns and Richards (2005). Second, in contrast to previous zero-type restriction SVAR studies, foreign factors account for over half of the output forecast errors whereas innovations from output itself have only a modest effect. The result is robust across different foreign specifications using data for the United States and the G7 countries.

The rest of the paper is organised as follows. Section 2 describes the Beveridge-Nelson decomposition used to extract the cyclical component of GDP. Section 3 outlines the estimated small open economy DSGE model together with the data used in the analysis. A set of robust sign restrictions are derived from the estimated DSGE model for the open economy SVAR. Section 4 describes the estimation and identification of the open economy SVAR model. Section 5 summarises the estimation results. Finally, Section 6 reviews the main findings.

2. The Cyclical Component of GDP

The first step of the analysis in this paper is to obtain a measure of the cyclical component of GDP. The cyclical component is defined as the difference between the actual and the permanent component of GDP.[1] The permanent component is extracted by means of a Beveridge-Nelson (BN) decomposition, which is preferred to one popular alternative, the Hodrick-Prescott (HP) filter, as the BN decomposition allows for correlation between the innovations to the permanent and cyclical components.

A time series y_t with an ARIMA(p,1,q) representation can be decomposed into a permanent (τ_t) and cyclical (c_t) component using the BN decomposition as follows:

$$y_t = \tau_t + c_t \tag{1}$$

where $\tau_t = \mu + \tau_{t-1} + \alpha\varepsilon_t$ is the unobserved permanent component, which is assumed to follow a random walk with an average growth rate of μ; and $c_t = \phi_p(L)c_t + \psi_q(L)\varepsilon_t + (1-\alpha)\varepsilon_t$ is a stationary and invertible ARMA(p,q) process, where $\phi_p(0) = 0$ and $\Psi_q(L) = 0$.

1 The terms permanent component and trend are used interchangeably, as are cyclical component and the cycle. A detailed review of various detrending methods can be found in Canova (1998).

Likelihood ratio tests suggest that an ARIMA(2,1,1) model provides the best empirical fit for Australian real GDP between 1980:Q4 and 2006:Q1.[2] Figure 1 shows that the BN cycle is more volatile than the cycle derived using the HP filter (based on the smoothing parameter λ = 1 600). This is particularly so in the first half of the sample which displays more pronounced cycles.[3] This may reflect the fact that the HP filter dampens long- and short-run growth cycles, while strongly amplifying growth cycles at the business cycle frequencies (5–7 years). As a result, the HP filter may induce spurious periodicity that does not necessarily exist in the underlying data. The two cycles have a similar frequency of peaks (estimated using the periodogram) of around 17 quarters over the sample, with the BN cycle containing noticeably more high-frequency oscillations.

Figure 1: Cycles in Australian GDP

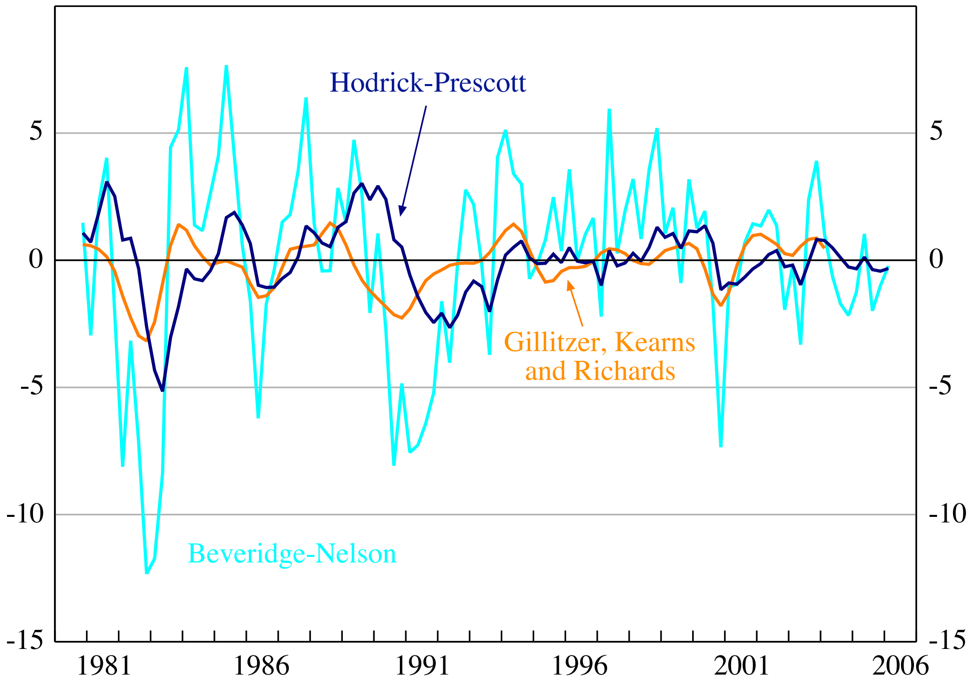

Figure 1 also shows the coincident (GKR) index of Australian economic activity derived by Gillitzer *et al* (2005) using a factor model. This index provides a plausible measure of the Australian business cycle using a large number of macroeconomic variables. For all three series, the two recessions during the early

2 The BN decomposition is computed based on the method suggested by Newbold (1990).

3 The standard deviation of the BN cycle is 3.9 per cent compared with 1.4 per cent for the HP cycle over the whole sample.

1980s and 1990s are apparent. The BN cycle and GKR index coincide with respect to the timing of recessions, suggesting a bottoming out of economic activity around 1983:Q1 and 1991:Q1. The HP cycle is a bit slower at picking up the recessions.[4] In addition, the BN cycle identifies two episodes of weak economic activity over the sample period. The first, in 1986, coincides with Paul Keating's *banana republic* remark over concerns about Australia's foreign debt position, a sharp depreciation of the exchange rate, and a downturn in household expenditure. The slowdown of the economy following the end of the Sydney Olympic Games and the introduction of the goods and services tax in 2000 is also apparent.

3. A Small Open Economy DSGE Model

This section presents the estimated small open economy DSGE model. The model is based on a slightly modified version of that proposed by Monacelli (2005) and Galí and Monacelli (2005). The set of estimated parameters is used to simulate Impulse Response Functions (IRFs) to provide a set of robust sign restrictions for the VAR analysis. The model consists of an open economy IS equation and a Phillips curve incorporating imperfect exchange rate pass-through. The monetary authority sets interest rates according to a Taylor-type reaction function, while the exchange rate depends on the interest rate differential between the domestic and foreign economies. The variables for the rest of the world are taken to be exogenous processes.

The open economy IS equation derived from the consumer's optimising problem is:

$$\begin{aligned} y_t = n_1 y_{t-1} + (1-n_1)E_t y_{t+1} - n_2(r_t - E_t\pi_{t+1}) \\ + n_3 E_t \Delta y^*_{t+1} - n_4 z_t + n_5 E_t \Delta \psi_{t+1} \end{aligned} \tag{2}$$

where: $n_1, \ldots, n_5$ are parameters; y_t is the aggregate output gap; r_t is the nominal interest rate; π_t is the inflation rate; y^*_t is the foreign output gap; and z_t represents technology disturbances that follow an AR(1) process.[5] $\psi_t = (1-\gamma)s_t - q_t$ can

[4] The HP filter can be thought of as a two-step filter: in the first step it renders y_t stationary; in the second it smooths the resulting stationary series with asymmetric moving average (MA) weights, which can contribute to a delay in identifying the recessions.

[5] A positive innovation to technology will increase the potential output of the economy, hence has a negative effect on the output gap.

be interpreted as the *law of one price gap* which measures the deviation of the domestic price of imported goods from the world price, where s_t is the terms of trade, defined as export prices relative to import prices, and q_t is the real exchange rate. A non-zero ψ_t implies imperfect exchange rate pass-through to import prices. The backward-looking component, y_{t-1}, in the IS equation is motivated by the assumption of habit persistence in consumer preferences.

The open economy new Keynesian Phillips curve derived by solving the firm's pricing decision can be written as:

$$\pi_t = g_1\pi_{t-1} + (1-g_1)E_t\pi_{t+1} + g_2 y_t + g_3\psi_t + \varepsilon_{\pi,t} \tag{3}$$

where $\varepsilon_{\pi,t}$ represents a cost-push shock. The Phillips curve is based on the assumption of monopolistically competitive firms, subject to pricing constraints (Calvo pricing and indexation). If $g_3 = 0$, Equation (3) collapses down to a familiar closed-economy Phillips curve where inflation dynamics are partly driven by past and expected inflation in addition to the output gap. The open economy dimension includes the effects from the exchange rate as an important part of the monetary policy transmission process.

The assumption of perfect capital markets yields the standard uncovered interest parity condition (which links the expected exchange rate depreciation to the interest rate differential):

$$q_t = E_t q_{t+1} + \left(r_t - E_t\pi_{t+1}\right) - \left(r_t^* - E_t\pi_{t+1}^*\right) + U_{q,t} \tag{4}$$

where $U_{q,t}$ is a time-varying risk premium that follows an AR(1) process.

The monetary authority is assumed to set the nominal interest rate according to a Taylor rule based on contemporaneous inflation and output as well as an interest rate smoothing term:

$$r_t = \rho_r r_{t-1} + (1-\rho_r)[\phi_1\pi_t + \phi_2 y_t] + \varepsilon_{r,t} \tag{5}$$

where $\varepsilon_{r,t}$ represents a non-systematic deviation from the reaction function. To complete the description of the structural model, the terms of trade s_t, the foreign output gap y_t^*, foreign interest rates r_t^* and foreign inflation π_t^* are assumed to follow exogenous AR(1) processes.

The structural model can be summarised as:

$$A_0Y_t = A_1Y_{t-1} + A_2E_tY_{t+1} + \varepsilon_t \tag{6}$$

where $Y_t = [y_t, r_t, \pi_t, q_t, s_t, r_t^*, y_t^*, \pi_t^*, \psi_t, z_t, U_{q,t}]$ is a 11×1 vector containing the state variables of model and $\varepsilon_t = [\varepsilon_{z,t}, \varepsilon_{r,t}, \varepsilon_{\pi,t}, \varepsilon_{q,t}, \varepsilon_{s,t}, \varepsilon_{r^*,t}, \varepsilon_{y^*,t}, \varepsilon_{\pi^*,t}]$ is an 8×1 vector of structural innovations.[6] The solution of the model can be represented as a first-order VAR:

$$Y_t = B_1Y_{t-1} + B_2\varepsilon_t \tag{7}$$

3.1 Data Description

Data from 1980:Q1 to 2006:Q1 for the Australian economy are used to estimate the structural model and the SVAR.[7] The starting period coincides with previous SVAR studies of the Australian economy including Dungey and Pagan (2000). Quarterly observations on real total GDP (y_t), headline CPI inflation (excluding interest rates and taxes) (π_t), the (goods and services) terms of trade (s_t), the real exchange rate (q_t), the nominal interest rate (measured by the 90-day bank bill rate) (r_t), US GDP (y_t^*), US CPI inflation quarter-on-quarter (π_t^*) and US nominal interest rate (r_t^*) are sourced from the Reserve Bank of Australia, the Australian Bureau of Statistics and the IMF's *International Financial Statistics* (IFS) database.[8]

The cyclical component of GDP for both Australia and the United States – that is, the output gap measures – are constructed using the BN decomposition described earlier. Due to the unusual upswing in Australia's terms of trade between 2004 and 2006, this time series is detrended using an HP filter to ensure stationarity of the series. All variables apart from inflation and interest rates are entered in log form.

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6 In the numerical simulation and estimation of the model, the structural equation is solved using a solution algorithm described in Uhlig (1995).

7 The effective sample period is from 1980:Q4 to 2006:Q1 after differencing and construction of the cyclical component of GDP.

8 Data for the equivalent G7 series are also taken from the IFS and combined using the following weights: the United States (0.49); Japan (0.16); Germany (0.10); the United Kingdom (0.07); France (0.07); Italy (0.07); and Canada (0.04).

3.2 Estimating the DSGE Model

The parameters of the DSGE model are estimated using constrained maximum likelihood (ML). The likelihood function is computed via the state-space representation of the model's solution in Equation (7), together with the measurement equation linking the observed data and the state vector:

$$Z_t = GY_t \tag{8}$$

where: Z_t denotes the observed data; and the matrix G specifies the relationship between the state variables and the observed data. The posterior parameter distribution is simulated using the Metropolis Hasting algorithm described in Lubik and Schorfheide (2007).

The ML estimates are generated conditional on the OLS estimate of the model's four exogenous processes that explain developments in the rest of the world: the terms of trade s_t, foreign inflation π_t^*, foreign interest rates r_t^* and foreign output gap y_t^*. There are two advantages in estimating the observed exogenous processes independently of the model. First, it reduces the number of parameters to be estimated in the simulation algorithm. Second, Fukac and Pagan (2006) argue that rigid restrictions imposed by DSGE models on the data may yield invalid estimates of the model's observable shocks (that is, shocks that are mapped into actual data, such as the foreign output gap y_t^*).

The ML estimate of the model's parameters from the 1.5 million Markov chain draws are summarised in Table 1.[9] The set of Markov chain diagnostic tests imply that the simulated chains attain their stationary distributions.[10] The degree of backward-lookingness is estimated to be 0.09 for the IS equation (n_1) and 0.27 for the Phillips curve (g_1). The estimated coefficient on the real interest rate (n_2) in the IS equation is relatively small, suggesting output variation is relatively insensitive to interest rate changes. The response of inflation to output gap changes (g_2) is also estimated to be low. The Taylor rule displays a significant degree of interest rate smoothing behaviour with ρ_r estimated to be 0.90. The estimated

9 A 50 per cent burn-in is discarded before computing the summary statistics.

10 There is only one exception, n_4, which is significant at the 5 per cent level. However, a small Brooks and Gelman statistic of 1.12 indicates that the chain has converged.

Table 1: Maximum Likelihood Estimates (MLE) of the DSGE Model[(a)]

Parameter	MLE statistics				Diagnostics		
	Mean	Std	2.5%	97.5%	NSE[(b)]	p-value[(c)]	B-G[(d)]
				IS equation			
$n1$	0.09	0.06	0.01	0.24	0.00	0.06	1.03
$n2$	0.01	0.01	0.00	0.04	0.00	0.75	1.00
$n3$	0.21	0.10	0.05	0.43	0.01	0.54	1.01
$n4$	0.26	0.09	0.15	0.50	0.01	0.02	1.12
$n5$	–0.70	0.16	–1.11	–0.43	0.02	0.56	1.01
				Phillips curve			
$g1$	0.27	0.05	0.16	0.37	0.01	0.93	1.00
$g2$	0.01	0.01	0.00	0.04	0.00	0.09	1.01
$g3$	0.00	0.00	0.00	0.01	0.00	0.24	1.00
				Taylor rule			
ρ_r	0.90	0.02	0.84	0.93	0.00	0.07	1.11
ϕ_1	1.31	0.22	1.02	1.87	0.03	0.24	1.05
ϕ_2	1.56	0.38	0.78	2.30	0.05	0.16	1.09
				Persistence of shocks			
ρ_z	0.78	0.07	0.62	0.89	0.01	0.22	1.04
ρ_u	0.98	0.01	0.95	1.00	0.00	0.94	1.00
				Std of shocks			
σ_z	2.10	0.16	1.83	2.52	0.02	0.95	1.00
σ_π	1.03	0.22	0.72	1.54	0.03	0.36	1.03
σ_r	1.10	0.08	0.97	1.28	0.01	0.92	1.00
σ_q	1.78	0.13	1.55	2.06	0.02	0.13	1.05
Persistence of world shocks							
ρ_s	OLS	0.90					
ρ_{r^*}	OLS	0.94					
ρ_{π^*}	OLS	0.62					
ρ_{y^*}	OLS	0.29					
Std of world shocks							
σ_s	OLS	1.75					
σ_{r^*}	OLS	1.07					
σ_{π^*}	OLS	1.67					
σ_{y^*}	OLS	4.14					

Notes: (a) The posterior statistics are computed based on 1 million draws using the Markov Chains Monte Carlo method with a 50 per cent burn-in period.
(b) Refers to the numerical standard error of the Markov chain.
(c) Relates to the test of two means between the first and second half of the stationary Markov chain.
(d) Refers to the Brooks and Gelman (1998) univariate distribution.

weight on output is slightly higher than the weight on inflation and consistent with standard calibrated values used in the literature. However, as the estimation covers a period before the inflation-targeting regime, it is no surprise that there is a wide confidence interval around the Taylor-rule coefficient on output, ϕ_2.

3.3 Qualitative Analysis of the DSGE Model's Impulse Response Functions

This section presents the impulse response functions of the model. The IRFs are simulated by sampling the empirical distribution of the estimates of the DSGE model. This takes into account the uncertainty of the responses associated with parameter uncertainty. The median along with the 5th and 95th percentile responses are shown in Figures B1 and B2. The IRFs of the model are broadly consistent with other open economy studies based on new Keynesian models. Moreover, the initial responses of key variables are generally quantitatively significant, providing a useful set of robust sign restrictions for the SVAR analysis. The discussion here will focus more on the initial responses rather than the dynamic adjustments to the shocks.

A positive technology shock decreases the output gap since actual output takes time to adjust in response to higher capacity. This causes the interest rate to fall. The real exchange rate depreciates to reflect the change in the interest rate differential, which contributes to a small increase in the inflation rate, despite the boost to productivity.

A cost-push shock increases inflation and leads to an increase in interest rates that causes the exchange rate to appreciate and output to contract.

A negative shock to the risk premium causes lower inflation and output due to an appreciating exchange rate. The monetary authority responds by reducing the interest rate. An unexpected tightening of monetary policy has a negative effect on the output gap, lowers inflation and appreciates the exchange rate.

Turning to external factors, following a positive shock to Australia's terms of trade, the output gap increases, the real exchange rate appreciates, and inflation and interest rates rise. An exogenous increase in the foreign interest rate leads to a depreciation of the domestic currency, which is sufficient to raise the output gap, and together these forces push up inflation. Given the simple structure of the model, an increase in foreign inflation has a similar but opposite effect on the domestic economy as an increase in the foreign nominal interest rate. An increase in foreign output actually decreases the domestic output gap, while both domestic inflation and interest rates stay relatively static and the depreciating exchange rate helps balance the international consumption risk-sharing condition.[11]

3.4 Robust Sign Restrictions

The focus of the study is to gather a set of sign restrictions from the impulse responses of the DSGE model to identify the small open economy SVAR. The complete set of estimated IRFs from the DSGE model provides more sign restrictions than are necessary to disentangle the eight structural shocks. The set of sign restrictions adopted is presented in Table 2.

Table 2: VAR Sign Restrictions

Shock	r^*	y^*	π^*	y	r	π	q	s
Foreign interest rate	↑	–	↓	–	–	–	–	–
Foreign output	↑	↑	–	–	–	–	–	–
Foreign inflation	↑	↓	↑	–	–	–	–	–
Output (composite)	0	0	0	↑	↑	–	–	↓
Interest rate	0	0	0	–	↑	↓	–	–
Cost-push	0	0	0	↓	↑	↑	↑	–
Risk premium	0	0	0	–	–	↓	↑	–
Terms of trade	0	0	0	–	↑	↑	↑	↑

Notes: ↑ (↓) means positive (negative) response of the variables in columns to shocks in rows. 0 means no response (as implied by the small open economy assumption). – means no restriction is imposed on the response.

There are a few important things worth highlighting. First, given that the three foreign variables enter the structural model as exogenous driving processes, the set of sign restrictions imposed on the foreign economy follows the dynamic responses implied by a canonical closed-economy new Keynesian model. The responses of the domestic variables to the three foreign shocks are left unrestricted. Second, the terms of trade is treated as an endogenous variable and its response to other shocks, apart from the output shock, in the system is also left unrestricted.

[11] Galí and Monacelli (2005) provide a detailed account of the way in which such a shock can lower domestic potential output.

With the presence of sticky home prices in the short run, the terms of trade responds to other variables in the system via changes to domestic inflation. Third, the output shock can be viewed as anything that moves output and interest rates together but is orthogonal to all other shocks in the system. Last, the sign restrictions are imposed for the initial two quarters only.

4. Estimating a SVAR Model

This section sets out the small open economy sign-restricted VAR model estimated using the data described in Section 3.1. An eight-variable VAR(2) is fitted to quarterly observations from 1980:Q4 to 2006:Q1 where the number of lags are determined by the Akaike Information Criteria.

Consider a general VAR(p) model with n variables Y_t:

$$BY_t = A(L)Y_{t-1} + \varepsilon_t \tag{9}$$

where: $A(L) = A_1 L + \cdots + A_p L^p$ is a p^{th} order matrix polynomial; B is a $(n \times n)$ matrix of coefficients that reflect the contemporaneous relationships among Y_t; and ε_t is a set of $(n \times T)$ normally distributed structural disturbances with mean zero and variance covariance matrix Σ, $\Sigma_{i,j} = 0 \; \forall i \neq j$. The structural representation in Equation (9) has the following reduced form:

$$Y_t = \Pi(L)Y_{t-1} + e_t \tag{10}$$

where $\Pi(L) = B^{-1}A(L)$ and e_t is a set of $(n \times T)$ normally distributed reduced-form errors with mean zero and variance covariance matrix V, $V_{i,j} \neq 0 \; \forall i, j$. The aim is to map the statistical relationships summarised by the reduced-form errors e_t back into economic relationships described by ε_t. Let $P = B^{-1}$. The reduced-form errors are related to the structural disturbances in the following manner:

$$e_t = P\varepsilon_t \quad \text{and} \quad V = E(e_t e_t') = HH' \tag{11}$$

for some matrix H such that $HH' = P\Sigma P'$. An identification problem arises if there are not enough restrictions to uniquely pin down H from the matrix V.[12]

[12] There are n^2 unknown elements in H with only $n(n+1)/2$ unique elements in V.

4.1 Identification through Sign Restrictions

The identification of structural shocks is often a controversial issue, with different identifying assumptions leading to quite different conclusions. Typical restrictions employed in the literature are based on the short-run or long-run impact of certain shocks on a subset of variables. These are known as zero or constant restrictions. The Choleski decomposition is an example of one such strategy where the contemporaneous impact of shocks follows a recursive ordering. One noticeable feature of standard empirical DSGE models is that they almost never imply zero-type restrictions. This is also the case with the estimated structural model presented in Section 3.

The central idea behind SVAR analysis is to decompose the set of reduced-form shocks, characterised by V, into a set of orthogonal structural disturbances characterised by Σ. However, there are an infinite number of ways in which this orthogonality condition can be achieved. Let H be an orthogonal decomposition of $V = HH'$. The multiplicity arises from the fact that for any orthonormal matrix Q (where $QQ' = I$), such that $V = HQQ'H', \tilde{H}\tilde{H}'$ is also an admissible decomposition of V, where $\tilde{H} = HQ$. This decomposition does not have any economic content but nevertheless produces a set of uncorrelated shocks $\varepsilon_t = \tilde{H}e_t$, without imposing zero-type restrictions.

The identification strategy used here closely follows Canova and De Nicolo (2002), Peersman (2005) and Uhlig (2005) in using qualitative information directly from IRFs to achieve identification without the need to impose potentially invalid zero-type restrictions. Canova and De Nicolo proposed an algorithm to trace out all possible orthogonal VMA representations of the VAR consistent with a given set of sign restrictions. See Appendix A for a more detailed description of the algorithm.

4.2 Finding the Median Impulse

The next step is to construct a summary measure from all the VAR representations consistent with the given set of sign restrictions. A common approach is to examine all of the feasible IRFs implied, and report the median response at each horizon for each variable. However, Fry and Pagan (2005) criticise this approach since the implied 'median' IRF may not actually be a feasible response (since it is likely to consist of selected parts of paths implied by different candidate functions). In other words, inference is difficult because the orthogonality condition may be violated.

Fry and Pagan suggest locating a unique identification matrix such that all of the feasible impulses are closest to its median while maintaining the orthogonality condition. Each feasible VAR representation can be distinguished by the rotation angle, θ. So the objective is to choose θ so as to minimise:

$$\Upsilon(\theta_j) = \sum_{i=1}^{q} (\phi_i^j - \bar{\phi}_i)(\phi_i^j - \bar{\phi}_i)' \tag{12}$$

where: the index i refers to the horizon for which the impulses are calculated; ϕ_i^j is an $n \times n$ matrix of standardised impulses for the jth rotation; and $\bar{\phi}_i$ is the median impulse over all possible rotations.[13] Full details of the methodology and implementation are provided in Appendix A.

5. Sign-restricted VAR Results

The identification scheme based on the sign-restricted VAR allows for a structural interpretation of the effects of shocks. The impulse response of the output gap, the interest rate, inflation, the real exchange rate and the terms of trade with respect to the three foreign shocks are shown in Figure B3. An exogenous increase in the foreign interest rate results in a depreciation of the exchange rate which raises domestic inflation. In contrast to the DSGE model, the depreciation of the exchange rate is more gradual, reaching a peak at eight quarters before returning to equilibrium. A more important difference from the DSGE results is that output falls, which appears to reflect the decline in foreign output (not shown) and would also help to explain why domestic interest rates decline.

In contrast to the DSGE estimates, the sign-restricted VAR estimates imply that an increase in foreign output leads to a positive domestic output gap, reaching a peak after four quarters. The positive domestic output gap implies increased inflationary pressure, which induces a tightening of monetary policy over time to bring both output and inflation back to steady-state. The response of the domestic economy following a foreign inflation shock is very similar to that implied by the DSGE

[13] In Fry and Pagan (2005), q is set to 1 focusing only on the initial period impulse.

model. The exchange rate appreciates in response to the lower real interest rate differential. This leads to a fall in the output gap and subsequently a decline in inflation. There is a small monetary loosening to bring both output and inflation back to equilibrium.

Figures B3 and B4 display the summary IRFs from the sign-restricted VAR for the remaining five domestic shocks. A positive output shock (that is, a negative technology shock) raises the interest rate consistent with the sign restriction. This shock also induces inflationary pressure and the interest rate remains above its steady-state level for some time. An unanticipated tightening of monetary policy lowers both inflation and output while the exchange rate appreciates in response to higher real interest rates. After the shock, the interest rate falls so as to stimulate output and bring inflation back to its steady-state level. Following a positive cost-push shock, the domestic interest rate increases, the exchange rate appreciates and the output gap falls. A negative shock to the risk premium triggers an appreciation of the exchange rate leading to lower inflation. The monetary authority responds to this by lowering the domestic interest rate. In contrast to the structural model, the effect of the monetary response is estimated to outweigh the effect of the higher exchange rate, leading to higher output. A terms of trade shock has a positive effect on both output and inflation, leading to a tightening of monetary policy. The exchange rate also responds to the higher terms of trade, helping to stabilise both output and inflation.

5.1 Main Drivers of Output over the Business Cycle

Variance decompositions are often used to determine the relative contribution of shocks to the forecast error variance of a variable of interest over different horizons. As a benchmark, I first present a variance decomposition based on the Choleski decomposition. The variables are ordered according to the convention that the most exogenous (or predetermined) variables appear first. The variance decomposition results reported in Table 3 are based on the following ordering: foreign output, foreign inflation, the foreign interest rate, the terms of trade, the output gap, the interest rate, inflation and the real exchange rate. Investigation of other ordering schemes, where the order of output among the domestic variables varies from first to last, reveals little difference in the variance decomposition results for output. The benchmark results show that at the one-year horizon, shocks to the domestic output gap account for around two-thirds of the total variance in the output gap while other domestic factors play only a modest role. Foreign shocks account for just over one-quarter of the output gap forecast error variance, with the biggest contributor being foreign output accounting for around 16 per cent. At longer horizons, the role of domestic output shocks decreases slightly while other domestic factors play a slightly larger role. The contribution from all foreign factors stays fairly constant across the different forecasting horizons.

Table 3: Baseline Choleski Variance Decomposition

Quarter	Shock							
	Foreign interest rate	Foreign output gap	Foreign inflation	Technology	Interest rate	Cost-push	Risk premium	Terms of trade
				Output gap				
1	0.3	2.0	7.5	89.0	0.0	0.0	0.0	1.2
4	3.3	15.7	7.5	65.8	0.9	3.5	2.3	1.0
8	3.1	14.8	8.9	62.1	1.9	4.5	3.3	1.4
12	3.0	14.5	9.1	60.1	2.8	5.3	3.7	1.5
50	3.0	14.4	9.1	58.6	3.8	5.8	3.8	1.6
				Interest rate				
1	0.7	0.1	1.2	3.7	90.5	1.6	0.0	2.1
4	1.9	9.8	5.3	17.2	53.7	10.8	0.7	0.7
8	5.1	16.7	4.5	24.9	35.7	12.3	0.3	0.4
12	6.4	19.7	3.7	28.4	29.2	11.5	0.4	0.7
50	8.9	23.0	2.9	29.1	22.5	9.1	1.1	3.4
				Inflation				
1	3.0	0.9	0.1	0.7	0.0	94.9	0.0	0.4
4	2.7	2.4	1.8	0.9	12.1	74.1	4.0	2.0
8	3.7	5.8	2.2	4.4	12.5	64.3	4.2	3.0
12	5.1	8.4	2.0	6.8	11.6	58.2	4.5	3.4
50	7.4	11.7	1.8	8.8	10.3	50.8	4.6	4.6
				Real exchange rate				
1	0.7	0.1	0.0	0.1	3.0	0.0	87.8	8.2
4	0.7	0.1	6.8	3.2	2.8	3.9	80.5	2.1
8	4.5	1.2	14.3	2.2	2.8	5.3	68.0	1.7
12	9.3	2.8	17.6	1.7	6.5	5.3	55.1	1.7
50	11.7	4.0	17.0	1.8	13.5	5.4	44.6	2.0

Looking at the variance decomposition of the shocks identified by the sign-restricted VAR model reveals some important differences (Table 4). These results

Table 4: Sign-restricted VAR Variance Decomposition

Quarter	Shock							
	Foreign interest rate	Foreign output gap	Foreign inflation	Technology	Interest rate	Cost-push	Risk premium	Terms of trade
				Output gap				
1	49.1	0.0	1.5	5.2	0.2	0.7	7.4	35.9
4	41.7	17.1	1.8	4.4	0.5	5.2	4.8	24.5
8	40.5	17.0	1.9	4.4	0.5	6.6	4.8	24.3
12	40.1	16.7	1.9	4.3	0.5	7.2	4.8	24.6
50	39.4	16.6	2.0	4.4	0.5	7.5	5.0	24.6
				Interest rate				
1	2.4	2.2	5.6	11.1	3.1	6.6	59.4	9.5
4	1.8	3.7	3.6	8.1	1.4	13.7	46.4	21.2
8	1.6	20.3	1.9	7.3	1.4	10.3	34.4	22.6
12	1.3	32.5	1.5	7.2	1.4	8.0	28.9	19.2
50	1.1	54.7	1.6	5.2	1.0	5.5	18.6	12.3
				Inflation				
1	25.7	0.8	1.2	0.1	8.2	63.1	0.5	0.4
4	19.6	3.1	1.6	3.7	6.0	44.2	19.8	2.1
8	16.2	11.9	1.7	6.1	4.9	37.2	19.2	2.8
12	14.1	21.4	1.5	6.5	4.3	32.3	17.5	2.5
50	10.8	38.9	1.8	5.1	3.3	24.6	13.2	2.3
				Exchange rate				
1	0.5	2.2	23.3	43.9	2.7	1.0	26.2	0.1
4	8.6	3.2	18.9	27.6	3.2	6.1	30.2	2.3
8	13.2	11.9	12.7	20.2	4.0	12.6	21.1	4.4
12	13.5	25.8	8.8	13.8	3.5	14.0	14.3	6.3
50	10.7	40.0	7.8	9.4	2.5	11.9	10.1	7.5

suggest that domestic output shocks only account for 4–5 per cent of the variation across all horizons. At the shorter horizons, all three foreign factors combine to account for more than 60 per cent of the output gap forecast error variance. A sizeable share of this appears to be due to foreign monetary policy innovations, although this may, in part, reflect factors that are outside of the model, such as global confidence, that are transmitted to the domestic economy via international financial markets. This view is consistent with the findings in Dungey and Pagan (2000), which show that international financial linkages are important when modelling the Australian economy. At the longer forecasting horizon, all three foreign factors maintain their influence on domestic output gap variations, with both the foreign interest rate and foreign output remaining the dominant contributors. Although the model treats the terms of trade as endogenous, realistically it can be thought of as exogenous, at least over longer horizons. So in this respect the terms of trade could be thought of as another foreign factor. The terms of trade account for a quarter of the variation in output across all but the shortest of horizons. This is consistent with the significance of commodities in Australian exports. Turning to domestic factors, interest rate shocks are estimated to have only a small influence on output gap fluctuations, while inflation (cost-push) and exchange rate (risk premium) shocks each contribute around 5–8 per cent to the variance of the output gap. This is broadly similar to the Choleski baseline results.

One may ask what is the role of foreign factors among other admissible rotations since it is impossible to distinguish them statistically. To check the sensitivity of the variance decomposition results around the optimised median impulse, the chosen median rotation is dropped and the next median impulse is found by re-optimising Equation (12) over the remaining admissible rotations. This procedure is repeated 50 times around the 'median region'. The results imply that foreign factors explain between 45 to 60 per cent of the unconditional variance in output, with foreign interest rates remaining the dominant contributor. To give a more complete picture, Figure 2 plots the forecast error variance for the output gap attributed to foreign factors at both the one-year and 50-quarter horizon across all 2 000 admitted rotations.[14] The first point to note is that the results presented above lie exactly on the mode of the distribution, while the baseline Choleski decomposition lies in the thin tail of the distribution. Looking at the range of values from the sign-restricted VAR analysis, it appears that the true importance of foreign factors may not be easily captured by traditional Choleski decompositions that impose contemporaneous (zero) coefficient constraints.[15]

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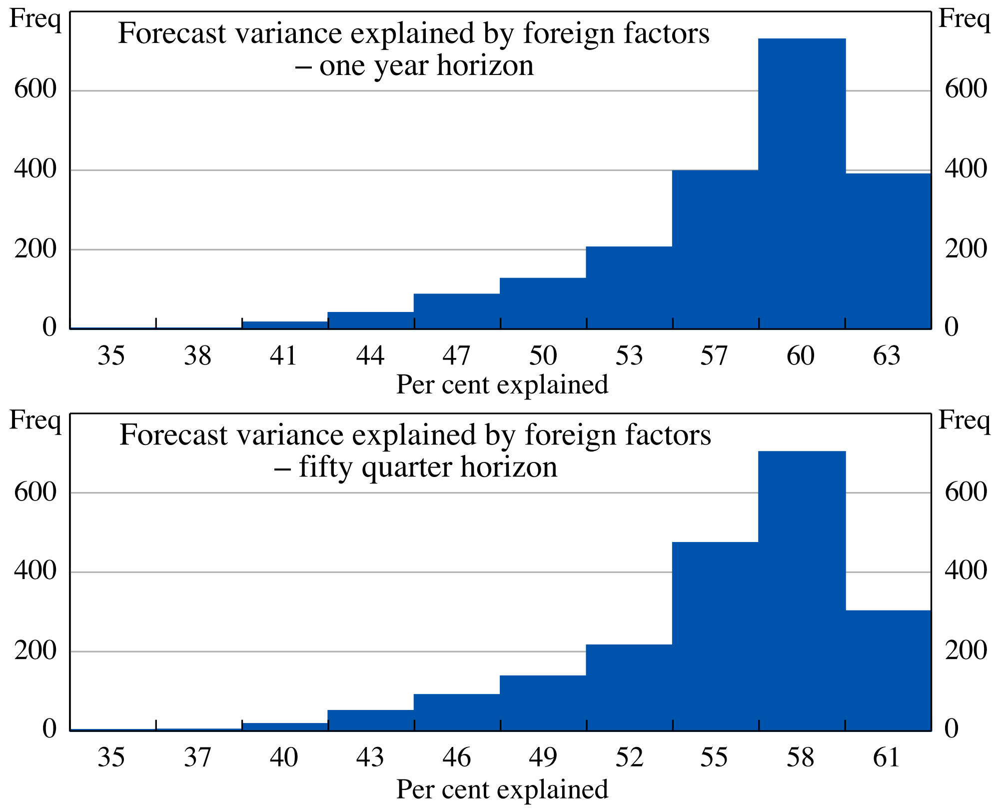
[14] The contribution from domestic factors can be easily read off the figure since the two factors must sum to 100.

[15] Estimating the sign-restricted VAR over the shorter sample 1992:Q1– 2006:Q1 suggests that, if anything, foreign output shocks have become more important for explaining the variance of the domestic output gap, while shocks to foreign interest rates have become less so. However, this sample may be too short to produce reliable estimates of the relatively high-dimensional VAR.

Figure 2: Sign-restricted VAR Variance Decomposition of Foreign versus Domestic Factors across 2 000 Rotations



Variance decompositions may reveal which shocks are important at explaining the forecast errors of output across different horizons. However, Fry and Pagan (2005) argue they may not be very useful in understanding the nature of business cycle fluctuations. One useful statistic is to decompose the historical observation of output into its MA representation in terms of shocks, that is:

$$y_t = \sum_{j=1}^{k} C_j(L)\varepsilon_{j,t} + \text{initial condition} \tag{13}$$

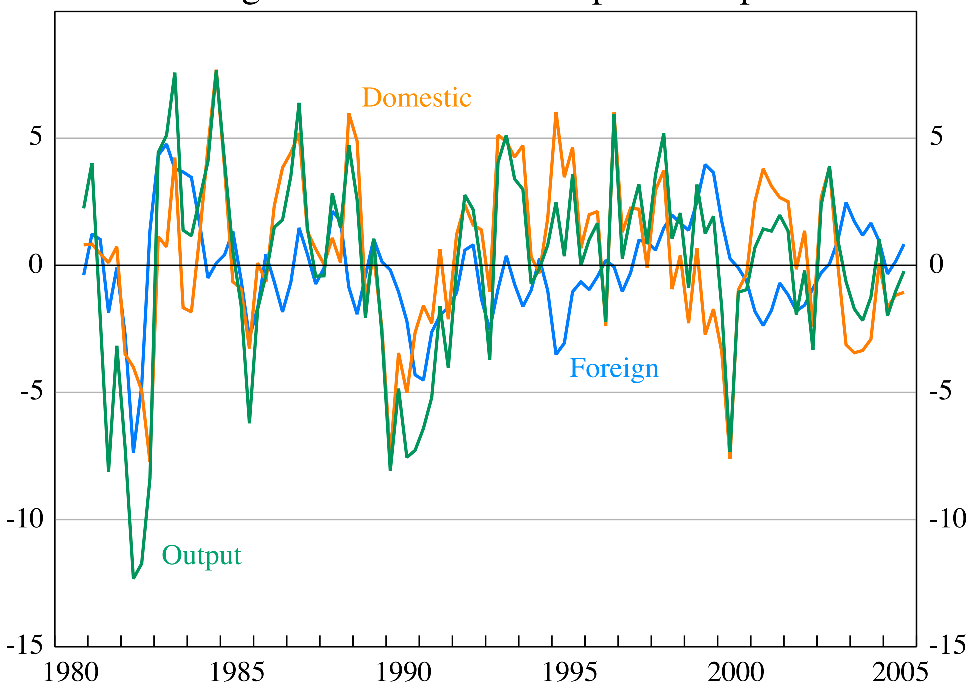
where $C_j(L)$ is the impulse response to the shock j.[16] Historical decompositions are particularly useful in relating certain events that have happened over the business cycle.

16 Since the entire history of shocks is not observed, the decomposed components of y_t may not add up exactly for the initial periods of the sample. In the case of output, this is around six to eight quarters, which are dropped from the decomposition results shown in Figure 3 below.

Figure 3 plots the historical decomposition of output into foreign (output, inflation and interest rates) versus domestic factors. During the two recessionary periods (the early 1980s and 1990s), both foreign and domestic factors had contributed negatively to output. This observation is consistent with the results reported in Dungey (2002). From the early 1990s onwards, the Australian economy experienced relatively stable and low inflation combined with robust output growth. Coincidentally, foreign and domestic shocks appear to have had offsetting effects so as to moderate domestic business cycle fluctuations during this period. For example, the slowdown in the economy after the Sydney Olympic Games together with the introduction of GST in 2000 was somewhat offset by buoyant conditions before the bursting of the 'dot-com' bubble in the United States. A buoyant housing market and strong household consumption in the early part of this decade was moderated by a temporary downturn in the US economy following the terrorist attacks in September 2001. The pattern continued in late 2003 where slowing conditions in the Australian housing market were offset somewhat by a relatively strong US economy.

Figure 3: Historical Decomposition of Output Using US Data

Foreign versus domestic – optimal impulse



5.2 G7 as the Foreign Economy

To check the robustness of these results, the sign-restricted VAR model is re-estimated using G7 data as the foreign economy. The overall conclusion is supported, although minor differences do arise.[17]

The combined contribution of foreign shocks accounts for around 63 per cent of the forecast error variance for the output gap at the one-year horizon, similar to that reported earlier. At the 50-quarter horizon, this increases to 76 per cent in contrast to 59 per cent based on using only US data. Consistent with the earlier estimates, innovations from domestic output play a smaller role in explaining domestic output gap forecast errors. However, within the set of international variables, foreign output now takes on a larger role compared with foreign interest rates. This tends to suggest that interest rates may have been picking up other global factors in the results based on US output alone.

6. Conclusion

This paper uses a small open economy model to investigate the sources of business cycle fluctuations for the Australia economy. A SVAR is identified using robust sign restrictions derived from an estimated small structural (DSGE) model rather than imposing zero-type restrictions. The results suggest that international factors account for over half the domestic output fluctuations while demand type shocks play a small role.

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[17] Detailed statistics are not reported but are available upon request.

Appendix A: Sign Restriction Algorithm

Define an $(n \times n)$ orthonormal rotation matrix Q such that:

$$Q = \prod_{i=1}^{n-1} \prod_{j=i+1}^{n} Q_{i,j}(\theta_{i,j}) \tag{A1}$$

$$\text{where} \quad Q_{i,j}(\theta_{i,j}) = \begin{array}{r} \\ \\ \\ \\ \text{row } i \rightarrow \\ \\ \text{row } j \rightarrow \\ \\ \\ \end{array} \begin{array}{c} \begin{array}{ccccccc} & & \text{col } i & & \text{col } j & & \\ & & \downarrow & & \downarrow & & \end{array} \\ \begin{bmatrix} 1 & & & & & & \\ & \dots & & & & & \\ & & \cos(\theta_{i,j}) & \dots & -\sin(\theta_{i,j}) & & \\ & & \dots & 1 & \dots & & \\ & & \sin(\theta_{i,j}) & \dots & \cos(\theta_{i,j}) & & \\ & & & & & \dots & \\ & & & & & & 1 \end{bmatrix} \end{array}$$

where $\theta_{i,j} \in [\ 0, \pi\ ]$. This provides a way of systematically exploring the space of all VMA representations by searching over the range of values of $\theta_{i,j}$. While Canova and De Nicolo (2002) propose setting up a grid over the range of values for $\theta_{i,j}$, the following algorithm generates the Qs randomly from a uniform distribution:

1. Estimate the VAR in Equation (10) using OLS to obtain the reduced form variance covariance matrix V and compute $\tilde{V}$.

2. Compute the Choleski decomposition of $\tilde{V_{11}}$ and $\tilde{V_{22}}$, where $H_{11} = chol(\tilde{V_{11}})$ and $H_{22} = chol(\tilde{V_{22}})$.

3. For both the foreign and domestic block, draw a vector of $\theta_{i,j}$ from a uniform $[\ 0, \pi\ ]$ distribution.

4. Calculate $Q = \prod_{i=1}^{n-1} \prod_{j=i+1}^{n} Q_{i,j}(\theta_{i,j})$.

5. Use the candidate rotation matrix Q to compute $\varepsilon_t = HQe_t$ and its corresponding structural IRFs $C(L)$ for domestic and foreign shocks.

6. Check whether the IRFs satisfy all the sign restrictions described in Table 2. If so keep the draw, if not, drop the draw.

7. Repeat (3)–(6) until 2 000 draws that satisfy the restrictions are found.

Appendix B: Supplementary Figures

Figure B1: Structural Model – Impulse Response Functions

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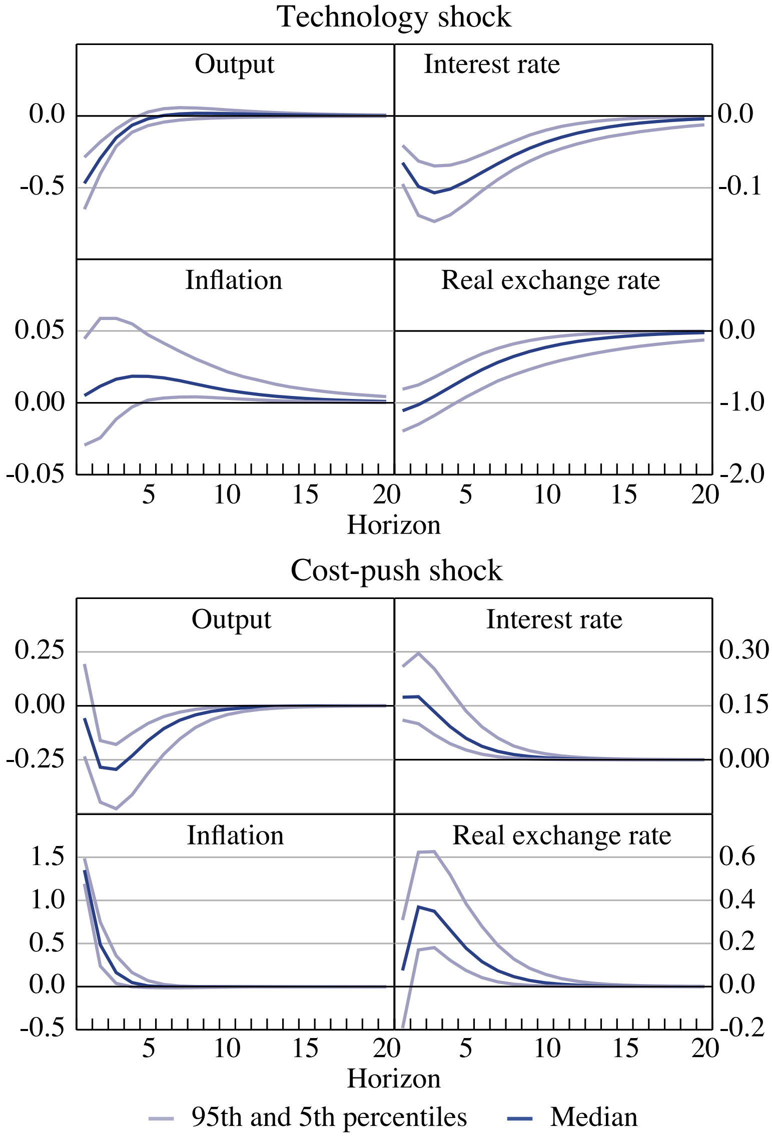

Figure B1: Structural Model – Impulse Response Functions

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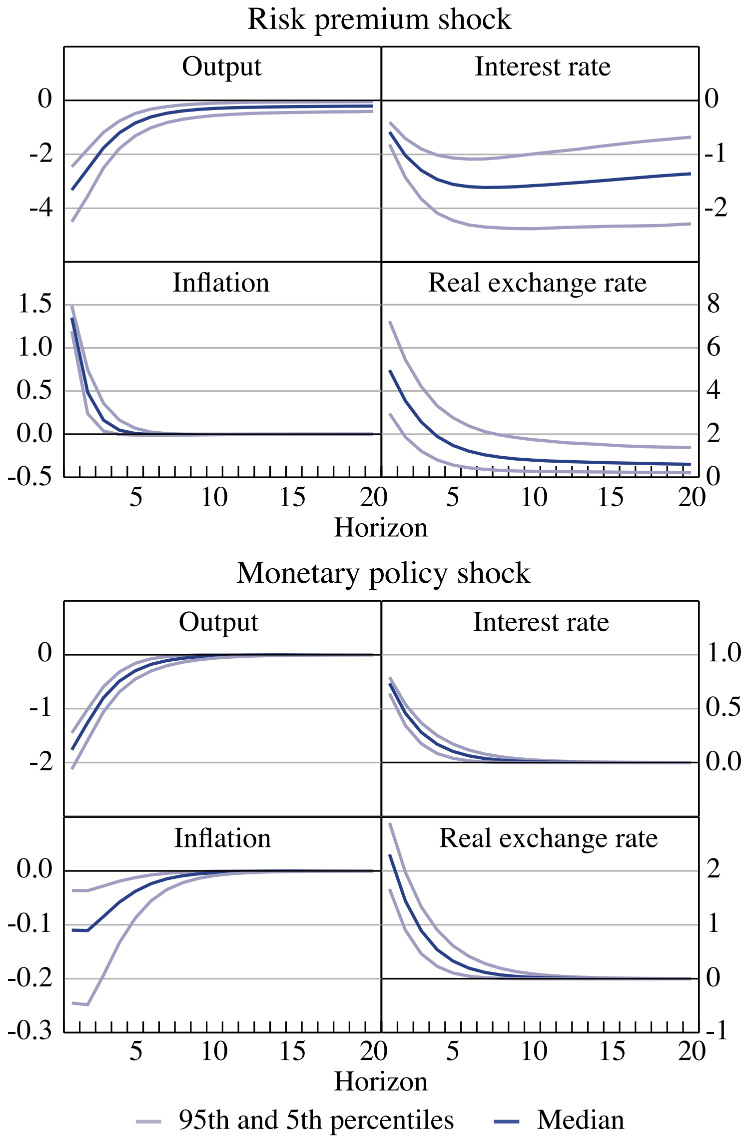

Figure B2: Structural Model – Impulse Response Functions

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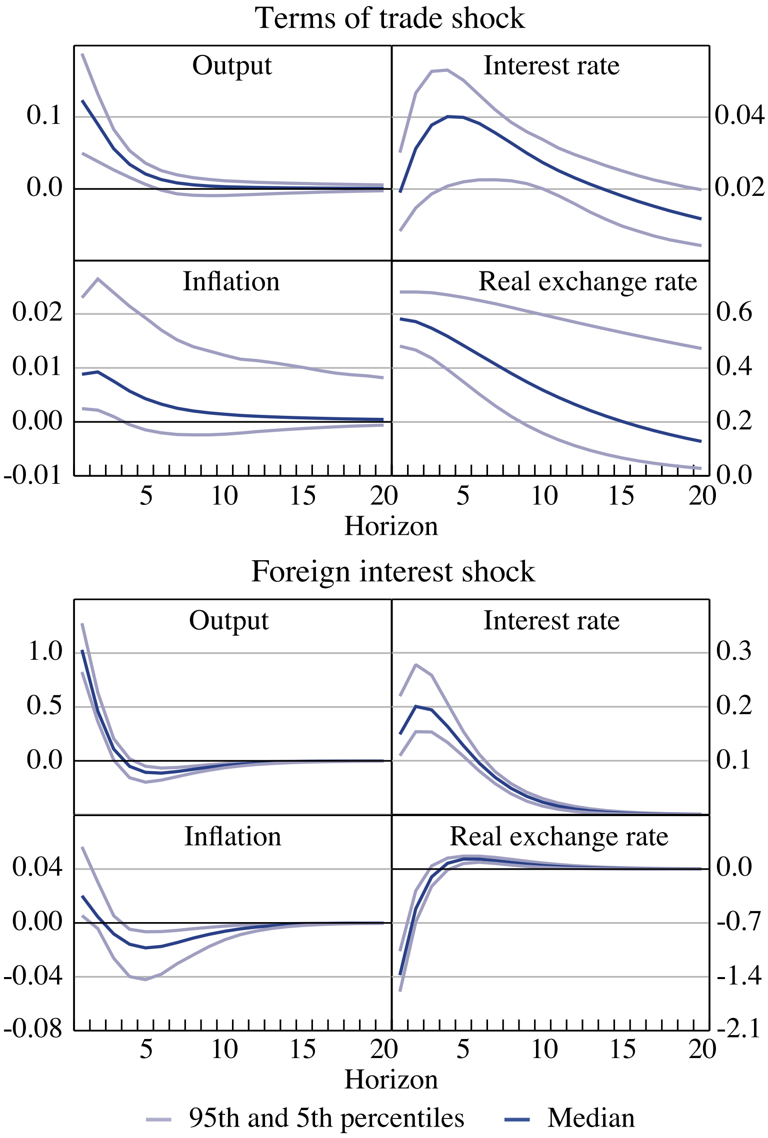

Figure B2: Structural Model – Impulse Response Functions

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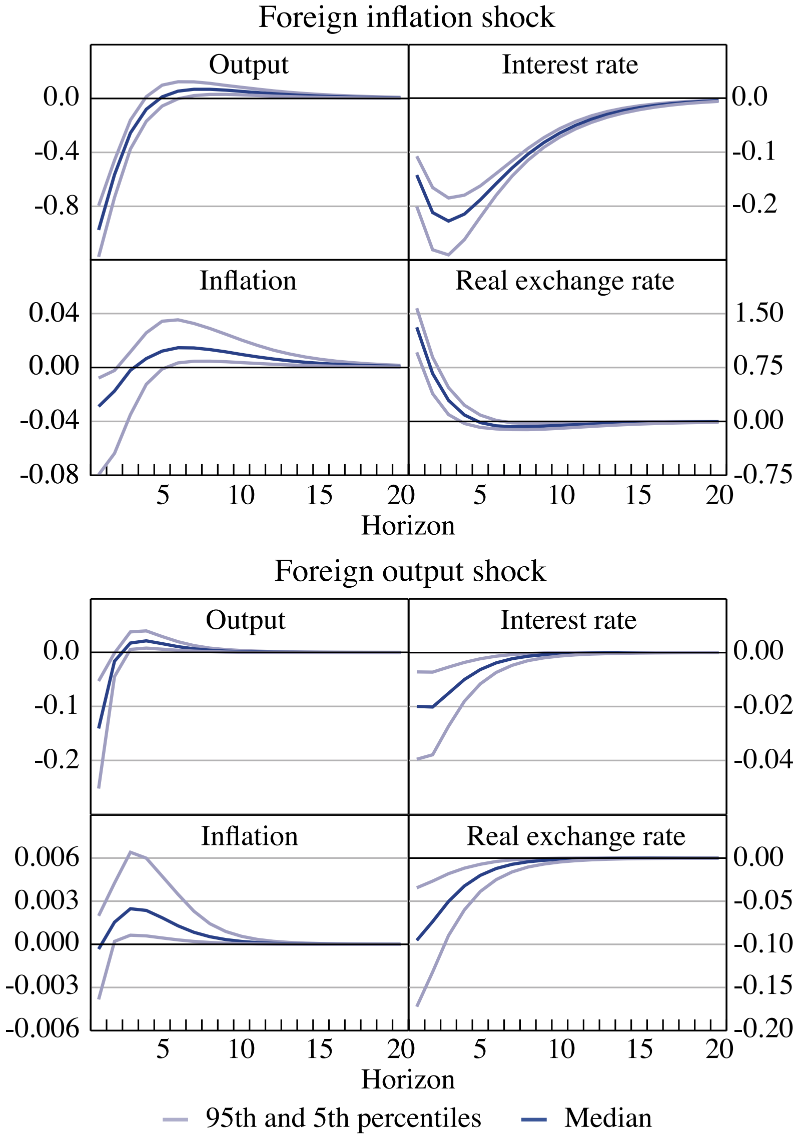

Figure B3: Sign-restricted VAR – Impulse Response Functions

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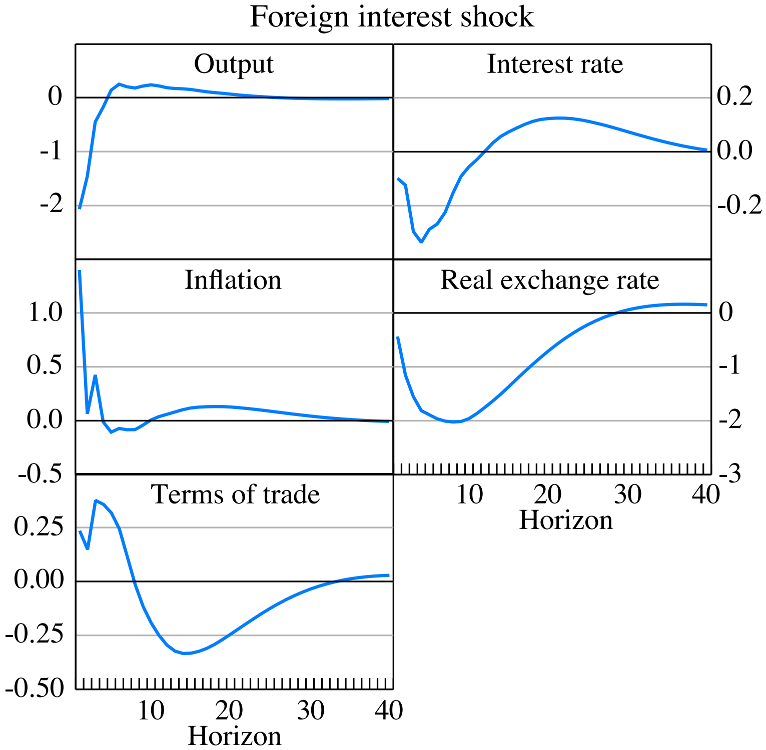


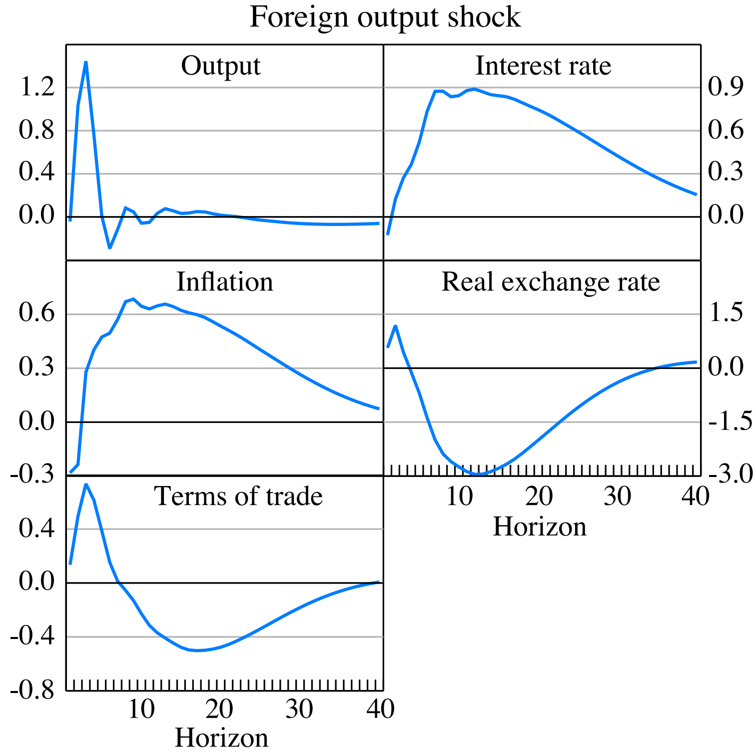
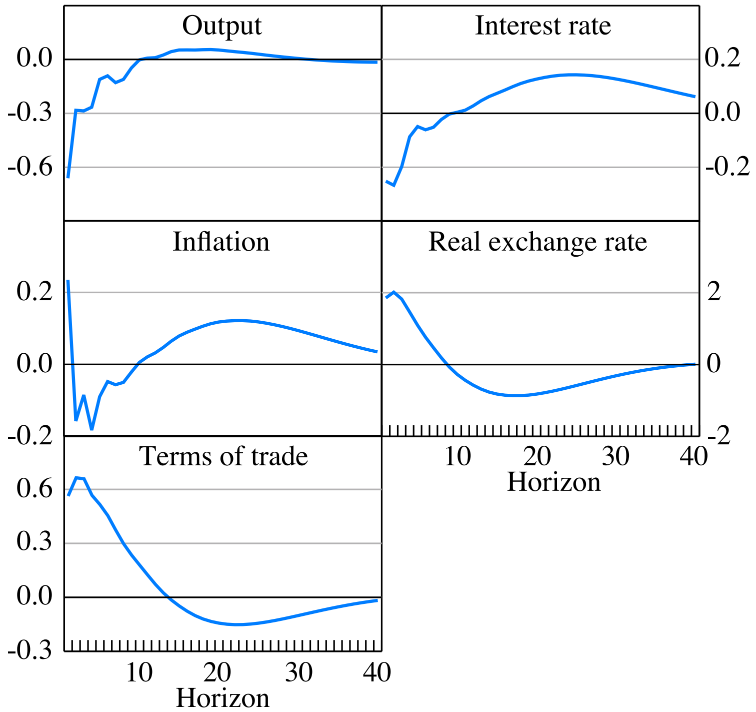


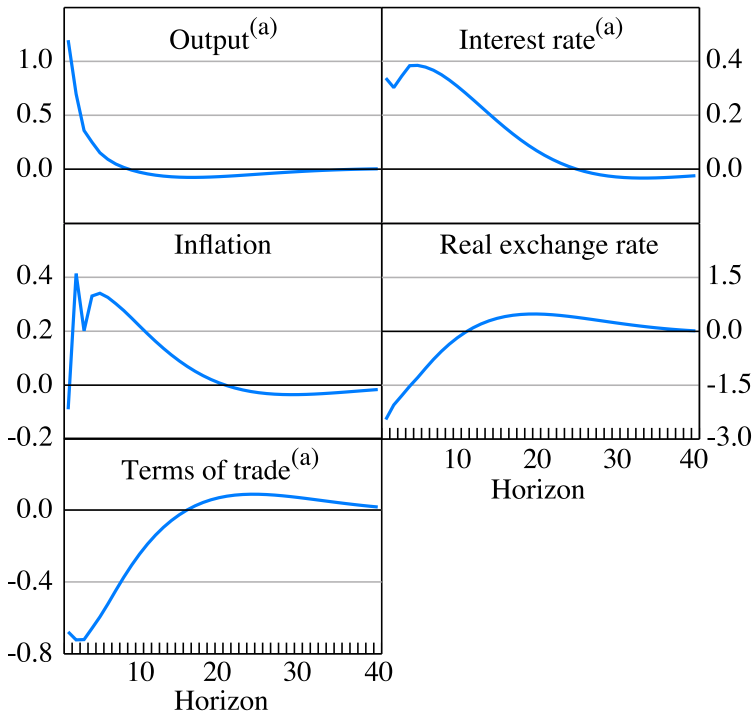
Figure B3: Sign-restricted VAR – Impulse Response Functions

(continued)

Foreign inflation shock



Domestic output shock



Note: (a) indicates impulse responses where sign restrictions are imposed.

Figure B4: Sign-restricted VAR – Impulse Response Functions

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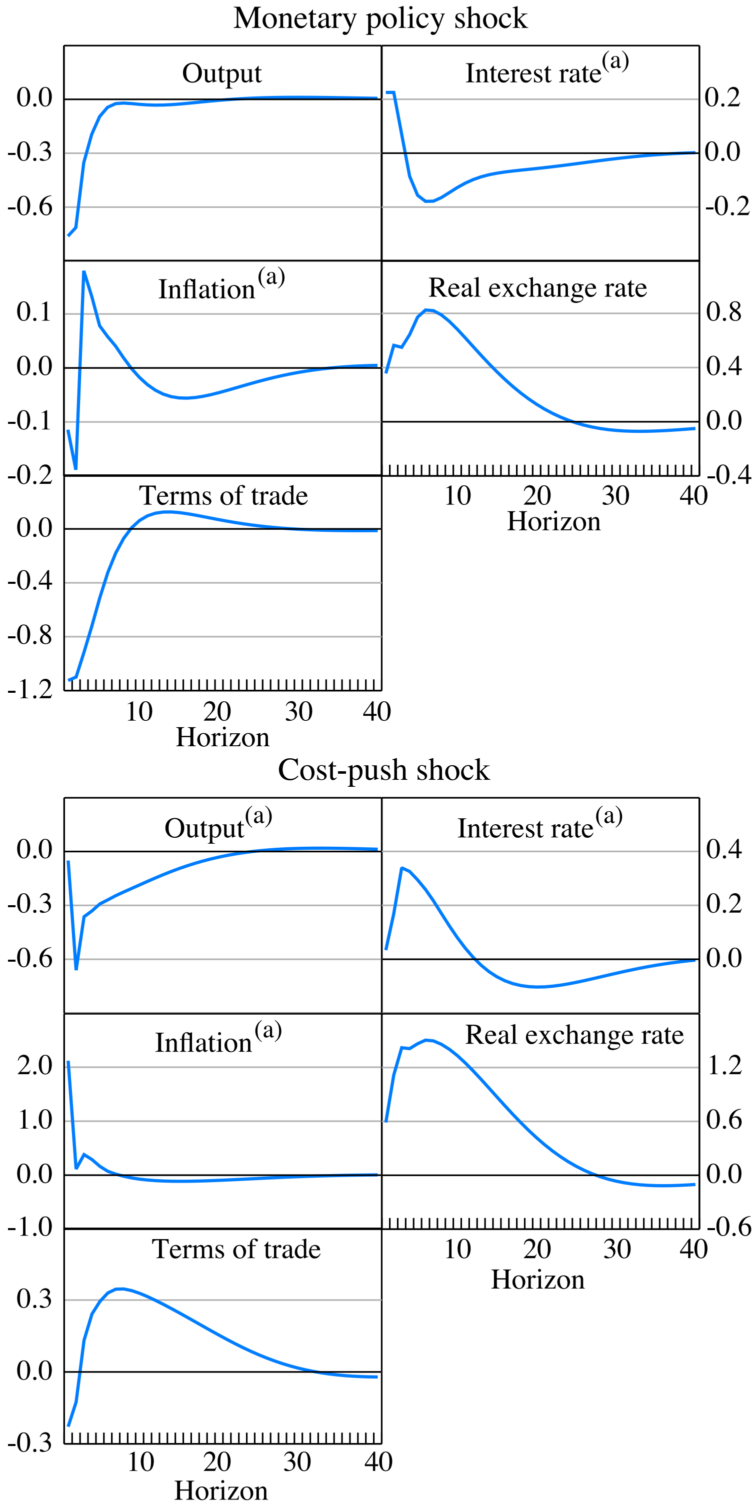
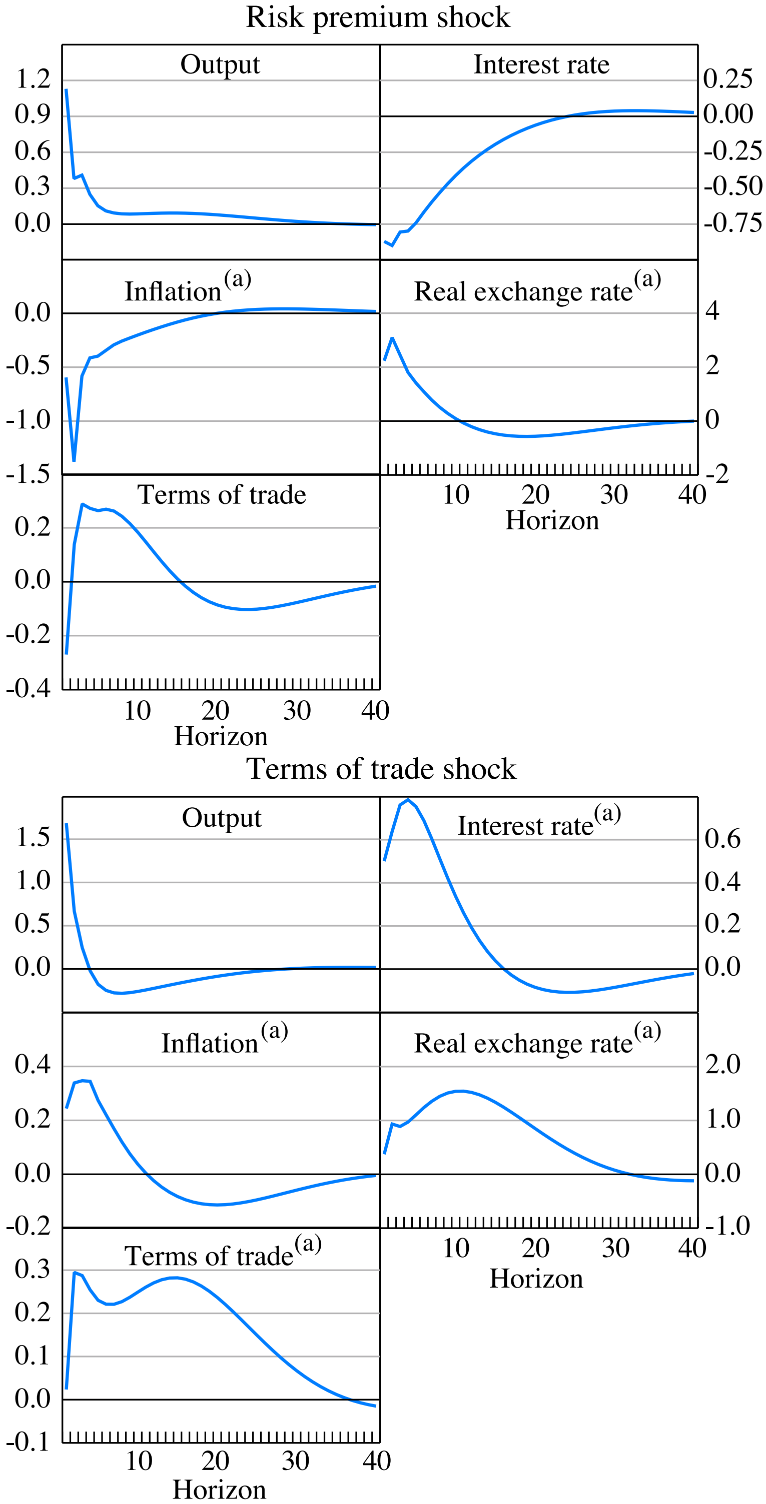


Note: (a) indicates impulse responses where sign restrictions are imposed.

Figure B4: Sign-restricted VAR – Impulse Response Functions

(continued)



Note: (a) indicates impulse responses where sign restrictions are imposed.

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