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Abstract:

This paper establishes vector autoregressive moving average (VARMA) models for Malaysian monetary policy analysis by efficiently identifying and simultaneously estimating the model parameters using full information maximum likelihood. The monetary literature is largely dominated by vector autoregressive (VAR) and structural vector autoregressive (SVAR) models, and to the best of our knowledge, this is the first paper to use VARMA modelling to investigate monetary policy. Malaysia is an interesting small open economy to study because of the capital control measures imposed by the government following the 1997 Asian financial crisis. A comparison of the impulse responses generated by these three models for the pre- and post-crisis periods indicates that the VARMA model impulse responses are consistent with prior expectations based on economic theories and policies pursued by the Malaysian government, particularly in the post-crisis period. Furthermore, uncovering the way in which various intermediate channels work would help Bank Negara Malaysia to steer the economy in the right direction so that monetary policy can still remain an effective policy measure in achieving sustainable economic growth and price stability.

Keywords: VARMA models, Identification, Impulse responses, Open Economy, Transmission mechanism.

1 Introduction

Over the past three decades, extensive investigations into modelling and analyzing monetary policies have led to the conclusion that differences in model specifications and parameter estimates across models can lead to widely different policy recommendations. Further, the potential loss from basing monetary policy on an invalid model can be substantial. Since the seminal paper by Sims (1980), vector autoregressive (VAR) and structural vector autoregressive (SVAR) modelling have dominated monetary policy analysis. For an extensive review, see Leeper et al. (1996) and Christiano et al. (1999). Despite the sound theoretical and empirical justifications for the superiority of VARMA models over VAR-type models for policy modelling, the use of the former is still in its infancy. More on this later. The main reason for this is the lack of methodological advances in establishing uniquely identified VARMA models. Recently, however, Athanasopoulos and Vahid (2008a) proposed a complete methodology for identifying and estimating canonical VARMA models by extending the work of Tiao and Tsay (1989). They established necessary and sufficient conditions for exactly identifying a canonical VARMA model, so that all parameters can be efficiently identified and estimated simultaneously using full information maximum likelihood (FIML) (Durbin, 1963).

In this paper, we apply the methodology of Athanasopoulos and Vahid (2008a) to empirically examine the advantages of using VARMA models for the monetary policy framework of a small emerging open economy: Malaysia. We seek to answer questions such as: (i) how does the Malaysian economy dynamically respond to money, interest rates, exchange rates and foreign monetary shocks, while imposing minimal assumptions based on economic theory? (ii) How do the results of (i) compare to those of VAR and SVAR models? (iii) Can VARMA modelling aid in resolving the economic puzzles commonly found in the monetary literature?[1] and (iv) Has the Asian financial crisis, which lashed the Southeast Asian region in mid-1997, affected the monetary policy transmission mechanism in Malaysia?

Monetary policy is widely implemented as a stabilization policy instrument for steering economies in the direction of achieving sustainable economic growth and price stability. The efficacy of monetary policy depends on the ability of policy makers to make an accurate assessment of the timing and effect of the policy on economic activities and prices. Although VARs provide useful tools for evaluating the effect of monetary policy shocks, there are ample warnings in the literature of their limitations on both theoretical and practical grounds. In what follows, we shall discuss some of the justifications for the use of VARMA models over VARs provided in the recent literature.

In studies of monetary policy, the dominant part of the analysis is based on the dynamics of impulse response functions of domestic variables to various monetary shocks; these impulse responses are derived using Wold's decomposition theorem (Wold, 1938). In a multivariate Wold representation, however, any covariance stationary time series can be transformed to an infinite order vector moving average (VMA(∞)) process of its innovations. Finite order VARMA models provide better approximations to the Wold representation than finite order VARs. Therefore, the VARMA models are expected to produce more reliable impulse responses than their VAR counterparts.

Several authors put forward convincing arguments in support of VARMA processes over VARs for modelling macroeconomic variables (see for example Zellner and Palm, 1974; Granger and Morris, 1976; Wallis, 1977; Maravall, 1993; Lütkepohl, 2005; Fry and Pagan, 2005). Economic and financial time series are invariably constructed data, involving for example seasonal adjustment, de-trending, temporal and contemporaneous aggregation. Such constructed time series would include moving average dynamics, even if their constituents were generated by pure autoregressive processes. Further, a subset of a system of variables that were generated by a vector autoregression would also follow a VARMA process. Moreover, Cooley and Dwyer (1998) claim that the basic real business cycle models follow VARMA processes. More recently, Fernández-Villaverde et al. (2005) demonstrated that linearized dynamic stochastic general equilibrium models in general imply a finite order VARMA structure.

To simplify the modelling and estimation of a system of variables, applied researchers tend to approximate a VARMA process using a VAR. The use of VAR approximations requires models with extremely long lag lengths, much longer than those selected by typical information criteria such as the AIC or BIC, in order to describe a system adequately and obtain reliable impulse responses. In a simulation study, Kapetanios et al. (2007) show that a sample size of 30,000 observations and a VAR of order 50 are required to sufficiently capture the dynamic effects of some of the economic shocks. However, in practice, the available sample sizes are inadequate to accommodate a sufficiently long lag structure, thus leading to poor approximations of the real business cycle models (see for example Chari et al., 2007). On the other hand, Athanasopoulos and Vahid (2008b) show that VARMA models forecast macroeconomic variables more accurately than VARs. Then, via a simulation study, they demonstrate that the superiority of the forecast comes from the presence of moving average components.

Despite the numerous theoretical and practical justifications and recommendations to employ VARMA models rather than VARs, the use of the former is not prevalent in applied macroeconomics, due mainly to difficulties in identifying and estimating unique VARMA representations. A search for an identified VARMA model is far more challenging than a simple VAR-type model specification, and the lack of enthusiasm for the use of VARMA models is due to these difficulties (see for example Hannan and Deistler, 1988; Tiao and Tsay, 1989; Reinsel, 1997; Lütkepohl, 2005; Athanasopoulos et al., 2007; Athanasopoulos, 2007). In this paper, we implement the methodology of Athanasopoulos and Vahid (2008a) for identifying and estimating VARMA models for the Malaysian economy. In light of the foregoing discussions, we expect that VARMA models will produce more reliable dynamic impulse responses than the widely used VAR and SVAR models, as predicted by both theory and stylized facts.

Using monthly data from seven variables from January 1980 to December 2007, the dynamic responses of the Malaysian economy to domestic and foreign shocks are investigated. Of the seven variables used, the world oil price index and the Federal funds rates represent the foreign variables, while the Malaysian industrial production index, consumer price index, monetary aggregate M1, overnight inter-bank rates and nominal effective exchange rates represent the domestic variables. Along with its Southeast Asian neighbours, Malaysia experienced a devastating financial crisis, which caused huge financial and economic turmoil in these economies. In September 1998, the Malaysian government made a controversial decision to implement exchange rate and selective capital control measures to stabilize the depreciating exchange rate and the outflow of short term capital. In view of the changes in the financial environment and the choice of policy regimes, the period of study is divided into the pre-crisis period (1980:1 to 1997:6) and the post-crisis period (1999:1 to 2007:12). The two sub periods are considered primarily in order to assess the impact of the changes in the exchange rate regime on the Malaysian monetary transmission mechanism, where Malaysia adopted a managed float exchange rate regime prior to the crisis and a pegged exchange rate regime (to the US dollar) after the crisis.

The orthogonal monetary, exchange rate and foreign monetary shocks identified through the VARMA models are used to evaluate the impulse responses of the domestic variables to these shocks. The empirical results are expected to provide Bank Negara Malaysia (BNM) with valuable insights into identifying the important monetary channels that carry more information about the monetary policy shocks during the pre- and post-crisis periods. This would further help BNM to influence the appropriate channels to ensure that the monetary policy is effective in achieving economic growth and maintaining price stability under different economic conditions. The paper is organized as follows: Section 2 briefly describes the Malaysian economy and the choice of variables. Section 3 illustrates the VARMA methodology, while Section 4 discusses impulse response functions and block exogeneity. Section 5 reports and discusses the empirical findings. Finally, Section 6 concludes the paper.

2 Background of the Malaysian economy and choice of variables

The Malaysian economy has evolved in line with the liberalization and globalization processes, and has witnessed widespread changes in the conduct of monetary policy and the choice of monetary policy regimes (see for example Tseng and Corker, 1991; Dekle and Pradhan, 1997; Athukorala, 2001; McCauley, 2006; Umezaki, 2006). As stated by Awang et al. (1992), the major phase of the liberalization process commenced in October 1978, when BNM introduced a package of measures as a concrete step toward a more market-oriented financial system. The measures included freeing the interest rate controls and reforming the liquidity requirements of the financial institutions. Since then, while maintaining a managed float exchange rate system, the conduct of monetary policy by BNM has depended not only on inflation and real output, but also on foreign monetary policy (see Cheong, 2004; Umezaki, 2006, for details).

In the 1980s, BNM's monetary strategy was to focus on monetary targeting, and especially the broad money M3, as it was found to be closely linked to inflation. To maintain its monetary policy objectives of price stability and output growth sustainability, BNM influenced the day-to-day volume of liquidity in the money market to ensure that the supply of liquidity was sufficient to meet the economy's demand for money. Subsequent developments in the economy and the globalization of financial markets in the early 1990s, however, weakened the relationship between monetary aggregates and the target variables of income and prices (see for example Dekle and Pradhan, 1997; Tseng and Corker, 1991). Around this time, the globalization process also caused notable shifts in the financing pattern of the economy, that is, moving from an interest-inelastic market (government securities market) to a more interest rate sensitive market (bank credit and capital market). As investors became more interest rate sensitive, the monetary policy framework based on interest rate targeting was seen as an appropriate measure for promoting stability in the financial system and achieving the monetary policy objectives. As a result, in the mid-1990s, BNM shifted toward an interest rate targeting framework.

The globalization process came to Malaysia with a cost, as the economy was not only vulnerable to domestic shocks but was also largely exposed to external shocks. The mid-1997 East Asian financial crisis had a substantial impact on the Malaysian economy, mainly causing a significant downward pressure on the Ringgit and equity prices. The volatile short-term capital flows and excessive volatility of the Ringgit made it impossible for BNM to influence interest rates based on domestic considerations. In September 1998, Malaysia imposed exchange rate and selective capital control measures to stabilize the depreciating exchange rate. The Ringgit was fixed at RM3.80 per US dollar, while the short-term capital flows were restricted. These measures were needed to give BNM the breathing space required before embarking on an expansionary monetary policy to overcome the contraction in the economy. More details on the evolution of the Malaysian monetary policy since the financial crisis can be found in Athukorala (2001); Azali (2003); Cheong (2004); Ooi (2008) and Singh et al. (2008).

In this study, we use seven variables similar to those used by Kim and Roubini (2000) and Brischetto and Voss (1999) to model the monetary policy of small open economies. The variables are summarized in Table 1. Kim and Roubini (2000) and Brischetto and Voss (1999) demonstrated that these seven variables are sufficient to describe the monetary policy framework of small open economies. In fact, they provided evidence that these variables can capture the features of large dimensional and more complex open economy models, such as that considered by Cushman and Zha (1997).

Table 1: *Variables included in the Malaysian Monetary Policy Model*

Variable	Definition	Abbreviation
Foreign		
Oil Price	World Oil Price Index, Logs	OPI
US Interest Rate	Federal Funds Rate, Percent	R_U
Domestic		
Output	Industrial Production (SA), Logs	IP
Price	Consumer Price Index (SA), Logs	CPI
Money	Monetary Aggregate M1 (SA), Logs	$M1$
Interest Rate	Overnight Inter-Bank Rate, Percent	R_M
Exchange Rate	Nominal Effective Exchange Rate, Logs	ER

Sources: International Financial Statistics

The variables OPI and R_U represent the foreign block. The OPI is included to account for inflation expectations, mainly to capture the non-policy induced changes in inflationary pressure to which the central bank may react when setting monetary policy. It is also common in the monetary literature of small open economies to use the US Federal fund rates as a proxy for foreign monetary policy (see for example Cushman and Zha, 1997; Kim and Roubini, 2000; Dungey and Pagan, 2000).

The five domestic variables describe the Malaysian economy. The Malaysian industrial production index (IP) and the consumer price index (CPI) are taken as the target variables of monetary policy, known as non-policy variables. The M1 monetary aggregate ($M1$) and the overnight inter-bank rate (R_M) represent policy variables. According to Cheong (2004), BNM used a combination of several variables such as monetary aggregates and various interest rates as policy instruments. Among various potential monetary aggregates investigated, Tang (2006) found M1 to be the most reasonable candidate for monetary policy instruments. In many recent studies on Malaysian monetary policy (see for example Domac, 1999; Ibrahim, 2005; Umezaki, 2006), the overnight inter-bank rate was selected as the instrument of monetary policy. The exchange rate (ER) is the information market variable. Considering the US dollar peg of the Malaysian Ringgit during the period of study, we employ the nominal effective exchange rate instead of the bilateral US dollar exchange rate. As stated by Mehrotra (2005), this trade-weighted exchange rate is believed to capture the movements in the exchange rate that may have inflationary consequences in the Malaysian economy more comprehensively. These five domestic variables are also the standard set of variables used in the monetary literature to represent open economy monetary business cycle models (see for example Sims, 1992; Cushman and Zha, 1997; Kim and Roubini, 2000; Christiano et al., 1999).

The sample period of this study is from January 1980 to December 2007. The sample period covers only the post-liberalization period in Malaysia, which also includes the mid-1997 East Asian financial crisis. To assess the impact of the financial crisis and the subsequent implementation of capital and exchange control measures on the Malaysian monetary transmission mechanism, the period of the study is divided into the pre-crisis period (1980:1 to 1997:6) and the post-crisis period (1999:1 to 2007:12). All data are extracted from the IMF's International Financial Statistics (IFS) database. The variables are seasonally adjusted and in logarithms, except for the interest rates, which are expressed as percentages.

We consider unit root tests for all variables over the whole sample and for both the pre- and post-crisis periods. Both the Augmented Dickey Fuller and Philips-Perron unit root tests show that all of the variables are difference stationary over all sample periods. Johansen's co-integration test also provides evidence of long run relationships among the seven variables. Given that the variables in levels are non-stationary and cointegrated, the use of a VAR model in first differences leads to a loss of information contained in the long run relationships. Since the objective of this study is to assess the interrelationships between the variables, we concur with Ramaswamy and Sloke (1997) that the VAR and VARMA in levels remain appropriate measures to correctly identify the effects of monetary shocks.[2]

3 Identification and estimation of a VARMA model

For identifying and estimating a VARMA model, we use the Athanasopoulos and Vahid (2008a) extension of the Tiao and Tsay (1989) scalar component model (SCM) methodology. The aim of identifying scalar components is to examine whether there are any simplifying embedded structures underlying a VARMA(p, q) process.

For a given K dimensional VARMA(p, q) process

$$\boldsymbol{y}_t = \boldsymbol{A}_1 \boldsymbol{y}_{t-1} + \ldots + \boldsymbol{A}_p \boldsymbol{y}_{t-p} + \boldsymbol{v}_t - \boldsymbol{M}_1 \boldsymbol{v}_{t-1} - \ldots - \boldsymbol{M}_q \boldsymbol{v}_{t-q}, \tag{1}$$

a non-zero linear combination $z_t = \boldsymbol{\alpha}'\boldsymbol{y}_t$ follows a SCM(p_1, q_1) if $\boldsymbol{\alpha}$ satisfies the following properties:

$$\begin{aligned}
\boldsymbol{\alpha}'\boldsymbol{A}_{p_1} &\neq \mathbf{0}' \text{ where } 0 \leq p_1 \leq p, \\
\boldsymbol{\alpha}'\boldsymbol{A}_l &= \mathbf{0}' \text{ for } l = p_1 + 1, \ldots, p, \\
\boldsymbol{\alpha}'\boldsymbol{M}_{q_1} &\neq \mathbf{0}' \text{ where } 0 \leq q_1 \leq q, \\
\boldsymbol{\alpha}'\boldsymbol{M}_l &= \mathbf{0}' \text{ for } l = q_1 + 1, \ldots, q.
\end{aligned}$$

The scalar random variable z_t depends only on lags 1 to p_1 of all variables and lags 1 to q_1 of all innovations in the system. The determination of embedded scalar component models is achieved through a series of canonical correlation tests.

Denote the estimated squared canonical correlations between $\boldsymbol{Y}_{m,t} \equiv \left(\boldsymbol{y}'_t, \ldots, \boldsymbol{y}'_{t-m}\right)$ and $\boldsymbol{Y}_{h,t-1-j} \equiv \left(\boldsymbol{y}'_{t-1-j}, \ldots, \boldsymbol{y}'_{t-1-j-h}\right)'$ by $\widehat{\lambda}_1 < \widehat{\lambda}_2 < \ldots < \widehat{\lambda}_K$. As suggested by Tiao and Tsay (1989), the test statistic for at least s SCM$\left(p_i, q_i\right)$, i.e., s insignificant canonical correlations, against the alternative of less than s scalar components is

$$C(s) = -(n-h-j)\sum_{i=1}^{s}\ln\left\{1 - \frac{\widehat{\lambda}_i}{d_i}\right\} \overset{a}{\sim} \chi^2_{s\times\{(h-m)K+s\}} \tag{2}$$

where d_i is a correction factor that accounts for the fact that the canonical variates could be moving averages of order j, and is calculated as follows:

$$d_i = 1 + 2\sum_{v=1}^{j}\widehat{\rho}_v\left(\widehat{\boldsymbol{r}}'_i\boldsymbol{Y}_{m,t}\right)\widehat{\rho}_v\left(\widehat{\boldsymbol{g}}'_i\boldsymbol{Y}_{h,t-1-j}\right), \tag{3}$$

where $\widehat{\rho}_v(.)$ is the v^{th} order autocorrelation of its argument and $\widehat{\boldsymbol{r}}'_i\boldsymbol{Y}_{m,t}$ and $\widehat{\boldsymbol{g}}'_i\boldsymbol{Y}_{h,t-1-j}$ are the canonical variates corresponding to the i^{th} canonical correlation between $\boldsymbol{Y}_{m,t}$ and $\boldsymbol{Y}_{h,t-1-j}$. Let $\boldsymbol{\Gamma}(m,h,j) = E(\boldsymbol{Y}_{h,t-1-j}\boldsymbol{Y}'_{m,t})$. This is a sub-matrix of the Hankel matrix of the autocovariance matrices of $\boldsymbol{y}_t$. Note that zero canonical correlations imply and are implied by $\boldsymbol{\Gamma}(m,h,j)$ having a zero eigenvalue.

Below, we provide a brief description of the complete VARMA methodology based on scalar components. For further details, refer to Athanasopoulos and Vahid (2008a) and Tiao and Tsay (1989).

Stage I: Identifying the scalar components

First, by strategically choosing $\boldsymbol{Y}_{m,t}$ and $\boldsymbol{Y}_{h,t-1-j}$, we identify the overall tentative order of the VARMA(p,q) by searching for $s+K$ components of order SCM(p,q), given that we have found s SCM$(p-\kappa, q-\mu)$ for $\{\kappa,\mu\} = \{0,1\}$ or $\{1,0\}$ or $\{1,1\}$. The process of exploring the various possibilities of underlying simplifying structures in the form of SCMs is a hierarchical one. Hence, the identification process begins by searching for K SCMs of the most parsimonious possibility, i.e. SCM$(0,0)$ (which is a white noise process), by testing for the rank of $\boldsymbol{\Gamma}(0,0,0) = E(\boldsymbol{Y}_{0,t-1}\boldsymbol{Y}_{0,t}^{'})$, where $\boldsymbol{Y}_{m,t} = \boldsymbol{Y}_{0,t}$ and $\boldsymbol{Y}_{h,t-1-j} = \boldsymbol{Y}_{0,t-1}$. If we do not find K linearly independent white noise scalar processes, we set $m = h$, and by incrementing m and j we search for the next set of K linearly independent scalar components. First, we search for first order "moving average"components by testing for the rank of $\boldsymbol{\Gamma}(0,0,1) = E(\boldsymbol{Y}_{0,t-2}\boldsymbol{Y}_{0,t}^{'})$, and then we search for the first order "autoregressive"components by testing for the rank of $\boldsymbol{\Gamma}(1,1,0) = E(\boldsymbol{Y}_{1,t-1}\boldsymbol{Y}_{1,t}^{'})$, and then $\boldsymbol{\Gamma}(1,1,1) = E(\boldsymbol{Y}_{1,t-2}\boldsymbol{Y}_{1,t}^{'})$ for SCM$(1,1)$, and so on.

Conditional on the overall tentative order (p,q), we then repeat the search process, but this time searching for individual components. So, starting again from the most parsimonious SCM(0,0), we sequentially search for K linearly independent vectors $(\boldsymbol{\alpha}_1,\ldots,\boldsymbol{\alpha}_K)$ for $m = 0,\ldots,p$, $j = 0,\ldots,q$ and $h = m+(q-j)$. As for a tentative order of (p,q), each series is serially uncorrelated after lag q.

The test results from first identifying the overall tentative order and then the individual SCMs are tabulated in what are referred to as *Criterion* and *Root* tables. Reading from the Criterion table allows us to identify the overall tentative order of the model, while reading from the Root table allows us to identify the individual orders of the scalar components. Since an $SCM(m,j)$ nests all scalar components of order $(\leq m, \leq j)$, for every one $SCM(p_1 < p, q_1 < q)$ there will be $s = \min\{m-p_1+1, j-q_1+1\}$ zero canonical correlations at position $(m \geq p_1, j \geq q_1)$. Therefore, for every increment above s, a new $SCM(m,j)$ is found. We demonstrate the reading of these tables in Section (5). For a complete exposition of how to read from these tables and recognize the patterns of zeros, as well as for further details on the sequence of testing, see Athanasopoulos and Vahid (2008a).

Suppose that we have identified K linearly independent scalar components characterized by the transformation matrix $\boldsymbol{A}_0^* = (\boldsymbol{\alpha}_1,\ldots,\boldsymbol{\alpha}_K)'$. If we rotate the system in (1) by $\boldsymbol{A}_0^*$, we obtain

$$\boldsymbol{A}_0^*\boldsymbol{y}_t = \boldsymbol{A}_1^*\boldsymbol{y}_{t-1} + \ldots + \boldsymbol{A}_p^*\boldsymbol{y}_{t-p} + \boldsymbol{\eta}_t - \boldsymbol{M}_1^*\boldsymbol{\eta}_{t-1} - \ldots - \boldsymbol{M}_q^*\boldsymbol{\eta}_{t-q}, \tag{4}$$

where $\boldsymbol{A}_i^* = \boldsymbol{A}_0^*\boldsymbol{A}_i$, $\boldsymbol{\eta}_t = \boldsymbol{A}_0^*\boldsymbol{\upsilon}_t$ and $\boldsymbol{M}_i^* = \boldsymbol{A}_0^*\boldsymbol{M}_i\boldsymbol{A}_0^{*-1}$. This rotated model incorporates whole rows of zero restrictions in the AR and MA parameter matrices on the RHS, as each row represents one identified SCM(p_i,q_i). However, we should note that obtaining the orders of SCMs does not necessarily lead to a uniquely identified system. For example, if two scalar components were identified such that $z_{r,t} = SCM\left(p_r, q_r\right)$ and $z_{s,t} = SCM\left(p_s, q_s\right)$, where $p_r > p_s$ and $q_r > q_s$, the system will not be identified. To obtain an identified system, we need to set $\min\left\{p_r - p_s, q_r - q_s\right\}$, i.e. set either the autoregressive or moving average parameters to be zero. This process is known as the "general rule of elimination", and in order to identify a canonical VARMA model as defined by Athanasopoulos and Vahid (2008a), we set the moving average parameters to zero.

Stage II: Imposing identification restrictions on matrix A_0^*

Athanasopoulos and Vahid (2008a) recognized that some of the parameters in A_0^* are redundant and can be eliminated. This stage mainly outlines this process, and a brief description of the rules of placing restrictions on the redundant parameters is as follows:

1. Given that each row of the transformation matrix A_0^* can be multiplied by a constant without changing the structure of the model, one parameter in each row can be normalized to one. However, there is a danger of normalizing the wrong parameter, i.e. a zero parameter might be normalized to one. To overcome this problem, we add tests of predictability using subsets of variables. Starting from the SCM with the smallest order (the SCM with minimum $p+q$), exclude one variable, say the K^{th} variable, and test whether a SCM of the same order can be found using the $K-1$ variables alone. If the test is rejected, the coefficient of the K^{th} variable is then normalised to one, and the corresponding coefficients in all other SCMs that nest this one are set to zero. If the test concludes that the SCM can be formed using the first $K-1$ variables only, the coefficient of the K^{th} variable in this SCM is zero, and should not be normalised to one. It is worth noting that if the order of this SCM is uniquely minimal, then this extra zero restriction adds to the restrictions discovered before. Continue testing by leaving out variables $K-1$ and testing whether the SCM could be formed from the first $K-2$ variables only, and so on.

2. Any linear combination of a $\text{SCM}(p_1, q_1)$ and a $\text{SCM}(p_2, q_2)$ is a $\text{SCM}(\max\{p_1, p_2\}, \max\{q_1, q_2\})$. The row of matrix A_0^* corresponding to the $\text{SCM}(p_1, q_1)$ is not identified if there are two embedded scalar components with weakly nested orders, i.e., $p_1 \geq p_2$ and $q_1 \geq q_2$. In this case arbitrary multiples of $\text{SCM}(p_2, q_2)$ can be added to the $\text{SCM}(p_1, q_1)$ without changing the structure. To achieve identification, if the parameter in the i^{th} column of the row of A_0^* corresponding to the $\text{SCM}(p_2, q_2)$ is normalized to one, the parameter in the same position in the row of A_0^* corresponding to $\text{SCM}(p_1, q_1)$ should be restricted to zero. A detailed explanation on this issue, together with an example, can be found in Athanasopoulos and Vahid (2008a).

Stage III: Estimating the uniquely identified system

Finally, in the third stage, the identified model is estimated using FIML. As in Hannan and Rissanen (1982), a long VAR was used to obtain initial values of the parameters.

4 Impulse response functions and foreign block exogeneity restrictions

Impulse response functions are commonly derived and estimated to assess the persistence and dynamic effects of various macroeconomic shocks on policy and non-policy related variables. It is also apparent that shocks to small open economies have very little impact on major foreign countries such as the US, and therefore it is proper to treat the foreign variables as exogenous to Malaysian economic variables. Both of these issues are discussed below.

4.1 Impulse response functions

The effects of monetary policy shocks can be derived from impulse response functions by considering pure moving average representations of models. For a VARMA(p,q) process

$$\mathbf{A}(L)\mathbf{y}_t = \mathbf{M}(L)\boldsymbol{\upsilon}_t \tag{5}$$

the impulse responses can be obtained from

$$\mathbf{y}_t = \boldsymbol{\Theta}(L)\boldsymbol{\upsilon}_t = \boldsymbol{\upsilon}_t + \sum_{i=1}^{\infty}\boldsymbol{\Theta}_i\boldsymbol{\upsilon}_{t-i}, \tag{6}$$

where $\boldsymbol{\Theta}_i = \mathbf{M}_i + \sum_{j=1}^{i}\mathbf{A}_j\boldsymbol{\Theta}_{i-j}$, $\boldsymbol{\Theta}_0 = \mathbf{I}_k$ and $\boldsymbol{\upsilon}_t$ is a white noise process with $E(\boldsymbol{\upsilon}_t) = 0$ and $E(\boldsymbol{\upsilon}_t\boldsymbol{\upsilon}_t') = \boldsymbol{\Sigma}_{\boldsymbol{\upsilon}}$.

In order to directly attribute the responses of variables to economically interpretable shocks, we need to transform the exogenous shocks in equation (6) to a new set of orthogonal shocks. A traditional and convenient method is to use the Choleski decomposition, as first applied by Sims (1980). The impulse responses for the standardised orthogonal shocks $\mathbf{u}_t$ are obtained by

$$\mathbf{y}_t = \mathbf{P}\mathbf{u}_t + \sum_{i=1}^{\infty}\boldsymbol{\Theta}_i\mathbf{P}\mathbf{u}_{t-i}, \tag{7}$$

where $\mathbf{u}_t = \mathbf{P}^{-1}\upsilon_t$, $\boldsymbol{\Sigma}_\upsilon = \mathbf{PDP}'$ and $\mathbf{D} = E(\mathbf{u}_t\mathbf{u}_t') = \mathbf{I}_K$. Similarly, we obtain the impulse responses from orthogonal shocks for a reduced form VAR(p) model

$$\boldsymbol{\Phi}(L)\mathbf{y}_t = \mathbf{e}_t \tag{8}$$

with a pure VMA representation $\mathbf{y}_t = \boldsymbol{\Phi}(L)^*\mathbf{e}_t$ by

$$\mathbf{y}_t = \mathbf{P}_\mathbf{e}\varepsilon_t + \sum_{i=1}^{\infty} \boldsymbol{\Phi}_i^* \mathbf{P}_\mathbf{e}\varepsilon_{t-i}, \tag{9}$$

where $\boldsymbol{\Phi}_i^* = \sum_{j=1}^{i} \boldsymbol{\Phi}_j \boldsymbol{\Phi}_{i-j}^*$, $\boldsymbol{\Phi}_0^* = \mathbf{I}_K$, $\varepsilon_t = \mathbf{P}_\mathbf{e}^{-1}\mathbf{e}_t$ and $\boldsymbol{\Sigma}_e = \mathbf{P}_\mathbf{e}\mathbf{P}_\mathbf{e}{}'$.

A major criticism of the Choleski decomposition approach is that the assumed Wold ordering of the variables is considered atheoretical. In contrast, the SVAR methodology uses economic theory to identify the contemporaneous relationships between variables (see for example Bernanke, 1986; Sims, 1986; Blanchard and Watson, 1986). The relationship between the reduced form VAR disturbances and the orthogonal shocks $\mathbf{v}_t$ is

$$\mathbf{B}_0\mathbf{e}_t = \mathbf{v}_t, \tag{10}$$

where $\mathbf{B}_0$ is an invertible square matrix, $E(\mathbf{v}_t) = 0$, $E(\mathbf{v}_t\mathbf{v}_t') = \boldsymbol{\Sigma}_\mathbf{v}$ and $\boldsymbol{\Sigma}_\mathbf{v}$ is a diagonal matrix. Premultiplying equation (8) by $\mathbf{B}_0$, we obtain

$$\mathbf{B}(L)\mathbf{y}_t = \mathbf{v}_t,$$

where $\mathbf{B}(L) = \mathbf{B}_0 - \mathbf{B}_1 L - \ldots - \mathbf{B}_p L^p$ and $\mathbf{B}_i = \mathbf{B}_0\boldsymbol{\Phi}_i$, $i = 1, 2, \ldots, p$. $\mathbf{B}_0$ is normalized across the main diagonal, so that each equation in the system has a designated dependent variable. The innovations of the structural model are related to the reduced form innovations by $\boldsymbol{\Sigma}_\mathbf{e} = \mathbf{B}_0^{-1}\boldsymbol{\Sigma}_\mathbf{v}(\mathbf{B}_0^{-1})'$. The impulse responses from the SVAR are obtained from

$$\mathbf{y}_t = \mathbf{B}_0^{-1}\mathbf{v}_t + \sum_{i=1}^{\infty} \boldsymbol{\Phi}_i^* \mathbf{B}_0^{-1}\mathbf{v}_{t-i}. \tag{11}$$

Similar to Kim and Roubini (2000) and Brischetto and Voss (1999), we use a non-recursive identification structure on the contemporaneous matrix $\mathbf{B}_0$. We define

$$\mathbf{B}_0 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ b_{21}^0 & 1 & 0 & 0 & 0 & 0 & 0 \\ b_{31}^0 & 0 & 1 & 0 & 0 & 0 & 0 \\ b_{41}^0 & 0 & b_{43}^0 & 1 & 0 & 0 & 0 \\ 0 & 0 & b_{53}^0 & b_{54}^0 & 1 & b_{56}^0 & 0 \\ b_{61}^0 & b_{62}^0 & 0 & 0 & b_{65}^0 & 1 & 0 \\ b_{71}^0 & b_{72}^0 & b_{73}^0 & b_{74}^0 & b_{75}^0 & b_{76}^0 & 1 \end{bmatrix} \tag{12}$$

with the variables ordered as in Table 1. Our model differs slightly from Kim and Roubini's model, as we allow for the US interest rate to have a contemporaneous impact on domestic monetary policy by not setting $b_{62}^0 = 0$.

4.2 Foreign block exogeneity restrictions

It is sensible to assume that the foreign variables in the Malaysian VARMA, SVAR and VAR systems are predetermined, and that the domestic variables do not Granger cause the foreign variables (see for example Cushman and Zha, 1997; Dungey and Pagan, 2000). To impose foreign block exogeneity, we divide the variables into foreign and domestic blocks, i.e.,

$$\mathbf{y}_t = (\mathbf{y}_{1,t}, \mathbf{y}_{2,t})', \tag{13}$$

where $\mathbf{y}_{1,t} = (OPI_t, R_{U,t})$ and $\mathbf{y}_{2,t} = (IP_t, CPI_t, M1_t, R_{M,t}, ER_t)$. In all three models, we restrict all parameters of the domestic variables that enter into the equations of the foreign variables either contemporaneously or as lagged values to zero. For example, in the VARMA model we set

$$\mathbf{A}(L) = \begin{pmatrix} \mathbf{A}_{11}(L) & \mathbf{0} \\ \mathbf{A}_{21}(L) & \mathbf{A}_{22}(L) \end{pmatrix} \text{ and } \mathbf{M}(L) = \begin{pmatrix} \mathbf{M}_{11}(L) & \mathbf{0} \\ \mathbf{M}_{21}(L) & \mathbf{M}_{22}(L). \end{pmatrix} \tag{14}$$

Beside the foreign block exogeneity restrictions, no further restrictions are imposed on the lag structures of the VAR and SVAR models. On the other hand, due to the identification issues discussed in Section (3), further restrictions are imposed for the VARMA model in order to identify a unique VARMA process.

5 Empirical results

In this section, we apply the complete VARMA methodology outlined in Section (3) to the Malaysian monetary model of seven variables. The impulse responses generated from the identified VARMA, VAR and SVAR models for Malaysian monetary policy are then used to assess the effects of various monetary shocks.

5.1 Specifying VARMA, VAR and SVAR models

In Stage 1, we identify the overall order of the VARMA process and the orders of embedded SCMs in the data for the pre- and post-crisis periods. In Panel A of Table 2 we report the results of all canonical correlations test statistics, divided by their χ^2 critical values, for the pre-crisis period. This table is known as the "Criterion Table". If the entry in the $(m, j)^{th}$ cell is less than one, this shows that there are seven SCMs of order (m, j) or lower in this system.

From Panel A in Table 2, we infer that the overall order of the system is VARMA$(1, 1)$. Conditional on this overall order, the canonical correlation tests are employed to identify the individual orders of embedded SCMs. The number of insignificant canonical correlations identified are tabulated in Panel B of Table 2, which is referred to as the "Root Table". In the Root Table, the bold entries show that one scalar component of order $(1, 0)$ is initially identified in position $(m, j) = (1, 0)$. Then, there are seven SCMs of order $(1, 1)$ at position $(m, j) = (1, 1)$. From these seven, one is carried through from the previous one $(1, 0)$ scalar component, and the remaining six are new scalar components of order $(1, 1)$. Hence, the identified VARMA$(1, 1)$ consists of one SCM$(1, 0)$ and six SCM$(1, 1)$s.

Using the identification rules described in Section (3), a canonical SCM representation of the identified VARMA$(1, 1)$ of the Malaysian monetary model for the pre-crisis period is given below, where $\boldsymbol{y}_t = (OPI_t, R_{U,t}, IP_t, CPI_t, M1_t, R_{M,t}, ER_t)'$.

Table 2: *Stage I of the identification process of a VARMA model for the Malaysian Monetary System for the pre-crisis period*

PANEL A: Criterion Table						**PANEL B**: Root Table					
	j						j				
m	0	1	2	3	4	m	0	1	2	3	4
0	66.41[a]	6.79	3.51	2.30	1.68	0	0	0	0	1	2
1	4.33	**0.87**	0.77	0.91	1.00	1	**1**	**7**	7	7	8
2	1.07	1.11	1.00	0.85	0.92	2	6	9	14	14	14
3	0.91	0.97	0.96	1.03	0.89	3	7	13	16	20	21
4	1.15	1.09	0.99	0.98	1.03	4	6	12	20	23	26

[a]*The statistics are normalized by the corresponding 5% χ^2critical values*

$$
\begin{bmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1
\end{bmatrix} \boldsymbol{y}_t = \boldsymbol{c} + \begin{bmatrix}
\psi_{11}^{(1)} & \psi_{12}^{(1)} & 0 & 0 & 0 & 0 & 0 \\
\psi_{21}^{(1)} & \psi_{22}^{(1)} & 0 & 0 & 0 & 0 & 0 \\
\psi_{31}^{(1)} & \psi_{32}^{(1)} & \psi_{33}^{(1)} & \psi_{34}^{(1)} & \psi_{35}^{(1)} & \psi_{36}^{(1)} & \psi_{37}^{(1)} \\
\psi_{41}^{(1)} & \psi_{42}^{(1)} & \psi_{43}^{(1)} & \psi_{44}^{(1)} & \psi_{45}^{(1)} & \psi_{46}^{(1)} & \psi_{47}^{(1)} \\
\psi_{51}^{(1)} & \psi_{52}^{(1)} & \psi_{53}^{(1)} & \psi_{54}^{(1)} & \psi_{55}^{(1)} & \psi_{56}^{(1)} & \psi_{57}^{(1)} \\
\psi_{61}^{(1)} & \psi_{62}^{(1)} & \psi_{63}^{(1)} & \psi_{64}^{(1)} & \psi_{65}^{(1)} & \psi_{66}^{(1)} & \psi_{67}^{(1)} \\
\psi_{71}^{(1)} & \psi_{72}^{(1)} & \psi_{73}^{(1)} & \psi_{74}^{(1)} & \psi_{75}^{(1)} & \psi_{76}^{(1)} & \psi_{77}^{(1)}
\end{bmatrix} \boldsymbol{y}_{t-1}
$$

$$
+\boldsymbol{u}_t - \begin{bmatrix}
\mu_{11}^{(1)} & \mu_{12}^{(1)} & 0 & 0 & 0 & 0 & 0 \\
\mu_{21}^{(1)} & \mu_{22}^{(1)} & 0 & 0 & 0 & 0 & 0 \\
\mu_{31}^{(1)} & \mu_{32}^{(1)} & \mu_{33}^{(1)} & \mu_{34}^{(1)} & \mu_{35}^{(1)} & \mu_{36}^{(1)} & \mu_{37}^{(1)} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\mu_{51}^{(1)} & \mu_{52}^{(1)} & \mu_{53}^{(1)} & \mu_{54}^{(1)} & \mu_{55}^{(1)} & \mu_{56}^{(1)} & \mu_{57}^{(1)} \\
\mu_{61}^{(1)} & \mu_{62}^{(1)} & \mu_{63}^{(1)} & \mu_{64}^{(1)} & \mu_{65}^{(1)} & \mu_{66}^{(1)} & \mu_{67}^{(1)} \\
0\mu_{71}^{(1)} & \mu_{72}^{(1)} & \mu_{73}^{(1)} & \mu_{74}^{(1)} & \mu_{75}^{(1)} & \mu_{76}^{(1)} & \mu_{77}^{(1)}
\end{bmatrix} \boldsymbol{u}_{t-1}.
$$

Among the variables, CPI_t is found to be loading on its own as SCM$(1,0)$, while the rest of the variables were loading on as SCM$(1,1)$. The foreign block exogeneity restrictions are also imposed by excluding all domestic variables from entering the foreign block of equations. We also ensured that the individual tests described in Section (3) do not contradict the normalization of the diagonal parameters of the contemporaneous matrix to one.

Using the same approach in the post-crisis period, the overall order of the model was identified to be VARMA$(1,2)$, which consists of three SCM$(1,0)$, three SCM$(1,1)$ and one SCM$(1,2)$. OPI_t, CPI_t and $M1_t$ were loading as SCM$(1,0)$, and $R_{U,t}$, IP_t and ER_t were loading as SCM$(1,1)$, while $R_{M,t}$ was loading on its own as SCM$(1,2)$.

For the VAR and SVAR models, the standard information criteria AIC and HQ (Hannan-Quinn) chose an optimal lag length of two, while the BIC chose a lag length of one for both sub-periods. However, both the Ljung-Box and LM tests for serial autocorrelation in the residuals show that a lag length of six is required to capture all of the dynamics in the data. Hence, a VAR(6) is estimated for the two sample periods.

5.2 Responses of domestic variables to various policy shocks

The key impulse response functions of domestic variables to independent shocks, derived from VARMA, VAR and SVAR specifications, are revealed in Figures 1 to 4 and are discussed in this section. The sizes of the shocks are measured by one-standard deviation of the orthogonal errors of the respective models. Broadly speaking, a comparison of the results of the three alternative models for the pre- and post-crisis periods indicates the benefits of using the VARMA model over its VAR/SVAR counterparts. Furthermore, the VARMA model performs much better than the other two models in cases that matters to policymakers, particularly in the post-crisis period. Therefore, we say at the outset that the discussions that follow are based largely on VARMA models.

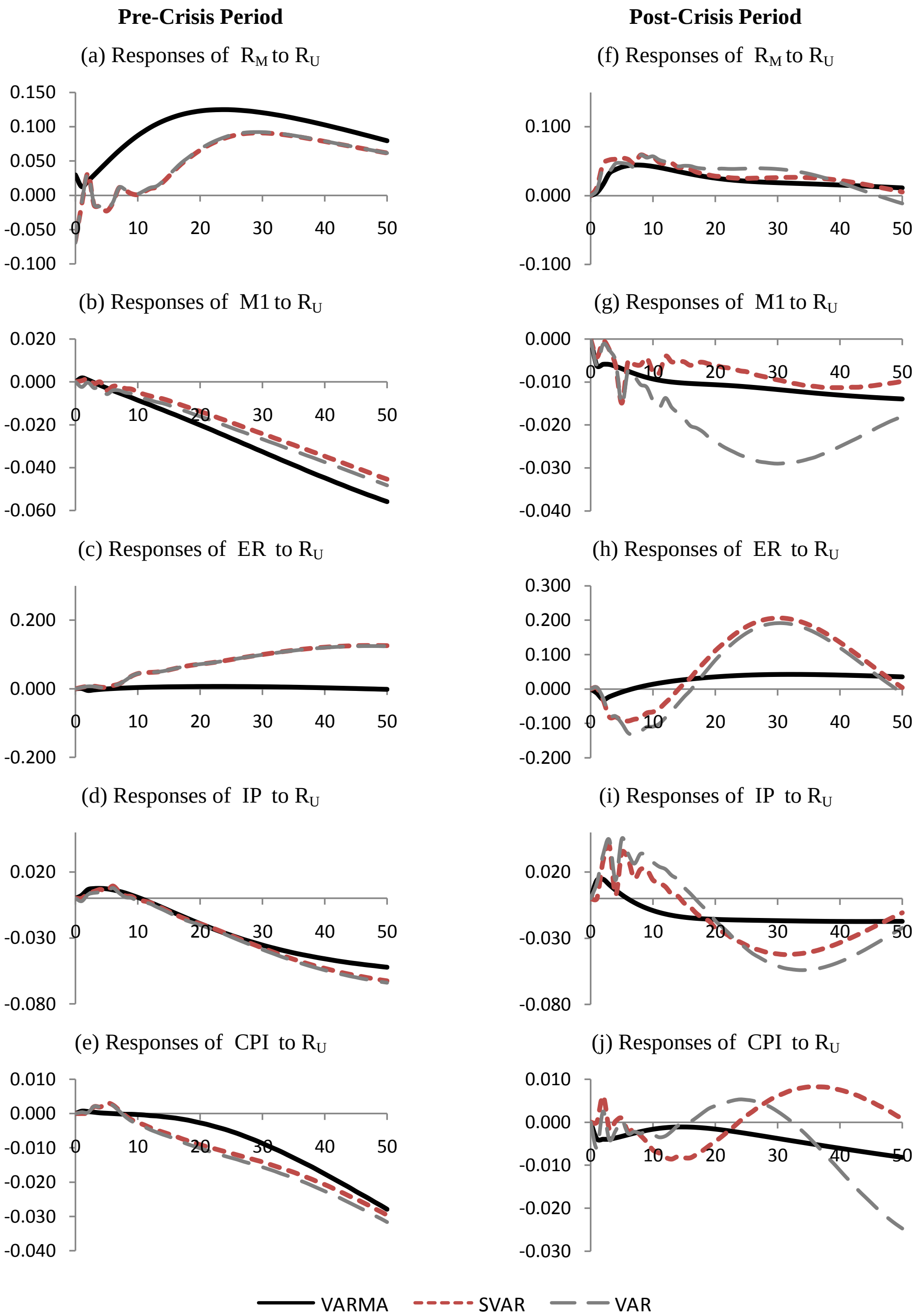
Responses to a foreign monetary policy shock

The responses of domestic variables to a R_U shock are shown in Figure 1 for the pre- and post-1997 crisis periods, and we first discuss the results for the pre-crisis period: an increase in R_M, as expected under a controlled exchange rate system with unrestricted capital flows - a regime Malaysia pursued over this period. This positive response of R_M caused a decline in $M1$. Furthermore, the Ringgit (ER) depreciated mildly as both a direct response to the R_U shock and an opposite reaction to the increase in R_M, which is only revealed by the VARMA model. This is also partly due to an attempt to lean against the nominal exchange rate depreciation, especially under a managed exchange rate regime. The combined effects of an increase in R_M and a largely insensitive exchange rate subsequently triggered a decline in both IP and CPI nearly a year later. For the post-crisis period, on the other hand, the responses of R_M, $M1$, IP and CPI to a R_U shock are the same as those for the pre-crisis period, although the changes are all less prominent. Moreover, as indicated only by the VARMA model, the Ringgit has slightly appreciated. While Malaysia has pegged its currency to the US dollar and introduced capital control measures in an effort to regain its monetary independence, the rise in R_M and the fall in $M1$ are indications that the country has not experienced absolute monetary autonomy under the fixed exchange rate regime. However, it is apparent from the mild effects on IP and CPI that the stringent capital control measures that Malaysia imposed have helped to insulate the economy to some extent from foreign monetary shocks.

Responses to a domestic monetary policy shock

Shocks to R_M are treated as changes to monetary policy. The responses of the domestic variables to a R_M shock are shown in Figure 2: a short-run increase in R_M, itself lasting for a year. In the pre-crisis period, $M1$ declined – with the effect accentuated by the VARMA model – ER appreciated, as influenced by market forces, and IP and CPI contracted. The sluggish response of CPI signals

Figure 1: *Responses of Malaysian variables to a US monetary policy shock*



the presence of a temporary price puzzle. The negative persistent response of IP may be due to a rise in the real cost of borrowing, the appreciation of the Ringgit, and a degree of price rigidity in the economy. In the post-crisis period, the responses of $M1$ and ER were marginal, suggesting that during this period the ER was determined quite independent of market forces. During this period of turmoil, IP also responded mildly to a monetary policy shock. More importantly, the price puzzle inherently observed by many studies and also existing in the pre-crisis period is no longer present in the post-crisis period, in that the price level responded negatively to a R_M shock.

Responses to a money shock

Theoretically, a positive shock to $M1$ is expected to trigger an easing of monetary policy, followed by a fall in R_M - a process known as the liquidity effect. However, Friedman (1969) argued that the expected inflation effects resulting from the change in $M1$ would exert countervailing pressure on interest rates. Hence, how long the liquidity effects would last, depends on the magnitude of the anticipated inflationary effects. Figure 3 displays the responses of domestic variables to an $M1$ shock, which indicates that $M1$ has played an important role in the Malaysian monetary transmission mechanism. In the pre-crisis period, a decline in R_M and increases in both IP and CPI were noted. These increases lead to a rise in demand for $M1$, and an ensuing rise in R_M. The observed negative relationship between $M1$ and R_M lasted for nearly three years before the combined effects of IP, CPI and the expected inflation dominated the liquidity effects. In the post-crisis period, the VARMA model reveals that the liquidity effect is only transitory, lasting for less than a year. Although the increase in CPI is marginal, the short-run liquidity effect could be attributed to countervailing pressure on R_M caused by strong positive transitory effects on IP, and anticipated inflationary effects. Since the Ringgit is determined to be quite independent of market forces under the pegged exchange rate system, the $M1$ shock would be expected to have little or no impact on the Ringgit and this result is only exposed by the VARMA model.

Responses to an exchange rate shock

Figure 4 displays the effects of domestic variables to an ER shock. In the pre-crisis period, there was a decline in R_M and a rise in $M1$, which may have been due to an unanticipated appreciation of the currency, prompting policy makers to lean against currency appreciation. The currency appreciation has two opposing effects on IP. On the one hand, it decreases the net exports as they become more expensive than the imports. On the other hand, it helps to reduce the cost of production through lower prices of imported intermediate goods. These combined effects transpiring through the demand and supply channels would help to determine the net influence of ER fluctuations on IP and CPI. Further, an unanticipated ER appreciation has a mild (positive) impact on IP, as the effect

Figure 2: *Responses of Malaysian variables to a domestic interest rate shock*

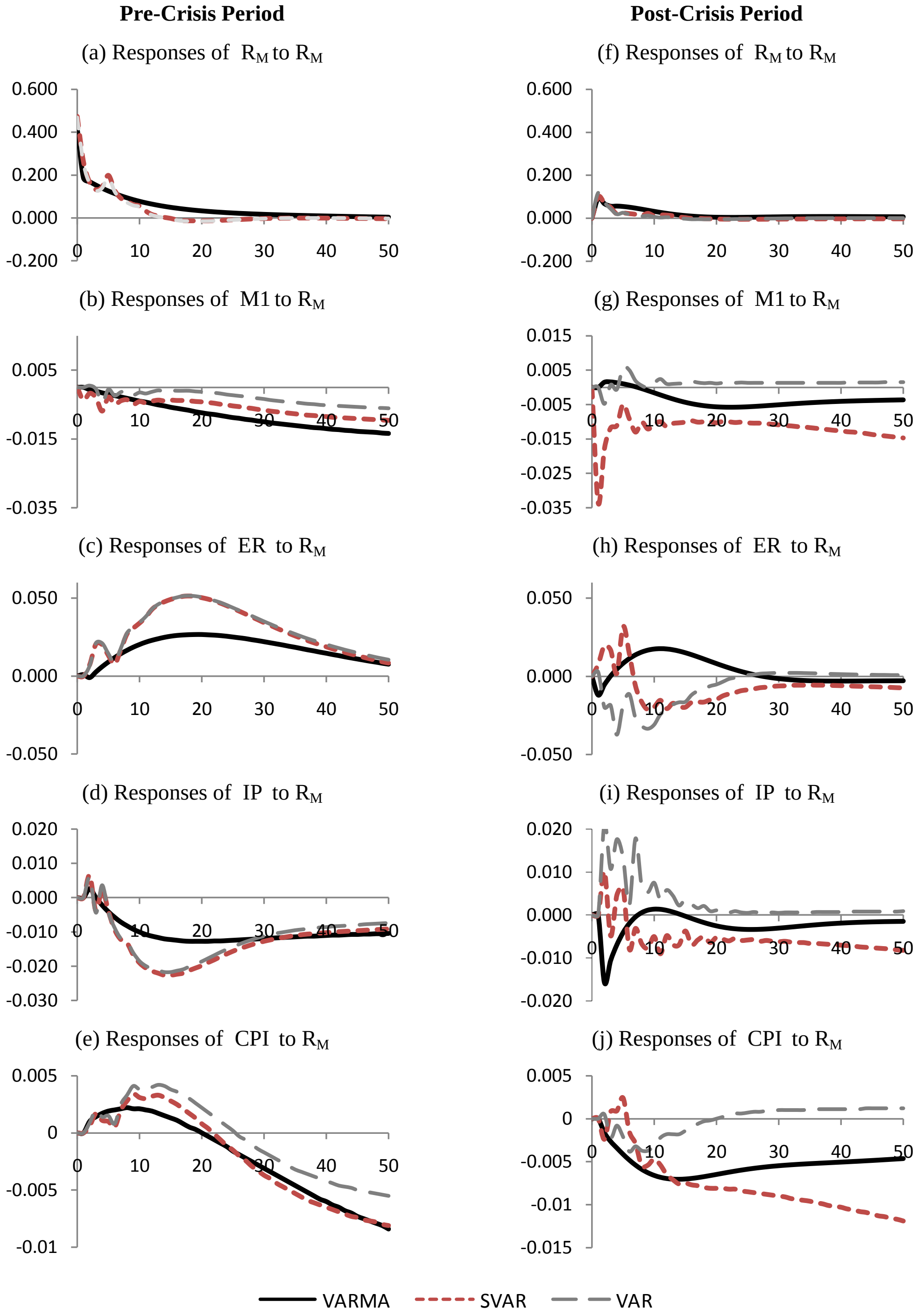
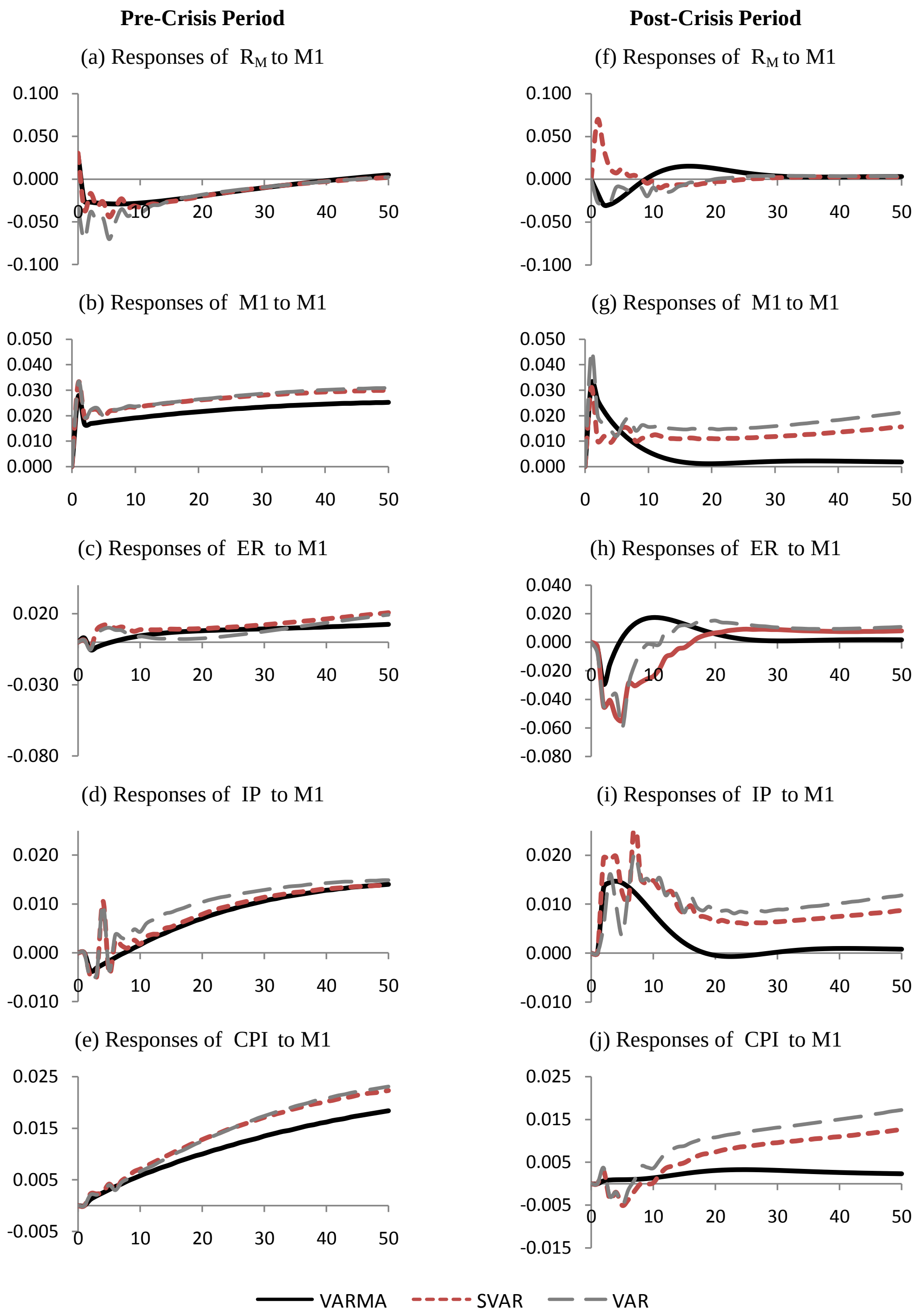


Figure 3: *Responses of Malaysian variables to a domestic money shock*



of a fall in production costs may be offset by the fall in net exports, while at the same time it has a negative effect on CPI, which could be attributed to both the decline in production costs and the prices of imported goods. In the post-crisis period, R_M declined, but the size of the fall was smaller than for the pre-crisis period. IP also declined, implying that the fall in net exports outweighed the benefits of the reduced production costs during this period. Overall, in the post-crisis period, we find that the VARMA model has uncovered more consistent results than its VAR or SVAR counterparts as to the way in which domestic variables respond dynamically to ER shocks.

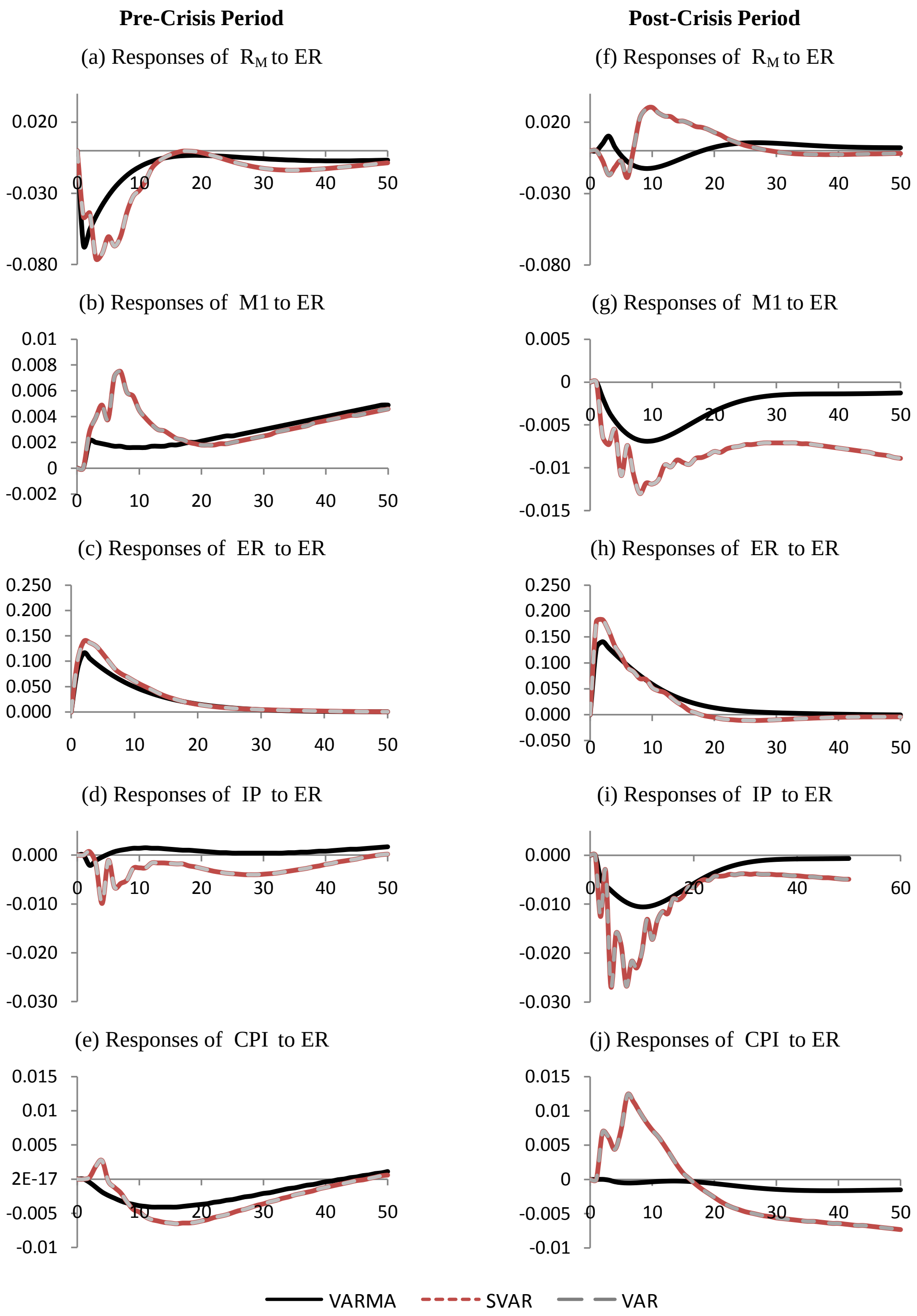
6 Conclusion

The VAR and SVAR models have been used extensively in the literature for modelling and analysing monetary policy. However, in the recent literature, several theoretical and empirical studies have had reservations regarding the use of these models for macroeconomic modelling and monetary policy analysis, and have provided persuasive arguments in support of VARMA models. At the same time, because of the difficulties involved in identifying a suitable VARMA model, such models have rarely been employed. To the best of our knowledge, this is the first paper to employ a VARMA model for identifying orthogonal monetary policy shocks in a small open economy framework.

We model the Malaysian monetary policy framework using VARMA, VAR and SVAR models. To demonstrate the importance and advantages of using VARMA models, we compare the impulse responses generated by these models for money, interest rates, exchange rates and foreign monetary shocks. Overall, relative to VAR and SVAR models, the VARMA model responses are found to be consistent with prior expectations based on the economic theories and policies pursued by the Malaysian government, particularly in the post-crisis period under the pegged exchange rate system.

The empirical results based on the VARMA methodology show notable differences in the monetary policy transmission mechanisms in the pre- and post-crisis periods. The changes in the Malaysian economic and financial systems, and the pegged exchange rate regime introduced in 1997, have significantly influenced the relationship between the monetary policy and the real economy. In the pre-crisis period, both foreign and domestic monetary shocks have prominent effects on the output, price, money, interest rate and exchange rate. In the post-crisis period, on the other hand, both of these shocks had less of an influence on the domestic variables. Regarding the unanticipated appreciation of the Ringgit, the output responded strongly in the post-crisis period, while the prices responded significantly in the pre-crisis period. Overall, based on the responses obtained from the VARMA model, it is apparent that the stringent capital control measures taken by the government have insulated the Malaysian economy to some extent against foreign monetary shocks.

Figure 4: *Responses of Malaysian variables to a domestic exchange rate shock*



Considering some disparities in the effects of monetary policy on the Malaysian economy during the pre- and post-crisis periods, it is indispensable for policymakers to understand how the economic transformation, the openness of the economy and the growing integration with external economies affect the nature of the monetary transmission mechanism. This study investigates these features of the Malaysian economy and uncovers the key issues that have implications for the conduct of monetary policy. In addition, uncovering how various transmission channels work, can help BNM to steer the economy in the right direction with an appropriate pressure, so that monetary policy can still remain an effective policy measure in achieving sustainable economic growth and price stability.

Notes

[1]Economic puzzles are referred to as liquidity puzzles (an unanticipated increase in money supply causes interest rates to rise instead of falling), price puzzles (an unanticipated tightening of monetary policy causes prices to increase instead of falling), and exchange rates puzzles (an unanticipated increase in interest rates causes exchange rates to depreciate instead of appreciating).

[2]The choice between a VAR in levels (unrestricted VAR) and a VECM (restricted VAR) depends on the economic interpretation attached to impulse response functions from the two specifications (see Ramaswamy and Sloke, 1997, for details). The impulse response functions generated from VECM models tend to imply that the impact of monetary shocks is permanent, while the unrestricted VAR allows the data series to decide whether the effects of the monetary shocks are permanent or temporary. It is also common in the monetary literature to estimate the unrestricted VAR model in levels (see for example Sims, 1992; Cushman and Zha, 1997; Bernanke and Mihov, 1998).

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