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Abstract

This paper examines the sources of Australia's business cycle fluctuations focusing on the role of international shocks and short run stabilization policy. A VAR model identified using robust sign restrictions derived from an estimated structural model is used to aid the investigation. The results indicate that, in contrast to previous VAR studies, foreign factors contribute over half of domestic output forecast errors whereas innovation from output itself has little effect. Furthermore, monetary policy was largely successful in mitigating the business cycle fluctuations in a counter-cyclical fashion while the floating exchange rate also help offset foreign disturbances. For Australia's stable economic success, good policy helped but so did good luck.

Keywords: Australia business cycle, sign restriction VAR, stabilization policy and international shocks

JEL Classification: E32, E52 , E63, F41

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1 Introduction

LUCAS (1977) advocated that understanding the nature of business cycles fluctuations should be the first step towards designing appropriate stabilization policies. The Australian economy is now in its sixteenth year of uninterrupted expansion together with relatively low inflation, one of the very few among OECD countries. It is important to ask what factors are contributing to this stable expansion path and the characteristics of shocks behind the business cycle fluctuations. Edwards (2006) highlights closer economic integration with the global economy as partly contributing to Australia's success. He also notes that while good policy has helped, good luck has also play an important role. In Edward's discussion, the *good policy* refers to the structural reforms in the 1980s while the role of short run stabilization policies was not elucidated.

This paper examines whether the stable expansion period is the result of good luck, focusing on the role of international shocks, or appropriate stabilization policies. This has important implications for future stabilization policy design. If Australia's stable and uninterrupted growth is mainly attributed to a favorable set of shocks drawn from the data generating process (DGP), the good luck scenario, then there are no reasons to believe the uninterrupted growth will continue far into the future. On the other hand, if appropriate stabilization policies are the key contributor and assuming these stabilization tools will continue to perform in a similar manner, then the stable growth path may persist for longer.

The effects of developments in the rest of the world on Australia often takes center stage in policy discussions. Despite the large existing literature on the topic, there is little consensus on the role played by the rest of the world in a small open economy's business cycle. Using an Australian structural vector autoregressive (SVAR) model, Dungey (2002) estimates the contribution from international factors accounts for 32% of output forecast errors at the one year horizon, while domestic GDP shocks remain the dominant contributor. A SVAR model by Brischetto and Voss (1999) reveals that only around 5% of output forecast errors came from exogenous 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% of the variance in output while domestic output shocks account for only 8%. Using a different criteria, Dungey and Pagan (2000) simulate data from a SVAR model and find recessions would have been less severe in the absence of foreign disturbances, while cumulated movements during the expansion phrase would also have been smaller. Dungey and Pagan's result also suggests monetary policy has largely performed in a counter-cyclical fashion in reducing output during expansions and stimulating output during contractions. However, little is said about the role of the floating exchange rate in offsetting domestic and foreign disturbances, and the identification of structural shocks rests on a set of tightly assumed restrictions.

This paper argues that much of the debate is a result of inconsistent estimation and/or identification of the structural disturbances that a small open economy (SOE) is subject to. Traditional SVAR analysis employing *zero-type* restrictions can place substantial misspecification on the features of the underlying economy leading to invalid inferences. On the other hand, identification of structural disturbances via cross equation restrictions using small DSGE models may be too simple to capture the complex probabilistic nature of the DGP. The work here contributes to this debate by developing a VAR 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 inter-relationships among the set of macro variables without imposing the full DSGE structure or potentially invalid zero-type restrictions used in VAR models.

Earlier sign restriction VAR studies mainly focus on identifying a subset of structural disturbances, examples include Faust (1998) and Uhlig (2005) in identifying 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 the studies mentioned above are based on large economies with little discussion on the role of the exchange rates. Farrant and Peersman (2006) did investigate the role of exchange rates in an open economy type setting, however, the role of international factors was not explicitly included. The impetus for this paper follows from previous observations that both monetary policy and the exchange rate interact to play a significant role in response to international developments.

The idea of using restrictions derived from a theoretical model to aid VAR estimation is not new. McKibbin et al. (1998) use the McKibbin-Sachs Global (MSG2) model to restrict the long run behavior of a VAR while the short run features are left unrestricted. Peersman and Straub (2004) use a calibrated RBC model to derive sign restrictions to help identify technology shocks. In terms of methodological contribution, this paper demonstrates how to identify SOE disturbances using short-run sign restrictions.

The analysis begins by using the Beveridge-Nelson decomposition to extract the cyclical component of GDP data to provide a reasonable measure of Australia's business cycle fluctuations. A simple structural SOE model is estimated to determine a set of robust sign restrictions for the VAR analysis. The 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 is consistent with the sign restrictions derived from the estimated structural model. Since there is not enough information to identify a unique set of structural disturbances, the median impulse approach suggested in Fry and Pagan (2005) is used to provide a summary of the results. The analysis reveals several interesting results. First, the Beveridge-Nelson decomposition produce a plausible measure of Australia's output fluctuations. 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 has little effect. The result is robust across different foreign specifications using US and G7 data. Third, for Australia's stable expansion path, good policy helped but so did good luck.

The paper is organized as follows. Section (2) describes the Beveridge-Nelson decomposition used to extract the cyclical component of GDP. Section (3) outlines the estimated SOE structural model together with the data used in the analysis. A set of robust sign restrictions is derived from the estimated model for the VAR model. Section (4) describes the estimation and identification of the sign restriction VAR model. Section (5) summarizes the estimation results along with some policy discussions. Finally, section (6) reviews the main findings and makes some suggestions for further work.

2 Decomposing the cyclical component of GDP

As with many empirical examinations on the business cycle, they often involve delicate and sometimes controversial issues of detrending.[1] The crucial problem comes down to trying to

[1] A detailed review of various detrending methods can be found in Canova (1998).

identify two separate components; the trend and the cycle, from a single time-series.[2] For the purpose of this study, it is useful to first clarify the cyclical component of the GDP data that the proposed economic model seeks to analyze. Two alternative methods are used to extract the permanent component of GDP for comparison. Depending on the detrending methods, this can lead to very different looking cycles. The first is the Hodrick and Prescott (HP) filter with the smoothing parameter, λ, set to 1600. One implicit assumption of the HP filter is that the shocks driving the trend are orthogonal to the shocks that drive the cycle.

As an alternative, the Beveridge Nelson (BN) decomposition is used. The permanent and cyclical component is implicitly assumed to be perfectly correlated. Consider a time series, y_t, with an ARIMA(p,1,q) representation. y_t can be broken down to a permanent (τ_t) and cyclical (c_t) component using the BN decomposition such that:

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

where $\tau_t = \mu + \tau_{t-1} + \alpha\epsilon_t$ is the unobserved trend, assumed to follow a random walk with average growth rate μ; and $c_t = \phi_p(L)c_t + \psi_q(L)\epsilon_t + (1-\alpha)\epsilon_t$ is a stationary and invertible ARMA(p,q) process.[3] To further understand the perfect correlation between the permanent and cyclical components, the BN decomposition can be cast into a *single-source-of-error* state space representation as in Anderson et al. (2006):[4]

$$y_t = Ax_{t-1} + \epsilon_t \tag{2}$$

$$x_t = Fx_{t-1} + H\epsilon_t \tag{3}$$

where $x_t = [\tau_t \; c_t \ldots c_{t-p+1} \; \epsilon_t \ldots \epsilon_{t-q+2}]'$ is the state vector. Equation (2) is the measurement equation obtained by substituting τ_t and c_t into equation (1). Inspection of equation (3) shows that both the trend and the cycle are driven by the same common shock ϵ_t. Furthermore, this is the same set of shocks underlying the original data y_t. It is this composite shock that the proposed VAR model aims to decompose into a set of structural disturbances to investigate the

[2]The terms permanent component and trend are used interchangeably, similar for cyclical component and the cycle.

[3]There are certain similarities between the BN and Unobserved Component decomposition that are discussed in Morley et al. (2003).

[4]Ignoring the constant.

effects of shocks originating from outside Australia.

An ARIMA(2,1,1) model is found to provide the best empirical fit (using the likelihood ratio test), for Australian GDP between 1980Q4 and 2006Q1.[5] Figure (1) plots the Australian GDP cycles derived from the HP filter and BN decomposition. There are a few interesting observations. First, the BN-cycle is much more volatile compared to the HP-cycle, the difference is more pronounced in the first half of the sample.[6] Second, the HP-cycle displays a much smoother and persistent cyclical behaviour. However, this may be attributed to the property of the HP filter with an integrated process, which dampens long and short run growth cycles while amplifying growth cycles at the business cycle frequencies (4-7 years). As a result, the HP filter may induce spurious periodicity that may not necessarily exist in the underlying data. Third, both cycles have the same peak frequency (estimated using the periodogram) of around 17 quarters. The BN cycle contains noticeably more high frequency fluctuations.

Figure (1) also includes the coincident index (GKR) of Australian economic activities using a factor model in Gillitzer et al. (2005). The aim of the index is to provide a plausible measure of the Australian business cycle using a large number of macro data sets. In all three series, the two recessions during the early 1980s and 1990s is apparent. However, the exact timing of the recessions are less clear. The BN-cycle and GKR index almost coincide exactly pointing to bottoming of economic activities around 1983Q1 and 1991Q1. As well as picking up the large economic downturns, the BN decomposition also identifies several large negative shocks that hit the Australian economy over the sample period. The first was related to Paul Keating's *Banana Republic* remark over growing concerns about Australia's foreign debt position that sparked a down turn in household expenditure in 1986. The slowdown of the economy following the end of the Sydney Olympic games and the introduction of GST in 2000 was also visible from the decomposition.

3 A stylized small open economy structural model

The estimated SOE structural model is based on a simplified version of the model proposed in Monacelli (2005) and Gali and Monacelli (2005). The model consists of an open economy IS equation and a Phillips Curve incorporating imperfect pass-through from import prices. The

[5]The BN decomposition is then computed based on the method suggested by Newbold (1990).

[6]The standard deviation of the BN-cycle is 3.89 compared with 1.41 for the HP-cycle over the whole sample.

monetary authority is described using a Taylor-type reaction function, while the expected change in the real exchange rate is equal to the real interest rate differential between the domestic and foreign economy. The rest of the world variables, in particular the foreign interest rate, inflation, output and the terms of trade (TOT), are described as AR(1) exogenous driving processes.

The open economy IS equation arising from the consumer's optimizing problem can be written as:[7]

$$\begin{aligned} y_t = n_1 y_{t-1} + (1 - n_1) E_t y_{t+1} - n_2 (r_t - E_t \pi_{t+1}) \\ + n_3 E_t \Delta y^*_{t+1} - n_4 z_t + n_5 E_t \Delta \psi_{t+1} \end{aligned} \tag{4}$$

where $n_1, \ldots, n_5$ are combinations of preference and technology 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.[8] $\psi_t = (1-\gamma)s_t - q_t$ can be interpreted as the *law of one price gap* which measures the deviation of domestic imported goods from the world price (s_t is the terms of trade and q_t is the real exchange rate). A non-zero ψ_t gives rise to imperfect exchange rate pass-through for import prices. The backward looking part of output in the IS equation is motivated by the existence of habit persistence in the consumer's preferences.

The open economy New Keynesian Phillips Curve (NKPC) arising from the firm's pricing decision can be written as:

$$\pi_t = g_1 \pi_{t-1} + (1 - g_1) E_t \pi_{t+1} + g_2 y_t + g_3 \psi_t + \epsilon_{\pi,t} \tag{5}$$

where $g_1, \ldots, g_3$ are also combinations of preference and technology parameters, and $\epsilon_{\pi,t}$ represent domestic cost push shocks. Underlying the NKPC is the assumption of monopolistic competitors that are subject to pricing constraints (Calvo pricing with indexation). When $g_3 = 0$, equation (5) collapses down to a familiar closed economy NKPC where inflation dynamics are partly driven by past and future expectations of inflation plus the output gap.[9] The open

[7] All equations are given in the linearized form.

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

[9] From the assumption of habit formation, a lagged output term should be included in the Phillips curve. To keep the structural model simple, the NKPC only includes the contemporaneous impact of output. This should have no effect on the signs of the impulse response functions.

economy dimension includes the effects from the exchange rate and terms of trade which gives rise to imperfect exchange rate pass-through in the short run that is crucial to the monetary authority's stabilization policy.

The assumption of perfect capital markets yields the exchange rate no arbitrage condition or the uncovered interest parity (UIP) condition such that:

$$q_t = E_t q_{t+1} + (r_t - E_t \pi_{t+1}) - \left(r_t^* - E_t \pi_{t+1}^*\right) + U_{q,t} \tag{6}$$

where $U_{q,t}$ represents the time varying risk premium following an AR(1) process. The behaviour of the monetary authority is assumed to follow a Taylor-type reaction function that responds to inflation and output contemporaneously as well as an interest rate smoothing term:

$$r_t = \rho_r r_{t-1} + (1 - \rho_r)[\phi_1 \pi_t + \phi_2 y_t] + \epsilon_{r,t} \tag{7}$$

where $\epsilon_{r,t}$ is the non systematic deviations from the reaction function. To complete the description of the structural model, the terms of trade s_t, foreign output y_t^*, interest rate r_t^* and inflation π_t^* are all assumed to follow an AR(1) exogenous process. The structural model can be summarized as:

$$A_0 Y_t = A_1 Y_{t-1} + A_2 E_t Y_{t+1} + \epsilon_t \tag{8}$$

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 state vector of the model's endogenous variables and $\epsilon_t = [\epsilon_{z,t}, \epsilon_{r,t}, \epsilon_{\pi,t}, \epsilon_{q,t}, \epsilon_{s,t}, \epsilon_{r^*,t}, \epsilon_{y^*,t}, \epsilon_{\pi^*,t}]$ is a 8×1 vector of structural disturbances.[10] The solution of the model can be represented as a first order VAR:

$$Y_t = B_1 Y_{t-1} + B_2 \epsilon_t \tag{9}$$

It is interesting to note that B_2, often interpreted as the *impact matrix*, rarely produces the zero-restrictions assumed in SVAR model. Furthermore, B_2 is a highly non-linear function of the model's structural parameters.

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

3.1 Data description

Time series data from 1980Q1 to 2006Q1 for the Australian economy is used to estimate the structural model and the VAR.[11] The starting period coincides with previous SVAR studies of the Australian economy as in Dungey and Pagan (2000). Quarterly observations on GDP (y_t), CPI quarter to quarter inflation rate (π_t), terms of trade (s_t), real exchange rate (q_t), nominal interest rate (r_t), US GDP (y_t^*), US CPI quarter to quarter inflation rate (π_t^*) and US nominal interest rate (r_t^*) are taken from the Reserve Bank of Australia database.

The cyclical component of GDP (both Australia and the US) are constructed using the BN decomposition described earlier. An ARIMA(2,1,2) model is fitted to US GDP as in Morley et al. (2003) before performing the decomposition. Due to the unprecedented increase in Australia's TOT between 2004 and 2006, an HP filtered trend is taken out of the TOT to ensure stationarity of the series.[12] All variables apart from inflation and interest rates enter in logs.

3.2 Estimation of the structural model

The model's likelihood function can be computed via the state-space representation of the model's solution in equation (9), together with the measurement equation linking the observed data and the state vector such that:

$$Y_t = B_1 Y_{t-1} + B_2 \epsilon_t \quad (10)$$

$$Z_t = G Y_t \quad (11)$$

where Z_t denotes the observed data and the matrix G specifies the relationship between the state variables and the observed data. Given the difficulties in maximizing the likelihood function using hill-climb methods, the empirical likelihood function is simulated using the Metropolis Hasting (MH) algorithm described in Geweke (1999).[13] The stationary Markov Chain distribution constitutes the empirical likelihood function.

The model's estimates are generated conditional on the OLS estimate of the model's four ex-

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

[12] This may be a less than ideal transformation of the data, however, it is necessary to ensure the stability of the estimated VAR.

[13] Direct maximization of the computed likelihood proves very difficult. The MH algorithm is traditionally used in Bayesian estimations to simulate the posterior distribution of the model. In this case, the prior distribution receives zero weight, hence the simulated distribution is equivalent to the likelihood function.

ogenous driving processes: the terms of trade s_t, foreign inflation π_t^*, interest rate r_t^* and output y_t^*.[14] There are two advantages in estimating the observed exogenous processes independent of the model. First, this reduces the number of parameters to be estimated in the simulation algorithm. Second, Fukac and Pagan (2006) emphasized that rigid restrictions imposed by DSGE (structural) models on the data may yield invalid estimates of the model's observable shocks.

The diagnostic tests indicates the simulated Markov Chains has converged to its stationary distribution and Table (1) summarizes the parameter estimates drawn from this distribution.[15] The degree of backward lookingness in the IS equation is estimated to be 0.09 and 0.27 for the Phillips curve. The estimated coefficient in front of the real interest rate (n_2) in the IS equation is relatively small suggesting output variations are relatively insensitive to interest rate changes. The response of inflation to output gap changes (g_2) is also estimated to be very low. Combining these two effects makes the central bank's inflation control problem much more difficult when inflation is rising; the flat Phillips curve phenomenon. The estimated Taylor-type reaction function displays a significant degree of interest rate smoothing behaviour with ρ_r to be 0.90. The estimated weight on output variation is slightly higher than the weight on inflation and calibrated values traditionally used in the literature. However, the estimation covers the period prior to inflation targeting , and the wide confidence interval around ϕ_2 reflects the uncertainty around this estimate.

3.3 Impulse response analysis of the structural model

This section presents the impulse response functions (IRF) of the model following a technology, monetary policy, cost push, risk premium, terms of trade and the three foreign shocks. The IRFs are simulated by sampling from the parameters' stationary distribution to take into account the uncertainty embedded in the estimation of the model. The median (solid lines) along with the 5th and 95th percentiles (dotted lines) responses are shown in Figures (2) and (3). The IRFs of the model are broadly consistent with other SOE studies using similar New Keynesian models. Moreover, the initial responses of key variables are quantitatively significant providing a useful set of robust sign restrictions for the VAR analysis. The discussions here will focus on the initial

[14] The OLS estimates of the observable shocks are shown in Table (1).

[15] There is only one exception, n_4, which is significant at the 5% level. However, a small Brooks and Gelman statistic of 1.12 indicate the chain has converged. A 40% burn-in is discarded before computing the summary statistics. The mean of the marginal density is reported here rather than the mode.

responses rather than the dynamic adjustment path following of the shocks.

A positive technology shock (equivalent to a negative output gap shock) has a negative impact on the output gap and interest rates. The real exchange rate depreciates reflecting the change in the real interest rate differential. In the structure of the model, technology influences output through lowering the cost of production. Given actual output takes time to adjust in response to higher capacity, the output gap will initially fall before production catches up with the increase in capacity. There is a small increase in the inflation rate, however, the effect is quantitatively insignificant. A negative supply shock that pushes up the cost of production has a negative and gradual impact on output forcing the central bank to tradeoff between lower output and higher inflation. In this instance, a monetary tightening of 20 basis points is required to bring inflation back to target. Inflation returns to steady state fairly quickly with the help of the higher exchange rate responding to a larger interest rate differential.

A small negative risk premium shock of 1% has a relatively large impact on the exchange rate with wide confidence intervals.[16] This translates into lower inflation and output. The central bank responds with a monetary expansion that reduces the nominal interest rate. On the other hand, a non-systematic tightening of monetary policy has a contractionary effect on the economy together with lower inflation. The exchange rate also appreciates in response to monetary tightening because domestic bonds are now relatively more attractive compared with foreign ones.

Turning to the external factors, an improvement in Australia's terms of trade has a positive effect on both output and inflation. It is interesting to note that the terms of trade shock only translates into relatively weak inflation pressure of 0.01% for the domestic economy. The exchange rate appreciates in response to the terms of trade improvement and acts like an automatic stabilizer for the domestic economy. The monetary tightening is relatively small with interest rates increasing by only 5 basis points at its peak. An exogenous increase in the foreign interest rate leads to a sharp depreciation of the local exchange rate leading to a higher output gap. The effect on inflation is relatively small while the domestic interest rate is higher, in response to the higher output gap and negative interest rate differentials. Given the simple structure of the model, an increase in foreign inflation has the same but opposite qualitative effects on the domestic economy as the foreign nominal interest rate shock. The natural level of output

[16] The negative risk premium acts to appreciate the exchange rate.

depends on the level of technology and foreign output, hence an increase in foreign output decreases the domestic output gap. Both domestic inflation and interest rates stay relatively static while the depreciating exchange rate helps balance the international consumption risk-sharing condition.[17]

3.4 Robust sign restrictions

The focus of the study is to gather a set of sign restrictions from a structural model to help guide identification of a SOE VAR model. It is possible to reduce the number of restrictions implied by the estimated structural model to form a set of robust sign restrictions to identify all the shocks.[18] The complete set of restrictions are presented in Table (2).

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 typical closed economy New Keynesian model. The response 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 in the system are also left unrestricted.[19] Third, the output shock can be viewed as a composite shock that moves output and interest rates higher but orthogonal to all other shocks in the system, for example: a demand shock. Lastly, the sign restrictions are imposed for the initial two periods only.

4 Estimation of sign restriction VAR

This section outlines the small open economy SRVAR model estimated using the data described in section (3.1). An eight-variable VAR(2) model is fitted to quarterly observations from 1980Q4 to 2006Q1 and the number of lags is determined by the Akaike Information Criteria (AIC).

Consider a general structural VAR(p) model:

$$BY_t = A(L)Y_t + \epsilon_t \tag{12}$$

[17]The international consumption risk sharing condition formally implies that, in equilibrium, the difference between foreign and domestic consumption is reflected in the changes in the real exchange rate.

[18]The complete set of estimated IRF from the structural model provides more than enough restrictions necessary to disentangle the eight structural shocks.

[19]With the presence of sticky prices in the short run, the terms of trade can respond endogenously to other variables in the system.

where Y_t is a vector of $(n \times 1)$ endogenous variables, $A(L) = A_1 L + \cdots + A_p L^p$ is an p^{th} order matrix polynomial, B is an $(n \times n)$ matrix coefficient summarizing the contemporaneous relationship between Y_t, ϵ_t is a set of $(n \times T)$ normally distributed structural disturbances with mean zero and variance covariance matrix Σ, where $\Sigma_{i,j} = 0 \ \forall i \neq j$. The reduced form representation corresponding to equation (12) can be written as:

$$Y_t = \Pi(L) Y_t + e_t \tag{13}$$

where $\Pi(L) = \Pi_1 L + \cdots + \Pi_p L^p = B^{-1}(A_1 L + \cdots + A_p L^p)$ and e_t is a set of $(n \times T)$ normally distributed reduced form errors with mean zero and variance covariance matrix V, where $V_{i,j} \neq 0 \ \forall i, j$. The aim is to map the statistical relationships summarized 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:

$$e_t = P\epsilon_t \quad \text{and} \quad V = E(e_t e_t') = HH' \tag{14}$$

for some matrix H such that $HH' = P\Sigma P'$. The problem arises where there is not enough restrictions to uniquely pin down H from the matrix V, the *identification problem*.[20] While linearized DSGE models seldom deliver the $n(n+1)/2$ set of restrictions needed to recover the n structural shocks, they contain a large number of sign restrictions usable for identification purpose. The next subsection explores this idea in more detail.

4.1 Identification of the SRVAR

The identification of VAR structural disturbances is often a highly controversial topic, researchers employing different identifying assumptions may reach different conclusions with respect to the same economic questions. Identification strategies that restrict either the short-run or long-run impact of certain shocks on a subset of variables to zero, are often referred to as *zero-type* (or constant-type) restrictions.[21] The Choleski decomposition is one such example, where the contemporaneous impact of shocks follow a recursive ordering. One noticeable divergence between the VAR and empirical DSGE literature is that the largely controversial zero restrictions are

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

[21] The discussion here will only focus on exactly identified VARs.

almost never replicated using the standard class of DSGE models. Canova and Pina (2005) emphasized that such invalid assumptions can place substantial misspecification on the features of the underlying economy. Another challenge related to the identification of structural shocks, is that the identification schemes are non-unique. More importantly, these schemes are indistinguishable in the face of the data even when T goes to infinity.

The central idea behind structural VAR analysis is to decompose the set of estimated reduced form shocks, characterized by V, back into a set of orthogonal structural disturbances characterized by Σ. However, there are an infinite number of ways where this orthogonality condition can be achieved. If H is an orthogonal decomposition of $V = HH'$, the multiplicity comes 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. One example is the Choleski factor of V, where $H = chol(V)$ and the set of economic disturbances is $\epsilon_t = He_t$. Another example of such orthogonal representation is the eigenvalue-eigenvector decomposition of $V = \Gamma\Lambda\Gamma' = \tilde{H}\tilde{H}'$, where Γ is a matrix of eigenvectors and Λ is a diagonal matrix of eigenvalues. In this case, $\tilde{H} = \Gamma\Lambda^{1/2}$, need not be a lower triangular matrix. This decomposition does not have any economic content, but nevertheless, produces a set of uncorrelated shocks $\epsilon_t = \tilde{H}e_t$, without imposing zero-type restrictions. One can observe that a different decomposition will result in a different set of structural disturbances hence a different vector moving average (VMA) representation.[22]

The identification strategy used here closely follows Canova and De Nicolo (2002), Uhlig (2005), and Peersman (2005) in using qualitative information directly on the IRF to achieve identification without the need to impose potentially invalid zero-type restrictions. Canova and De Nicolo (2002) 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) a for more detailed description of the algorithm.

4.2 Imposing the small open economy assumption

Given the Australian economy is relatively small in the face of the world economy, the general VAR model in equation (12) is restricted to reflect the small open economy assumption as in Cushman and Zha (1997), and Dungey and Pagan (2000). The SOE structural VAR can be

[22] Typical summary statistics from VAR studies are usually functions of the underlying VMA representation.

rewritten as:

$$B_{11}x_t = A_{11}(L)x_t + \epsilon_{x,t} \tag{15}$$

$$B_{21}x_t + B_{22}y_t = A_{21}(L)x_t + A_{22}(L)y_t + \epsilon_{y,t} \tag{16}$$

where x_t is a $(n_f \times 1)$ vector of foreign variables, y_t is a $(n_d \times 1)$ vector of domestic variables, the B's and A's are the contemporaneous and autoregressive matrix of coefficients respectively. The structural disturbances originating from foreign and domestic variables are represented by $\epsilon_{x,t}$ and $\epsilon_{y,t}$. Equations (15) and (16) imply that the domestic economy does not have a contemporaneous or lagged effect on the foreign economy, however, the converse is not true.[23] An important implication of the block exogeneity assumption is that the domestic disturbances are functions of the domestic reduced form shocks only, and similar for the foreign disturbances. Partitioning the unrestricted reduced form variance covariance V such that:

$$V = \begin{pmatrix} V_{11} & V_{12} \\ V_{21} & V_{22} \end{pmatrix} \tag{17}$$

The first step is to construct a set of domestic reduced form shocks that is orthogonal to the foreign block such that the restricted reduced form variance covariance matrix has the following structure:[24]

$$\tilde{V} = \begin{pmatrix} V_{11} & 0 \\ 0 & V_{22} - V_{21}V_{11}^{-1}V_{12} \end{pmatrix} \tag{18}$$

where $V_{22} - V_{21}V_{11}^{-1}V_{12}$ is the reduced form variance covariance of y_t given x_t. Intuitively, this amounts to removing the linear influence of $e_{x,t}$ from $e_{y,t}$. The block exogenous nature of $\tilde{V}$ allows the reduce form errors of each block to be decomposed separately by applying the orthogonal rotations. The contemporaneous matrix B will have the following form:

$$B = \begin{pmatrix} B_{11} & 0 \\ B_{21} & B_{22} \end{pmatrix} \tag{19}$$

[23]The block exogeneity assumption is imposed rather than tested against the data.

[24]This is simply a block triangular factorization of the matrix V.

where B_{11} is an orthogonal decomposition of V_{11} such that $B_{11}B'_{11} = V_{11}$, B_{22} from decomposing $V_{22} - V_{21}V_{11}^{-1}V_{12}$ and $B_{21} = -B_{22}V_{21}V_{11}^{-1}$ which measures the contemporaneous impact of $\epsilon_{x,t}$ on y_t.

4.3 Finding the median impulse

Since all accepted draws have the same statistical interpretation, that is same likelihood values, one important challenge remains; which one should the researcher report? Previous sign restriction studies, such as Peersman (2005), simply present the percentile measure (median and 95% intervals) across the whole range of possible rotations. However, Fry and Pagan (2005) highlight one potential flaw with this approach, which is the reported IRF's no longer retain the orthogonality condition that the sign restriction method emphasizes. To see this, consider the example where there are only two variables and the orthonormal rotation matrix Q has only one θ. Suppose the interest is in the response of the first shock on the first variable ι_{11} and the second shock on the second variable ι_{22}. The two median responses across all possible rotations $\bar{\iota}_{11}^{\theta_n}$ and $\bar{\iota}_{22}^{\theta_m}$ will almost certainly coincide with a different rotation angle θ, hence a different orthogonal matrix Q. As a result, the two shocks identified are no longer orthogonal to each other. Fry and Pagan suggest locating a unique vector of θ's such that the impulses are closest to their median while maintaining the orthogonality condition. The choice of θ here is the one that minimizes the following quantity:

$$\Upsilon(\theta_j) = \sum_{i=1}^{q} (\phi_i^j - \bar{\phi}_i)(\phi_i^j - \bar{\phi}_i)' \tag{20}$$

where the index i refers to the horizon to which the impulses are calculated up to $q = 40$, ϕ_i^j is an $n \times n$ matrix of standardized impulses for the jth rotation and $\bar{\phi}_i$ is the median impulse over all possible rotations.[25] Substituting θ^{min} back into $Q(\theta)$ will produce a set of orthogonal shocks and the summary statistics are computed based on this rotation.

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

5 SRVAR Results

5.1 SRVAR Impulse response analysis

Identification of international shocks using the SRVAR allows for a structural interpretation of the effects of shocks originating from outside Australia. The impulse responses of domestic output, interest, inflation, real exchange rate and the terms of trade with respect to the three foreign shocks are shown in the first three rows of Figure (4).[26] An exogenous increase in the foreign interest rate results in a depreciation of the exchange rate and higher domestic inflation. In contrast to the structural model, the depreciation of the exchange rate is more gradual reaching a peak of 8 quarters rather than immediately after the shock. Another interesting difference is that foreign monetary tightening will reduce foreign output hence lowering domestic export demands and the output gap. A domestic monetary expansion is required to bring the output gap back to zero.

In contrast to the foreign interest rate shock, a positive foreign output shock has relatively small contemporaneous effects on the domestic economy. The transmission of foreign shocks via financial markets appears to be much quicker than the goods market. Following the shock, domestic output rises slowly due to the higher export demand reaching a peak just over 1% after 4 quarters. While the structural model treats higher foreign output as a positive technology shock (one that reduces the output gap), the SRVAR clearly rejects this interpretation. Higher domestic output brings about increased inflationary pressure that induces the monetary authority to tighten policy to bring both output and inflation back to the steady state.

The response of the domestic economy is very similar to that implied by the structural model following a foreign inflation shock. The exchange rate appreciates by around 2% immediately after the shock in response to the lower real interest rate differential. The higher exchange rate has a contractionary effect on domestic output, a small decrease in the interest rate around 25 basis points is required to bring output back to zero.

Figure (5) and the last row of Figure (4) displays the response of domestic output, interest rate, inflation, real exchange rate and the terms of trade with respect to the remaining five domestic shocks. The response of the domestic economy is similar to that implied by the structural model (opposite sign to a productivity shock) even though only the interest rate

[26] Recall that the response of the domestic economy to foreign disturbances are left unrestricted in the SRVAR.

response is restricted. However, the magnitude of the inflation response is much greater. As the result, the interest rate stays positive for more than 20 quarters to bring both output and inflation back to zero.

A non-systematic tightening of monetary policy through higher interest rates lowers inflation as implied by the sign restrictions. The monetary tightening has a negative contemporaneous effect on domestic output while the exchange rate appreciates in response to the higher real interest rate. In contrast to the structural model, immediately after the shock, the interest rate falls below zero to stimulate both output and inflation back to zero.

Following a cost push shock, both inflation and interest rates are higher as expected from the sign restrictions, while output decreases in response to the tightening. The exchange rate appreciates as usual in response to the higher interest rate.

A negative risk premium shock that triggers an appreciation of the exchange rate will lower inflation as expected from the sign restriction. There is a sharp drop in the interest rate in response to the shock. The peak response of the exchange rate is around 3% compared to over 15% implied by the structural model. Another interesting difference is that, output actually rises in response to the massive monetary expansion that outweighs the effects from the higher exchange rate.

The terms of trade shock has a positive effect on inflation, interest rate and the exchange as implied by the sign restrictions. While the impact on output is left unrestricted, it increases in response to the higher terms of trades. Consistent with the structural model, the terms of trade shock displays a significant degree of persistence together with a relatively small impact on domestic inflation.

5.2 Main drivers of output over the business cycle

Variance decompositions are often used to offer some insights into which shocks on average contribute to the observed variance of output over different forecast horizons. As a benchmark, this subsection first presents the results from the Choleski decomposition. The variables are ordered according to the convention that the most "exogenous" variables appear first. The variance decomposition results reported in Table (3) are based on the following ordering: foreign output, foreign inflation, foreign interest rate, terms of trade, output, inflation, interest rate and the real exchange rate. Investigation using other ordering schemes where domestic output is ordered first among the domestic variables to last, reveal very little difference in the variance decomposition results for output.

The benchmark result shows at the one year forecast horizon, output shocks account for around two thirds of the total forecast variance of output, while other domestic factors play a minor role. Foreign shocks together account for just over a quarter of the variation, the biggest contributor comes from foreign output around 16%.[27] At the 50 quarter horizon, the role of output shocks decrease slightly to around 59% and other domestic factors play a slightly larger role. The contributions from foreign factors stay fairly constant across the different forecasting horizons. The picture painted by the Choleski ordering is that while foreign factors appear to be important, the majority of variation in output arises from innovations such as demand shocks.

Looking at the variance decomposition of the shocks identified via the SRVAR model, presented in Table (4), reveals some stark differences. Domestic output shocks only account for 4-5% of the variation across all horizons. At the shorter horizons, all three foreign factors combine to account for more than 60% of the variation in output with the largest contribution coming from foreign interest rate shocks. This cannot all be attributed to pure foreign monetary policy innovations, instead, the foreign interest rate maybe capturing other factors that are outside the model. For example, changes in global confidence can be transmitted to the domestic economy via international financial markets. This explanation is consistent with the findings in Dungey and Pagan (2000), where international financial linkages are very important at modeling the Australian economy. At the longer forecasting horizon, all three foreign factors maintain their influence on domestic output variations. Turning to domestic factors, the terms of trade account for a quarter of the variation in output across almost all horizons. This is consistent with the view that Australia is a very open commodity producer and its terms of trade have a large influence on domestic economic activities. Both the interest rate and exchange rate shocks are identified to have a relatively small influence on aggregate fluctuations. This is often taken as evidence that both monetary policy and the floating exchange rate act as stabilizers for the domestic economy, rather than a source of fluctuations. The next subsection investigates this in more detail. Lastly, cost push shocks contribute around 5-8% of output's forecast variance. This is similar to the Choleski ordering results.

[27] The contrast is even greater at the one quarter horizon with output shocks accounting for nearly 90% of the output variation.

Variance decompositions analysis reveals which shocks are important at explaining the forecast errors of output across different horizons. Another useful statistic is to decompose the historical observation of output into its MA representation (shocks) such that:

$$y_t = \sum_{j=1}^{k} C_j(L)\epsilon_{j,t} + \text{initial condition} \tag{21}$$

where $C_j(L)$ is the impulse response of shock j.[28] Historical decompositions are particularly useful in relating certain events that have happened over the business cycle to illuminate questions such as what caused the slowdown in output?

Figure (6) plots the historical decomposition of output into foreign versus domestic factors. During the two commonly agreed recession periods (early 1980s and 1990s), both domestic and foreign factors contributed negatively to output. This observation is consistent with the results reported in Dungey (2002). The only other period where both factors trended downwards was in 1986 that relate to Paul Keatings banana republic remark. The influence of the foreign economy is particularly important to Australia especially during periods of severe economic slowdowns or downturns. From 1994 onwards, the Australian economy experienced a relatively stable period of inflation together with robust growth. Interestingly, foreign factors help offset domestic shocks in a way that moderated domestic business cycle fluctuations over this period. 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 burst of the dot com bubble in the US. The increase in domestic house prices driving up consumption in 2001 was moderated by a temporary downturn in the US economy following the September terrorist attack. The pattern continued in late 2003 when slowing conditions from the housing market were boosted by the recovering US economy. The timing of international shocks has no doubt played an important role in offsetting domestic disturbances and contributed to its stable growth path.

5.3 Interest rate and exchange rate as stabilizers

Another interesting aspect is to uncover the role of macroeconomic stabilization tools, namely monetary policy and the floating exchange rate, over the business cycle. Figure (8a) plots the

[28]Since the entire history of shocks are not observed, the decomposed components of y_t may not add up exactly at the initial periods of the sample. In the case of output, this is around 6-8 quarters.

interest rate component decomposed from output against foreign factors. The interest rate component is calculated by adding together (i) the indirect effects of interest rates responding to domestic economic conditions and (ii) the direct effects of interest rate shocks.[29]

Focusing on the direct effects alone shows the interest rate has very little influence on output; a result that is consistent with the variance decomposition analysis. However, once the indirect effect is included, the impacts of monetary policy on domestic output is much stronger. In both of the recession periods (early 1980s and 1990s), monetary policy together with international factors contributed negatively to output. After the formal implementation of inflation targeting in 1994, monetary policy is observed to have a more stabilizing effect in offsetting foreign disturbances. The contemporaneous correlation between the interest rate component and foreign shocks is -0.29 over the entire sample period. This negative correlation increases to -0.69 from 1994 onwards.

To assess the effectiveness of monetary policy in response to overall output fluctuations, Figure (8b) displays the interest rate component (I_t) together with the sum of foreign and domestic components excluding the influence from interest rates ($Z_t = Y_t - I_t$). This can be thought of as a counterfactual experiment where the interest rate is assumed to play no role in the economy. If $I_t > 0$, monetary policy is said to have an expansionary effect on output and vice versa. The contemporaneous correlation between I_t and Z_t is -0.62 over the sample period. Monetary policy has been largely operated in a counter-cyclical manner that tightens during economic upswings and loosens during economic slowdowns. The moderating effects are more pronounced after the inflation targeting period.

Monetary policy has also helped reduce the variability of output over the whole sample from $\sigma_Z = 4.86$ to $\sigma_Y = 3.91$, Dungey and Pagan (2000) draw similar conclusions. Against the claims that monetary policy may have induced the early 1990's recession, according to the decomposition results, policy was effectively sitting at neutral at the beginning of the recession. However, excessively tight policy immediately afterwards exacerbated the economic slowdown and slowed the recovery. Rather than treating the episode as a policy error, many saw this as necessary to bring inflation down before the formal implementation of inflation targeting. It is difficult to assess whether monetary policy could have done more in moderating the business cycle. Exces-

[29] The indirect contribution is calculated by taking the difference between the original VAR impulse in equation (21) and a VAR where the lagged effects from other variables in the system are set to zero (apart from lagged interest rates).

sively aggressive stabilization objectives may risk inducing more instability elsewhere, such as a more volatile inflation rate and interest rate.

Turning to another stabilizer in a SOE, the floating exchange rate. Figure (7) plots the exchange rate component (E_t) of output against foreign factors (F_t). Similar to the calculation for the interest rate contribution, the indirect effects are added to the direct effects of the exchange rate shocks. Floating of the Australian currency took place in December 1983 and the shock that triggered the float was evident from the decomposition.[30] After the float, the Australia dollar generally moved in a manner that offset foreign disturbances by appreciating in response to strengthening world conditions and depreciating during slowdowns. Evidence of this was particularly apparent during the Asian financial crisis in 1997 and during the recent recovery of the world economy in 2003.

Over the whole sample, the correlation between E_t and F_t is -0.05. If only the floating period is taken into account, the negative correlation increases to -0.13. According to the decomposition, the exchange rate may have helped triggered the decline in output in the early 1990s that resulted in a recession later on. Overall, there is evidence to suggest that monetary policy, through both interest rates and the exchange rate, responded in such a way to help stabilize the domestic economy. The focus of monetary policy is in moderating aggregate economic fluctuations, whereas the exchange rate helps cushion the domestic economy against international disturbances. Both stabilizers worked much more effectively after the implementation of inflation targeting in 1994.

5.4 Robustness analysis

The discussions in section (5.2) is based on the optimal median response rotation matrix subject to the orthogonality condition. 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 optimized median impulse, the chosen median rotation is dropped and the next median impulse is found by re-optimizing the remaining admitted rotations by minimizing equation (20). Repeating this for 50 draws around the "median region" reveals foreign factors still explain between 45% to 60% of the unconditional variance of output, and the foreign interest rate remains the dominant contributor. The results

[30] The exchange rate and foreign factors contributed negatively to output in 1983.

reported in Table (4) lie exactly on the mode of the distribution. On the other hand, the base line Choleski decomposition lies somewhere in the thin tail of this distribution.[31] This indicates the true importance of foreign factors may not be easily captured by the traditional Choleski decomposition.

Another robustness check is to re-estimate the model using the G7 data as the foreign economy.[32] The overall conclusion is supported, although minor differences do arise.[33] The combined contribution of foreign shocks account for around 63% of the forecast error in output at the one year horizon, similar to the 60% reported earlier. At the 50 quarters horizon, this increases to 76% in contrast to 59% earlier. Innovations from domestic output continue to play a minor role in explaining domestic output 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 trade linkages are much more important to the Australian economy after allowing for broader world economic conditions.

Consistent with earlier observations, the moderating effects of international factors continue to be observed using the G7 data.[34] The slowdown of the Asian economies after the Asian crisis in 1997 is present in the decomposition, whereas it is not clearly identified using the US data alone. The effects from the 2001 world slowdown is estimated to have a much larger effect on the Australian economy. Subsequently, domestic factors play an even larger role in upholding domestic output from this negative external shock. Repeating the counterfactual experiments as earlier with the interest rate reveal some interesting differences. The decomposition suggests the economy was already in a tightening phrase prior to 1990 which helped triggered the 1991 recession, and policy easing was not put in place until after 1994. On the other hand, significant loosening of policy towards the end of 2001 was seen as one of the major contributing factors in avoiding the economic slowdown inflicted from weaker world conditions.

[31] Detailed statistics are available upon request.

[32] The G7 countries consists of the US (0.49), Japan (0.16), Germany (0.10), UK (0.07), France (0.07), Italy (0.07) and Canada (0.04).

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

[34] G7 historical decomposition graphs are available upon request.

6 Conclusion

This paper employs a VAR model identified using robust sign restrictions derived from an estimated small structural model to investigate the sources of business cycle fluctuations in the Australian economy. In contrast to the Choleski ordering results often reported in the literature, the analysis reveals over half of the output forecast errors can be explained by foreign factors. Initially, this may raise alarms for policy makers trying to stabilize the domestic business cycle. However, rather than concluding foreign shocks were the main source of business cycle fluctuations, historical decomposition of output indicates foreign factors play a significant role in offsetting domestic shocks in moderating the domestic business cycle. This moderating behavior can be attributed to good luck.

In terms of stabilization objectives, monetary policy is largely successful in mitigating business cycle fluctuations in a counter-cyclical fashion. The floating exchange rate, another important stabilization tool for a small open economy, is observed to respond to foreign factors by appreciating during booms and depreciating during slowdowns to offset foreign disturbances. Both stabilization tools worked much more effectively after the formal implementation of inflation targeting since 1994. This also lends support to good policy as one of the contributors to Australia's recent stable economic success.

The analysis presented here is based on a very stylized view of the structure of a small open economy. The results suggest that it would be worthwhile expanding the set of international variables to include financial variables to allow for additional transmission channels from the rest of the world to the domestic economy. The set of sign restrictions derived from the structural model only provided qualitative information in identifying the VAR. Further investigation using quantitative information from the structural model may be useful in solving the non-uniqueness problem.

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A Sign restriction algorithm

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

$$Q = \prod_{i=1}^{n-1} \prod_{j=i+1}^{n} Q_{i,j}(\theta_{i,j}) \tag{22}$$

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

where $\theta_{i,j} \in [\ 0, \pi\ ]$. This provides a way of systematically exploring the space of all VMA representations through Q by searching over the range of values of $\theta_{i,j}$. Canova and De Nicolo (2002) proposed setting a up grid over the ranges of values for $\theta_{i,j}$, the algorithm describe here generates the q s randomly from a uniform distribution. The following algorithm is use to explore the space of identification.

Algorithm 1 *Sign restriction VAR algorithm:*

1. *Estimate the VAR in equations (15) to (16) 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* $\epsilon_t = HQe_t$ *and its corresponding structural IRF* $C(L)$ *for domestic and foreign shocks;*

6. *Check whether the IRF satisfy all the sign restrictions describe in Table (2). If so keep the draw, if not, drop the draw;*

7. *Repeat (3)–(6) until 2000 draws satisfying the restrictions are found.*

Table 1: Maximum likelihood estimates of the Structural model

Parameters	**MLE statistics**				**Diagnostics**		
	Mean	Std	2.5%	97.5%	NSE	p-value	B-G
$n1$	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
$g1$	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
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
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
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
OLS estimates for exogenous shocks							
	ρ_s	0.90		σ_s	1.75		
	ρ_{r^*}	0.94		σ_{r^*}	1.07		
	ρ_{π^*}	0.62		σ_{π^*}	1.67		
	ρ_{y^*}	0.29		σ_{y^*}	4.14		

Notes: (a) The posterior statistics are computed based on 1 million MCMC draws after a 50% burn in period.
(b) NSE refers to the numerical standard error of the Markov chain.
(c) p-value relates to the test of two means between the first and second half of the stationary Markov chain.
(d) B-G refers to the Brooks and Gelman (1998) univariate shrink factor. A shrink factor close to 1 is an indication of attaining a stationary distribution.

Table 2: SRVAR sign restrictions

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

Table 3: Baseline Choleski variance decomposition of output, interest, inflation and real exchange rate

Horizon	Foreign interest	Foreign output	Foreign inflation	Output	Interest	Cost push	exchange rate	TOT
				Output				
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
				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

Table 4: SRVAR variance decomposition of output, interest, inflation and real exchange rate

Horizon	Foreign interest	Foreign output	Foreign inflation	Output	Interest	Cost push	exchange rate	TOT
				Output				
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

Figure 1: Australian HP filter and BN decomposition cycles

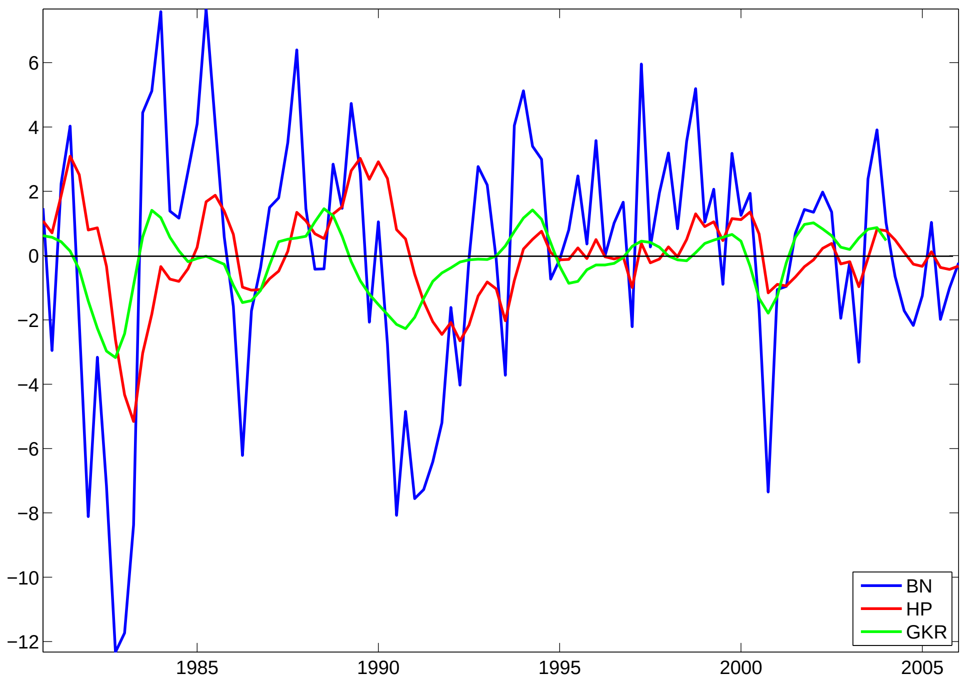


Figure 2: Structural model IRF of technology, monetary policy, cost push, risk premium shock.

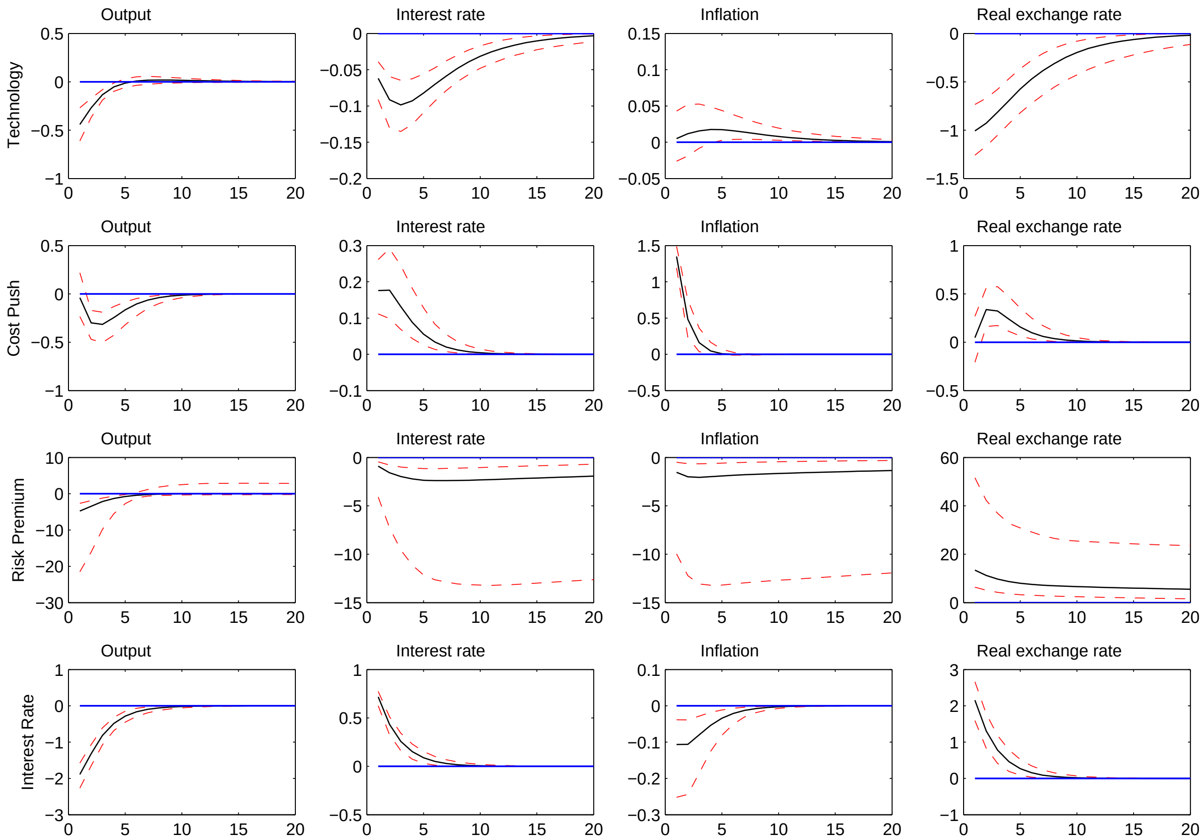


Figure 3: Structural model IRF of TOT, foreign interest, inflation and output shock.

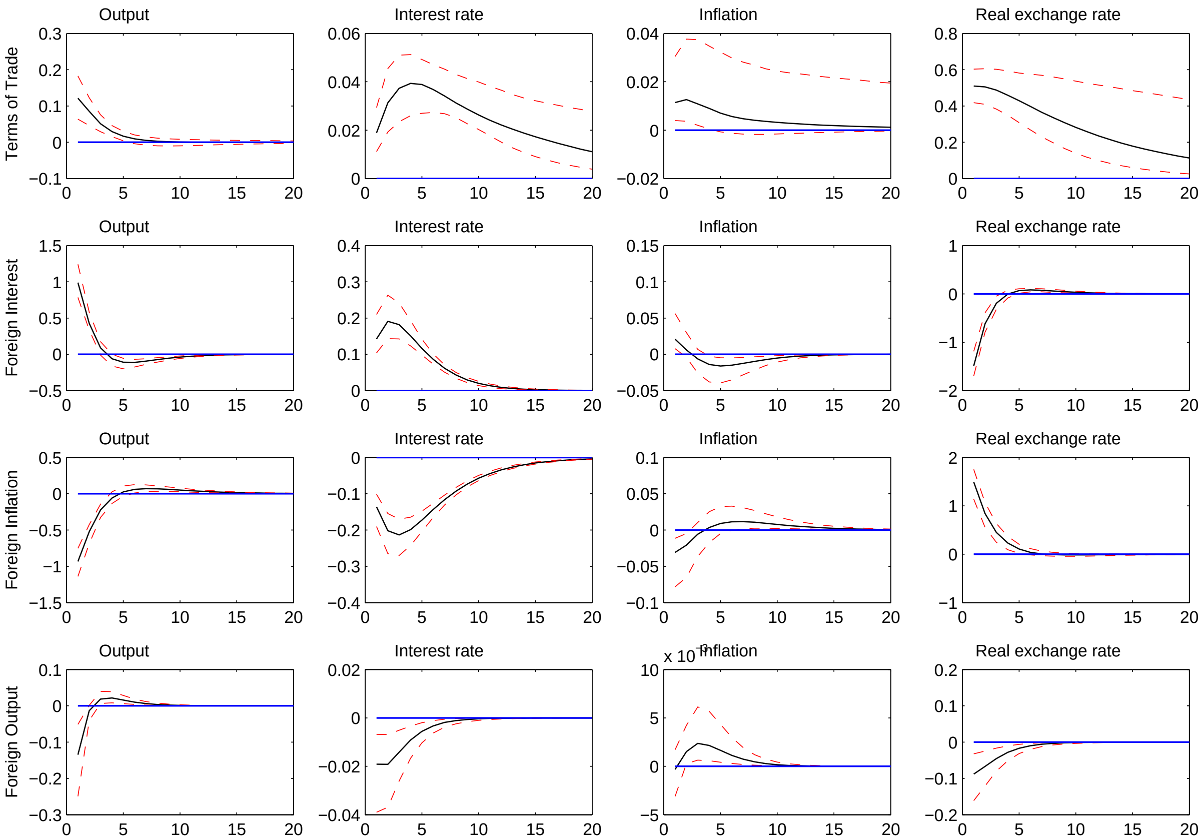
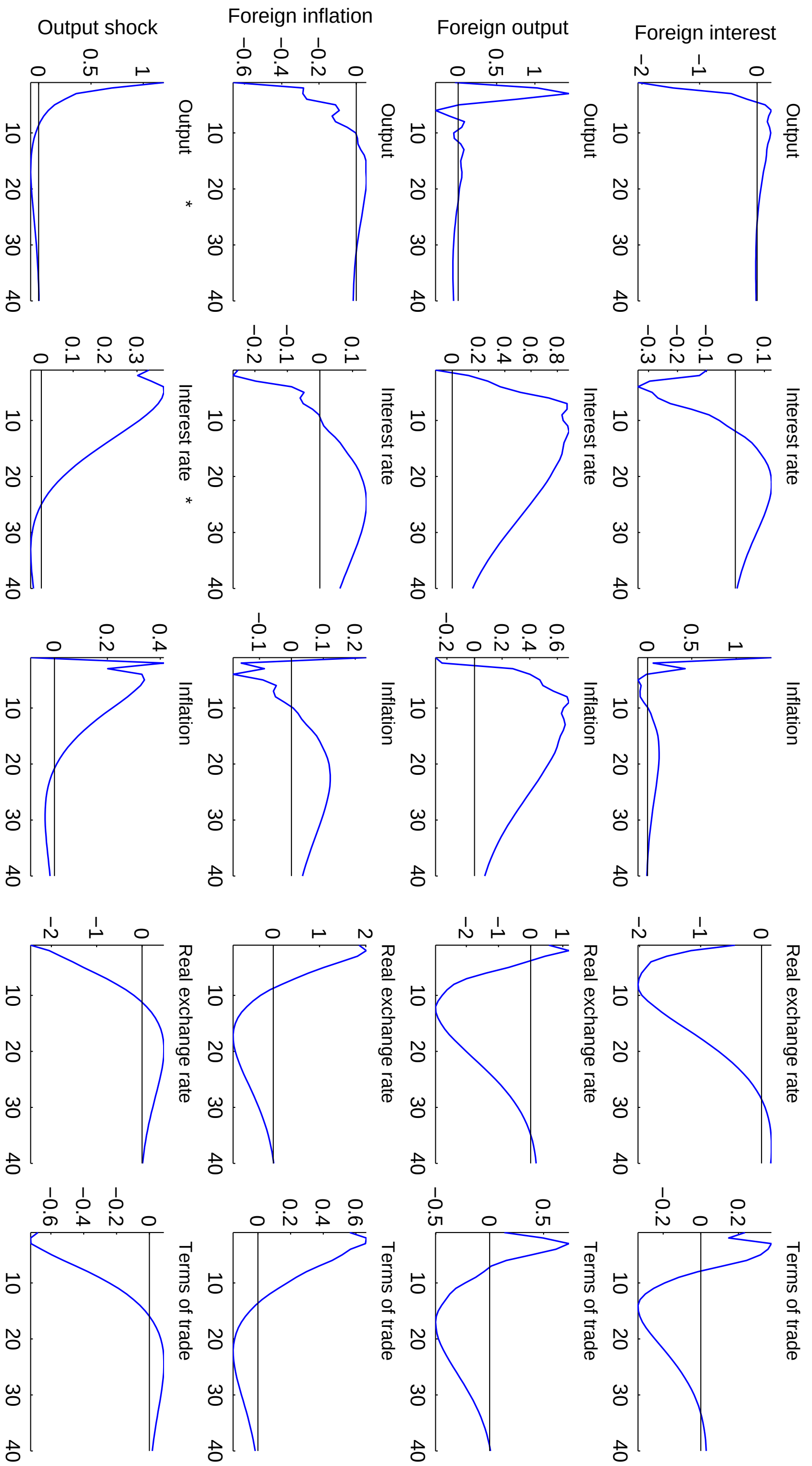
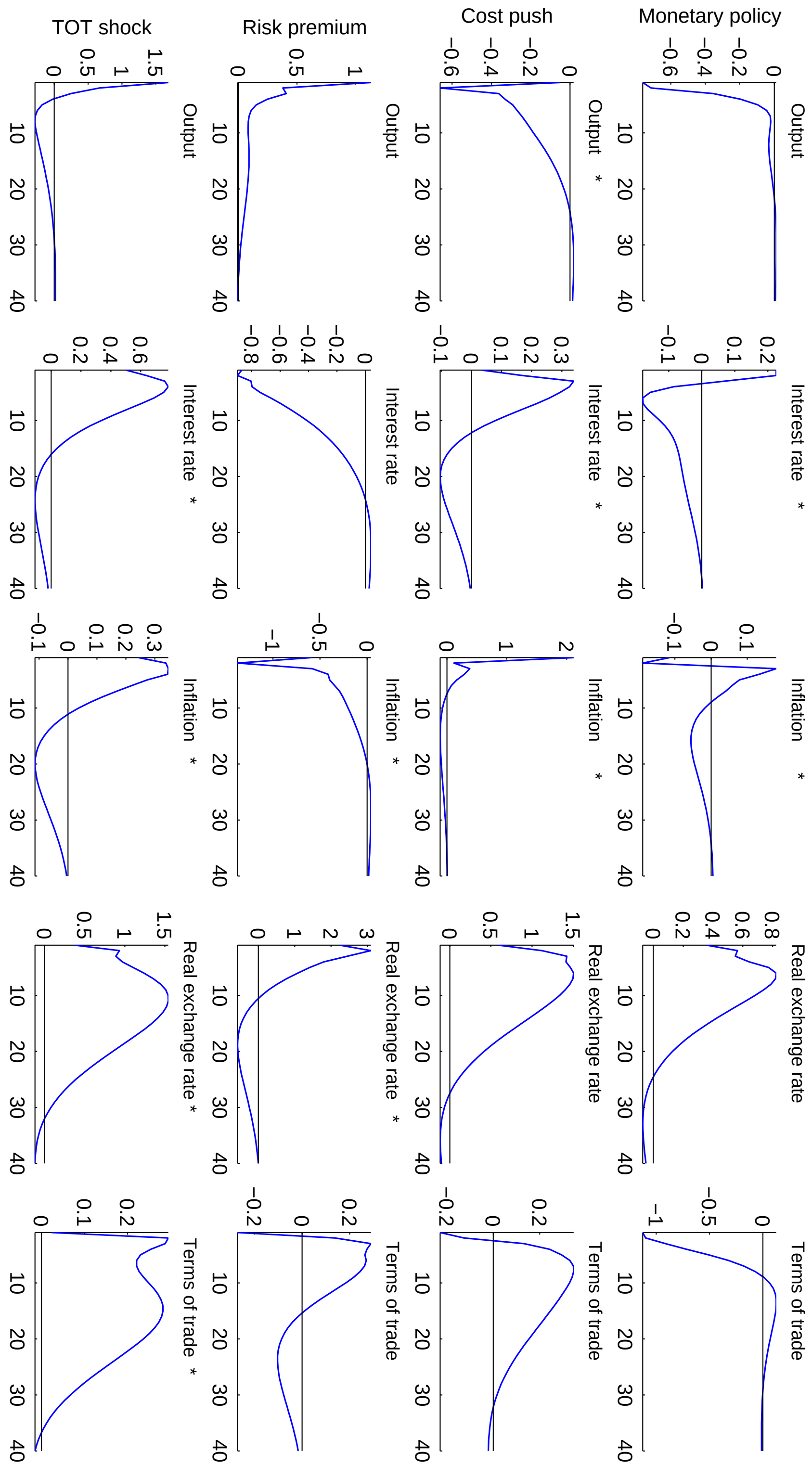


Figure 4: SRVAR IRF of foreign output, interest, inflation and domestic output shock.



Note: * indicate impulse responses where sign restrictions are imposed.

Figure 5: SRVAR IRF of monetary policy, cost push, risk premium and TOT shock.



Note: * indicate impulse responses where sign restrictions are imposed.

Figure 6: Historical decomposition of output using US data.

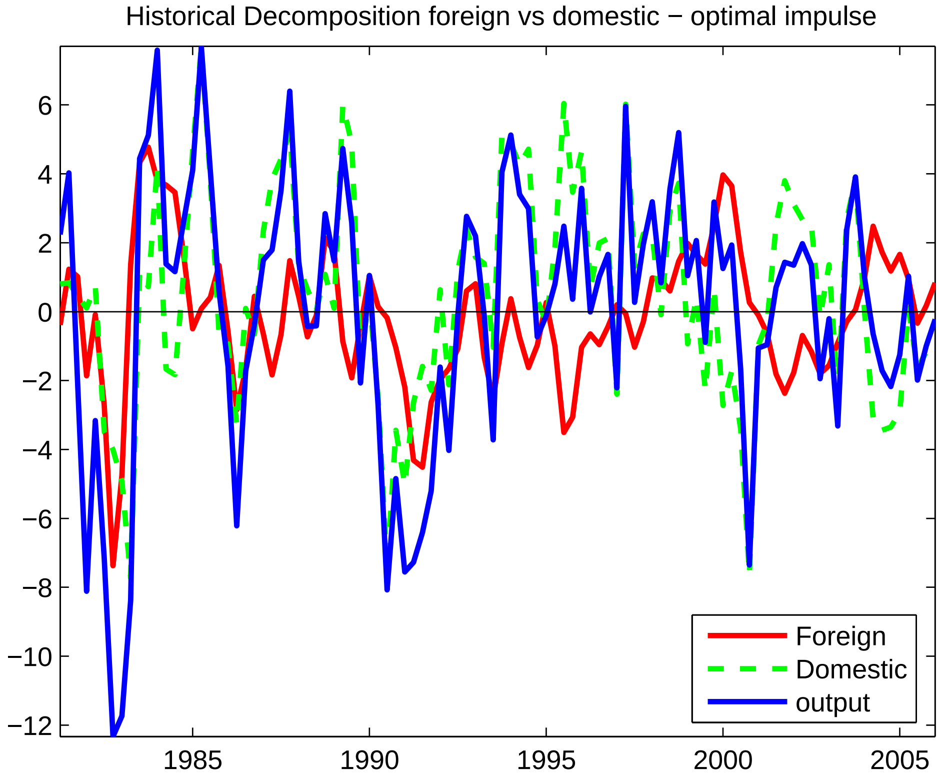


Figure 7: Historical decomposition of output using US data - effects from exchange rates shocks.

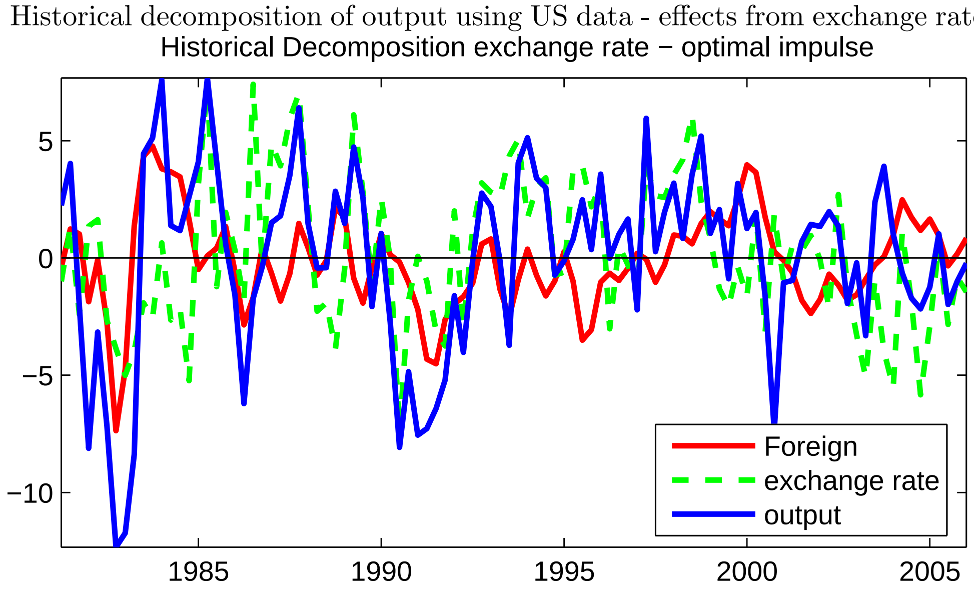
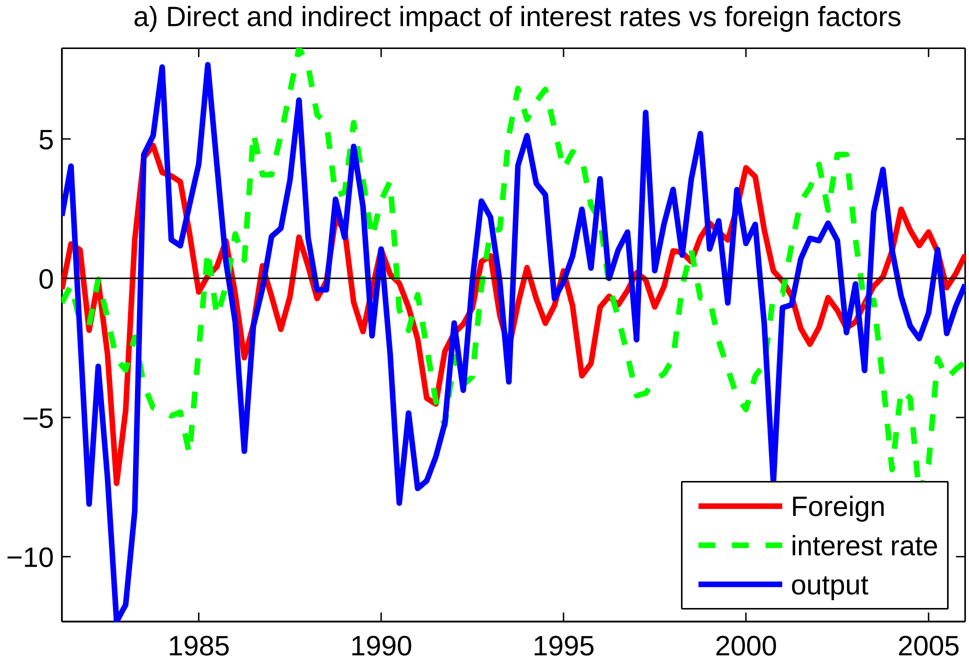
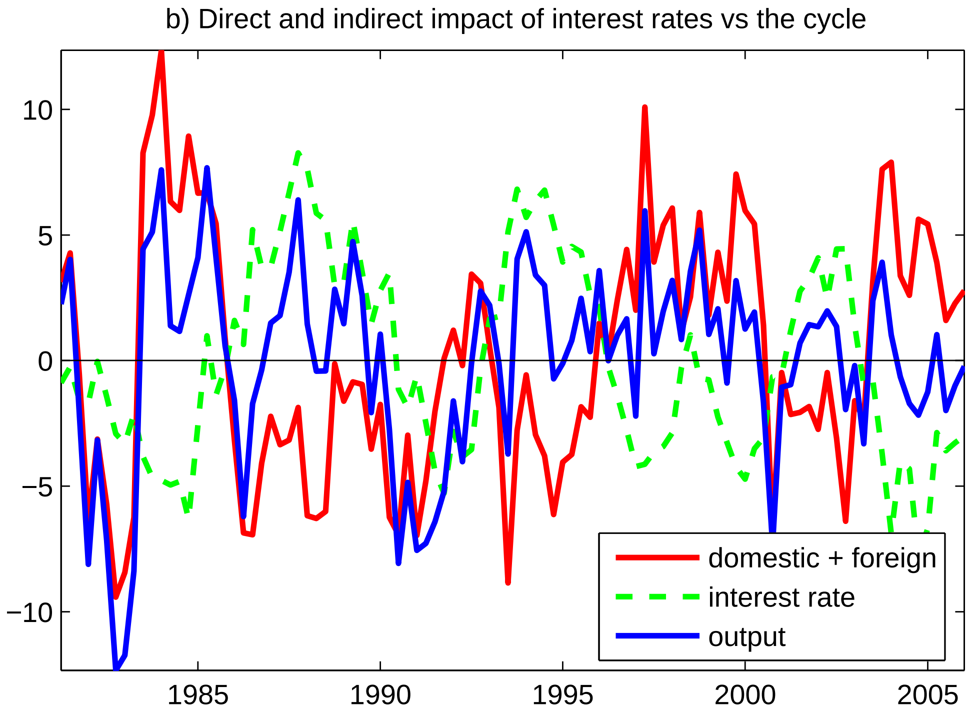


Figure 8: Historical decomposition of output using US data - effects from interest rates.





Additional statistical tables and figures for referees, not for publication:

- Table (5) and Figure (9) refers to the discussion in footnote (33) of the main text.
- Figures (10) and (11) refers to the discussion in footnote (34) of the main text.

Table 5: SRVAR variance decomposition of output, interest, inflation and real exchange rate using G7 data

Horizon	Foreign interest	Foreign output	Foreign inflation	Output	Interest	Cost push	exchange rate	TOT
				Output				
1	12.7	49.0	0.1	2.1	2.0	6.9	0.4	26.6
4	18.6	43.6	1.3	1.8	2.1	7.8	1.2	23.6
8	22.5	51.1	1.3	1.2	1.6	6.2	0.8	15.3
12	22.5	52.6	1.4	1.1	1.5	6.0	0.8	14.2
50	2.6	52.4	1.6	1.1	1.5	5.9	0.8	14.0
				Interest rate				
1	7.5	85.3	0.2	1.0	0.5	1.1	4.3	0.1
4	4.4	83.2	5.5	0.7	0.4	2.7	2.3	0.8
8	3.6	81.4	7.6	0.7	0.3	3.1	2.0	1.3
12	4.7	79.2	8.7	0.8	0.3	3.0	2.0	1.3
50	7.4	74.9	10.9	0.8	0.3	2.8	1.8	1.2
				Inflation				
1	6.0	85.9	0.1	0.3	1.8	3.9	0.0	2.0
4	5.4	86.3	0.5	0.5	1.3	3.2	1.2	1.5
8	4.9	86.9	0.7	0.7	1.2	3.0	1.1	1.5
12	5.1	86.6	0.8	0.7	1.2	3.0	1.1	1.5
50	6.0	85.2	1.5	0.7	1.1	2.9	1.1	1.4
				Exchange rate				
1	0.1	90.5	0.7	3.7	1.7	0.3	3.1	0.1
4	1.2	81.8	2.2	4.0	3.6	0.8	5.4	0.8
8	5.1	72.9	3.8	4.1	4.5	1.8	6.4	1.3
12	8.4	69.0	4.7	3.7	4.6	2.1	6.1	1.5
50	11.3	65.6	7.7	3.0	4.0	1.9	5.2	1.3

Figure 9: SRVAR variance decomposition of foreign vs domestic factors across 2000 rotations.

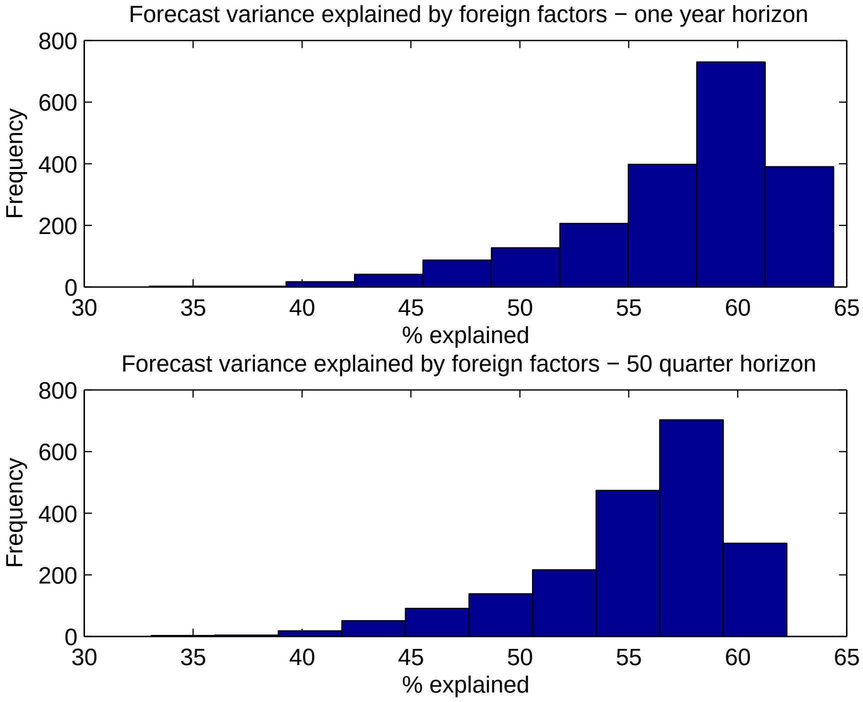


Figure 10: Historical decomposition of output G7 data.

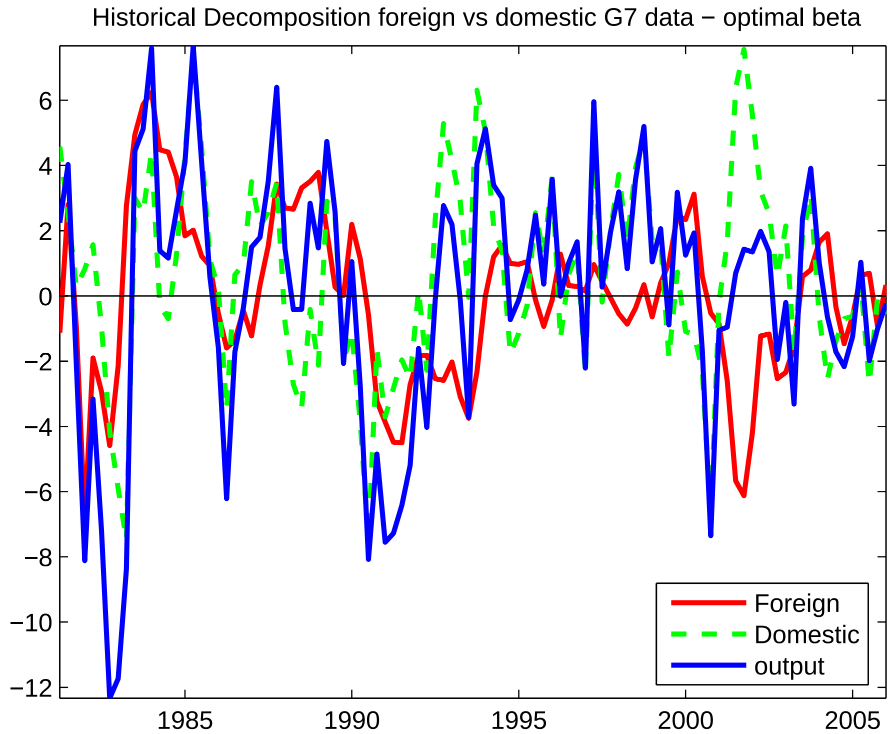


Figure 11: Historical decomposition of output G7 data - effect from interest rates.