Unexpected movement in monetary aggregates and its effect on asset price in Thailand

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This paper aims to develop a structural vector autoregressive (SVAR) model to study the dynamic relationships between broad money and other macroeconomics variables in Thailand. The structural restrictions on SVAR model are based on economics intuition and novel finding that money does not react contemporaneously to transitory component of the short-term interest rate. The model also features stock price and house price as the different response of asset price and goods price will be monitored. There are total of seven monthly endogenous variables included in the model covering the period of 2010 - 2020. The result based on forecast error variance decomposition suggests that the variance of shock in goods price is the main factor that contributes more than 90% to the total variance of forecast error for broad money. In addition, the impulse response analysis provides another three key findings. First, broad money significantly decreases after a few months in response to a rise in short-term rate. Second, an increase in money supply can lead to a rise in real output, goods price, and house price. Lastly, the response of goods price to shock in money supply is faster than the house price but the magnitude of the response is much smaller.

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Paripon Sriboon

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1. INTRODUCTION

After the lockdown announcement during the first wave of COVID-19 pandemic in Thailand, there was a surge in value of both narrow and broad money. This phenomenon was possibly resulted from various factors. For example, people in aggregate might become more risk-averse and chose to increase their saving rate to maintain their liquidity. Second, money issuers such as commercial banks provided abundant loans to a large group of people who are affected by the pandemic. Third, the Bank of Thailand (BOT) lowered the policy interest rate and deployed measures to temporarily suspend debt repayment. All these events were necessary to prevent recession, but they inevitably led to the growing quantity of money. In this paper, a theoretical model capturing the dynamic relationship between broad money and other macroeconomics variables will be developed. The proportion of unexpected movement in broad money caused by shocks from other variables will be explored. In addition, the impact of money supply on the price level will be estimated. Particularly, the different responses of goods, house, and equity prices following shocks are anticipated and will be monitored. The results from this paper will provide insight understanding on the role of broad money and price adjustment process.

Standard theory of money states that the level of money holding is judged based on income, price level and the opportunity cost of holding it. The interesting question is whether people will withdraw their money immediately once they know that the yield on bonds is going up from 1% to 2%. Benati (2020) econometrically reveals that when economic agents choose the amount of narrow money (M1) to hold, they will look at the permanent component of the short-term rate, not the whole level of the observed interest rate, which normally includes transitory shocks. In other words, if they think that the yield of 2% is only temporary and will revert to 1% in a near future, they may not bother themselves withdrawing their money to invest in bond just to capture the return of 2% for a short period of time. His finding implies that money, at least for M1, does not react contemporaneously to a shock in short-term rate. Therefore, this novel result will be taken into account when the model is being developed.

The relationship between money growth and price level is often observed and covered in voluminous literatures. Hossain and Arwatchanakarn (2017), for instance, have pointed out that there is a cointegration between money growth and inflation in Thailand. In addition, they state that money growth affects inflation with lag. Hammoudeh, Nguyen, and Sousa (2015) examine the effect of US monetary policy on sectoral commodity prices including food, fuel, metals, and more. Their results show that monetary contraction leads to an immediate increase in overall commodity price index which erodes after one and a half year but generates different responses for price indices from various sectors. Belke, Orth, and Setzer (2010) investigate the interaction between money supply, goods price and asset price at the multi-national level focusing on major OECD countries. They find some counterfactual evidence that high money growth rates have not coexisted with a rise in goods price. Instead, the sharp increase in asset prices such as housing is observed. These academic papers imply that the different response of asset and goods price is quite prevalent. For the case of Thailand, there are few literatures that study the different responses of price level to the shock in money supply. Thus, this paper is supposed to provide additional contribution to the gap in the field.

In addition, money is also gaining importance in many multivariate models aiming to explain the economy. Generally, the high level of money holding is usually observed with low interest rate, especially during the crisis. This potentially put a concern for policy maker as the short-term rate is constrained by the zero lower bound (ZLB). It also affects economists who are responsible for assessing the impact of the monetary policy. One good example of country that experienced this difficulty is the United States. Before 2008, there were abundant literatures studying the effect of monetary policy shock by using the federal fund rate as an indicator of monetary policy position. Most literatures conclude that an unexpected increase in the federal fund rate led to a drop in output and price level. After 2008, however, the shocks in monetary policy can no longer be extracted from the federal fund rate because of the zero lower bound restriction. The implement of unconventional monetary policy through quantitative easing (QE) even trivializes the sole use of the federal fund rate to capture the stance of monetary policy. To curb this, a model with a focus on the monetary aggregates potentially provides an alternative tool for analyzing the impact of monetary policy on the economy.

Keating, Kelly, Smith, and Valcarcel (2019) successfully developed a model of monetary policy shocks that can be employed in both period of financial crises and normal condition. Their model identifies shocks by using the broad monetary aggregate instead of the federal fund rate. The impulse response functions from the model generate no price, output, and liquidity puzzle which are often found in other literatures. In contrast to the models from developed countries, Phiromswad (2015) studies the impact of monetary policy in Thailand using a structural vector autoregression (SVAR) model which uses the interbank lending rate to proxy the monetary policy. The model contains no variable related to money and generates price puzzle. Alternatively, Arwatchanakarn (2019) employs a structural vector error correction model (SVECM) and includes narrow money as monetary aggregate variable. Nevertheless, there exists exchange rate puzzle and his model does not consider policy transmission through other forms of wealth such as electronic money, housings, and equities. The first component is only included in broad money. Hence, this limitation motivates the author to build a model that includes all forms of money and various asset classes to study its impact on the economy.

There are three research hypotheses to be investigated in this paper. First, the forecast error variance decomposition in broad money will be estimated to examine which variables plays an important role in explaining the variance of shock in broad money. The policy interest rate which is the traditional channel of monetary policy transmission is anticipated to significantly affect the level of money holding. In addition, an unexpected increase (decrease) in the policy interest rate caused by the central bank leads to a decrease (increase) in broad money with some lags. Second, it will be explored whether a shock in money supply leads to a decrease in interest rate, a rise in real output and a rise in price level for goods, housings, and equities. This is equivalent to test whether the responses are consistent with the economic theory and that price puzzle does not exist in the model. Third, it will be investigated whether the money supply shock has less effect on goods price than asset price with inelastic supply such as housing. The rationale is that excess liquidity leads to more domestic demand for goods and fixed assets. If the supply of domestic goods cannot meet its demand, foreign goods are available for substitution. However, fixed asset such as housing cannot be imported and its supply is inelastic. Thus, extra demand on housings potentially inflates its price.

The analysis of this paper employs a structural vector autoregression (SVAR) model. The impulse response function (IRF) and forecast error variance decomposition (FEVD) are the main tools for analyzing the hypotheses. The variables included in the model are selected in accordance with macroeconomic framework for a small open economy developed by Mundell and Fleming. These are broad money, real output, short-term interest rate, consumer price, house price, stock price, nominal exchange rate. All the seven variables are treated as endogenous in the system, while the federal fund rate is controlled as an exogenous factor. The identification of contemporaneous matrix for SVAR model relies on economic intuition using non-recursive strategy.

To the best of my knowledge, there are only few literatures in Thailand that study the impact of money supply on macroeconomics variables. Therefore, the model from this paper will be beneficial for future work, especially when the stance of monetary policy can no longer be extracted from the policy interest rate. This is not unlikely because the crisis initiated by the COVID-19 pandemic is far from over, at least in 2021, and the central bank may further lower the policy rate. Lastly, it is worth mentioning that the methodology employed in this paper is novel for existing literatures in Thailand as most of them use Cholesky decomposition to identify the contemporaneous matrix for the SVAR model.

2. LITERATURE REVIEW

2.1 Definition and the Theory of Money

The Bank of Thailand (BOT) provides two measurements of monetary aggregates, namely narrow and broad money. The former includes currency in circulation (banknotes and coins) and transferrable deposits. The latter includes narrow money plus other forms of deposits and money market instrument including saving deposits, time deposits, foreign currency deposits, certificate of deposit and bill of exchange. The central bank controls the supply of money through the control of currency and commercial bank reserves. For instance, the central bank can increase the level of reserves by open market operation or directly increase the required reserves. The commercial banks with excess reserve lend money to the public leading to more deposits and reserves. The commercial bank can continue lending until the excess reserves disappear and this process is known as 'money multiplier' effect. In sum, the quantity of broad money in the economy depends on the decision of both the central bank who controls the monetary base (currency and reserves) and the commercial banks who provide loan to the public.

Growing literatures study the money demand function and its opportunity cost. Judson, Schlusche, Wong (2014) review the demand for M2 at the zero lower bond using data from the United States. They find a significant change in the relationship between money and interest rate across time. Benati, Lucas, Nicolini, Weber (2020) investigate the behavior of long-run demand for M1 for 38 countries. They find evidence that a stable long-run relationship between the inverse M1-

velocity (the ratio of M1 to GDP) and a short-term rate exists. Choudhry (1996) study the effect of stock price on money demand and show that it helps to determine the stability in the money demand function. Huellen, Qin, Lu, H.Wang, C.Wang, and Moraitis (2020) develop an algorithm to measure opportunity cost effects resulting from the openness of economy. Following their approach, they reveal that stable money demand function can be identified.

2.2 Models with Monetary Aggregates

The importance of monetary aggregates on economy is extensively unraveled in various studies. Freeman and Kydland (2000) develop a model showing that the endogeneity of the money supply exists. It suggests that the supply of money responses to variables that fluctuate over the business cycle. In addition, they show that shocks to required reserve or monetary base affect real output. Belongia and Ireland (2016) employ Divisia monetary aggregates instead of simple-sum measures provided by the Federal Reserve's official to estimate a SVAR model. They find that, given identified monetary policy shocks, large and persistent effects on output and price are observed. In the following year, Belongia and Ireland (2017) work on the role of monetary base and monetary aggregates on transmitting a central bank's action to the economy. They propose that the Federal Reserve could more effectively stabilize nominal income around the long-run target by influencing the monetary base or a broader aggregate. These actions are not constrained by the zero lower bound.

Coen, Lefebvre, and Simon (2018) focus on using monetary aggregates to explain the risk premium for the Central London market. They construct a monetary index to represent the international money supply on the London office market and show that the index is one of the determinants of real estate risk premium. The link between monetary policies and real estate is explained under Mundell-Fleming framework for a small open economy with flexible exchange rate. Their results are obtained by using SVAR model and impulse-response function. Li, Iscan, and Xu (2010) also use SVAR model and Mundell-Fleming framework to analyze the impact of monetary policy shocks on stock prices in Canada and the United States. Their work focuses on the difference between the response of stock price from the two countries. Their model utilizes the broad money but does not contain variables related to real estate or other forms of wealth in the model.

2.3 Review on IS/LM model

The equilibrium model for close country such as IS/LM theorizes that real output of a country depends on consumption, private investment, and government spending. Consumption is determined by disposable income while investment is dependent on real output and real interest rate. As the central bank cuts the rate, there is more investment and so more output and consumption. For the government, both tax reduction and increase in spending also lead to more output and more demand on goods. In open economy, the real output is also affected by the import of foreign goods and the export of domestic goods. The former depends on exchange rate and level of domestic income, which equals to real output in equilibrium. The latter is determined by exchange rate and income level of foreign countries.

According to the theoretical framework by Mundell-Fleming, if the central bank increases the money supply which induces a decrease in the interest rate, the direct effect is higher investment, higher demand for domestic and foreign goods, and higher output. There is also another effect through the exchange rate. A lower interest rate leads to a depreciation of domestic currency, which then leads to a higher foreign demand on domestic goods due to its price competitiveness. The result is higher export and output. However, the short-term supply of housing cannot meet the domestic demand because of its inelasticity. Consequently, the short-run equilibrium is possibly reached by an increase in housing price.

2.4 Economic Puzzles from the Impulse-Response Functions

The common model for investigating the effect of monetary policy shock or money supply on other variables is a SVAR model proposed by Sims (1980). The model often includes real output, price level, short-term interest, monetary aggregate, and exchange rate. Other variables such as house price, trade balance, or stock price can be incorporated in the model depending on the objective of the studies. However, impulse response functions from previous analyses are suffered from economic puzzle, which is defined as the response that contradicts theory prediction. Christiano, Eichenbaum, and Evans (1999) develop a model using either M1 or M2 as a policy indicator to identify its effect on output, price, and other variables. However, they find puzzling responses generated from their money-based model. As a result, they suggest that using the federal fund rate as the policy indicator provides the most reasonable response. Keating, Kelly, Smith, and Valvacel (2019) later show that the previous model also exhibits price puzzle (i.e. price rise after contractionary monetary policy) when the sample period is extended from 1967Q1 - 1995Q2 to 1967Q1 - 2007Q4. Other common type of puzzling responses includes liquidity puzzle and exchange rate puzzle. The former is termed when a monetary base or monetary aggregates increase following an unpredicted increase in the interest rate. The latter is named when the domestic currency depreciates after an unexpected increase in the interest rate. These definitions can also be used for the process in reverse direction.

3. DATA

In the model, there are 7 endogenous variables, namely broad money, real output, policy interest rate, consumer price, house price, stock price, and nominal exchange rate. The federal fund rate is used as a proxy for foreign interest and is controlled as an exogenous factor in the model. All variables are chosen in conjunction with the basic features of the Mundell-Fleming framework and standard money demand theory. The data is obtained from the BOT's website and the Thailand's Integrated Database for Economics (Tide). The parameters in the SVAR model are estimated using monthly data from 2010m1 to 2020m12. Specifically, real output is measured by the coincident economics index, price level by core consumer price index (whole kingdom), and house price by single-detached house (including land) index. All indexes except SET index are normalized to 100 in 2010m1. It should also be noted that there are many interest rates in the economy that are relevant to the money creation process. However, all the rates are highly correlated with the policy interest rate. Hence, only the central bank rate is included in the model. The description and basic statistics of data are summarized in Table 1 and Table 2. The time-series plot is shown in Figure 1. The correlations between the variables are reported in Table 3. For model estimation, all variables are expressed in natural logarithms, except the policy interest rate and the federal fund rate as shown in Table 4.

Table 1. Summary of Variables Description

Notation	Description	Unit	Source
M	Broad money	Trillion THB	Bank of Thailand
CEI	Coincident economic indicator (real output)	% wrt. Base	Bank of Thailand
R	The policy interest rate	%	Bank of Thailand
CPI	Core consumer price index (whole kingdom)	% wrt. Base	Ministry of Commerce
HPI	Single-detached house (including land) price index	% wrt. Base	Bank of Thailand
SET	Stock Exchange of Thailand price index	% wrt. Base	SET
ER	Nominal exchange rate	THB/USD	Bank of Thailand
FFR	The federal fund rate	%	Bank of Thailand

Table 2. Summary of Basic Statistics (in level)

Statistics	*M*	*CEI*	*R*	*CPI*	*HPI*	*SET*	*ER*	*FFR*
N	132	132	132	132	132	132	132	132
Mean	16.9	106.1	1.9	107.8	123.4	1385.3	32.3	0.7
SD	3.2	2.7	0.7	3.6	14.5	265.6	1.7	0.7
Min	10.6	97.0	0.5	100.0	98.5	696.6	29.3	0.3
Max	22.9	110.6	3.5	112.2	149.0	1830.1	36.4	2.5

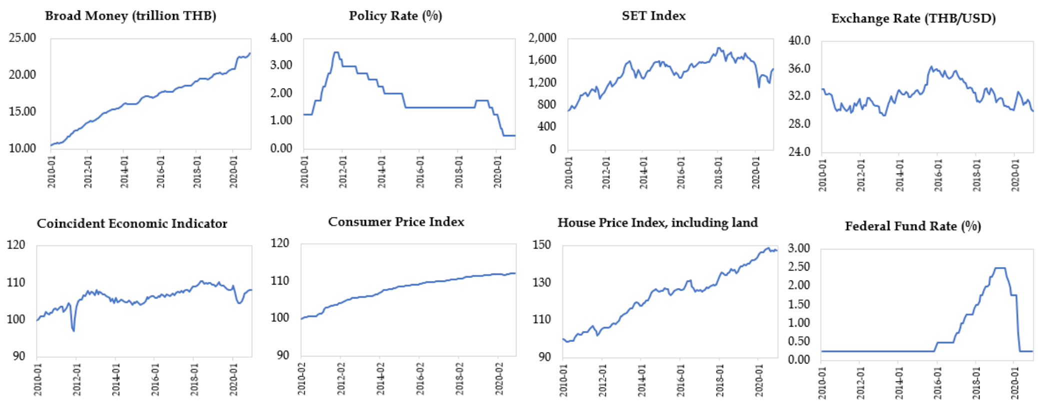

Figure 1. Time-Series Plot of all variables

Table 3. Correlation Table

Correlation	*M*	*CEI*	*R*	*CPI*	*HPI*	*SET*	*ER*	*FFR*
M	1.00							
CEI	0.74	1.00						
R	(0.63)	(0.28)	1.00					
CPI	0.98	0.78	(0.56)	1.00				
HPI	0.98	0.70	(0.69)	0.96	1.00			
SET	0.73	0.82	(0.24)	0.82	0.72	1.00		
ER	0.19	0.09	(0.38)	0.31	0.19	0.18	1.00	
FFR	0.57	0.69	(0.28)	0.59	0.58	0.61	(0.03)	1.00

Table 4. Summary of Transformed Variables

Transformed Variable	Formula
$\boldsymbol{m}$	$= \ln(M)$
$\boldsymbol{cei}$	$= \ln(CEI)$
$\boldsymbol{cpi}$	$= \ln(CPI)$
$\boldsymbol{hpi}$	$= \ln(HPI)$
$\boldsymbol{set}$	$= \ln(SET)$
$\boldsymbol{er}$	$= \ln(ER)$

4. METHODOLOGY

The hypotheses of this paper are analyzed by the SVAR model. An impulse-response functions are used to study (1) the movement of broad money in reaction to a shock in the policy interest rate (2) whether the price puzzle exists in the model and (3) the reaction of goods and house price following a shock in money supply. A forecast error variance decomposition is used for estimating the proportion of the unexpected movement in broad money that are due to variance of structural shocks from other variables.

4.1 Unit Root, Lag Length, and VAR Stability

All individual variables are tested for unit root by using augmented Dickey-Fuller framework to confirm that all series are at most $I(1)$. The test is conducted in two forms: (1) no constant and no trend and (2) with constant but no trend.

The relationship between the variables is then estimated by the reduced-form VAR model:

$$y_t = B_0 + B_1 y_{t-1} + B_2 y_{t-2} + .. + B_p y_{t-p} + \beta FFR_t + e_t \quad (1)$$

where $y_t = [m_t, cei_t, R_t, cpi_t, hpi_t, set_t, er_t]'$, and e_t is the vector of residual term. To examine the dynamic relation between endogenous variables, the lag coefficients of

VAR model in level are determined. The optimum number of lags is selected based on information criteria, but it is capped at 12. Specifically, this paper will focus on the result from the AIC as Kilian (1998a, 2001) showed that it can provide more accurate confidence interval for the impulse response functions.

The stability of the estimated VAR model is checked by computing the roots of the following equation:

$$\det\left(I - B_1 z - B_2 z^2 - \ldots - B_p z^p\right) = 0 \qquad (2)$$

where B_i is the coefficient of y_{t-i} in the model. If the modulus of all $1/z_i$ lies inside the unit circle, the stability condition of VAR is satisfied. Otherwise, there could be some cointegrations in the system.

4.2 Cointegration Test and VAR with I(1) variables

The cointegration between variables in the system is explored using the Johansen technique which transforms the VAR model in Equation (1) to the following VECM model:

$$\Delta y_t = \Pi y_{t-1} + \Gamma_1 \Delta y_{t-1} + \Gamma_2 \Delta y_{t-2} + .. + \Gamma_{p-1} \Delta y_{t-(p-1)} + \beta FFR_t + e_t \qquad (3)$$

where $\Pi = -\left(I - B_1 - \cdots - B_p\right)$ and $\Gamma_i = -\left(B_{i+1} + \cdots + B_p\right)$. The rank of Π matrix is equal to the number of cointegration in the system, i.e. $rk(\Pi) = r$. The hypothesis tests for r are

$H_0\!: r = 0$ vs $H_1\!: 0 < r \le g$

$H_0\!: r = 1$ vs $H_1\!: 1 < r \le g$

$H_0\!: r = 2$ vs $H_1\!: 2 < r \le g$

⋮

$H_0\!: r = g - 1$ vs $H_1\!: r = g$

where g is the number of variables in y. The number of lag p to include in the model is the same as the underlying VAR model from the previous section.

It should be noted that a VAR(p) process can be estimated with the presence of $I(1)$ variables for both cointegrated and non-cointegrated system if the scope of the work does not deal with joint probability distribution such as Granger-Causality Test. In particular, for a VAR(p) model with $p > 1$, the least square estimator of B_i remains consistent as VECM can still be rearranged to VAR(p) in level. Furthermore, the cointegration structure is hardly known with accuracy, thus it is more practical to estimate the VAR in level. The detailed explanation can be founded in chapter 2 (p.41) of Kilian and Lutkepohl (2017). In addition, many literatures also work with a VAR model in level, for example, Belke et al. (2010), Li et al. (2010), Phiromswad (2015), and Hossain and Arwatchanakarn (2017).

4.3 The SVAR Model

The residual term e_t in Equation (1) is sometimes called forecasted errors or surprise movement in y_t. In a VAR process, e_t is a vector of white noise, so $E(e_t) = 0$, $E(e_t e_t{}') = \Sigma_e$ and $E(e_t e_s{}') = 0$ for different period s and t where

$$\Sigma_\mathrm{e} = \begin{bmatrix} \sigma_1^2 & \sigma_{12} & \cdots & \sigma_{16} & \sigma_{17} \\ \sigma_{21} & \sigma_2^2 & \cdots & \sigma_{26} & \sigma_{27} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \sigma_{61} & \sigma_{62} & \cdots & \sigma_6^2 & \sigma_{67} \\ \sigma_{71} & \sigma_{72} & \cdots & \sigma_{76} & \sigma_7^2 \end{bmatrix} \tag{4}$$

Because Σ_e matrix is symmetry but not diagonal, there can be contemporaneous correlation between the errors. If impulse response analysis is performed based on the reduced-form VAR when the covariance term in Equation (4) is significantly different from zero, then the result does not truly reflect the effect of the structural shock.

To extract pure structural shocks, the matrix A_0 which contains the instantaneous relation between variables in y_t is used to transform the model in Equation (1) to the SVAR model:

$$A_0 y_t = B_0^* + B_1^* y_{t-1} + B_2^* y_{t-2} + .. + B_p^* y_{t-p} + \beta FFR_t + u_t \tag{5}$$

where A_0 is the 7x7 matrix and $u_t = [u_m, u_{cei}, u_R, u_{cpi}, u_{hpi}, u_{set}, u_{er}]'$. The variance-covariance of structural shock u_t has the following representation:

$$E[u_t u_t'] = \Sigma_u = \begin{bmatrix} \varsigma_m^2 & 0 & \cdots & 0 & 0 \\ 0 & \varsigma_{cei}^2 & \cdots & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \cdots & \varsigma_{set}^2 & 0 \\ 0 & 0 & \cdots & 0 & \varsigma_{er}^2 \end{bmatrix} \tag{6}$$

According to Equation (1) and (5), the structural shock can be written as $u_t = A_0 e_t$, so the variance-covariance matrix of u_t can be expressed by

$$\Sigma_u = E[(A_0 e_t)(A_0 e_t)'] = A_0 \Sigma_e A_0' \tag{7}$$

The structural shock in money supply and short-term interest rate can be imposed on the system by u_m and u_R, respectively. However, it must be noted that the elements of matrix A_0 is not known. So, the identification of the contemporaneous relations between the variables in matrix A_0 will be based on economics intuition described in the next section.

4.4 Identification of Matrix A_0

The number of unknown elements in A_0 is 7^2. By using Equation (7), it can be seen that Σ_u has only 7 unknowns on the diagonal elements because other $7(7-1)$ elements are zero and Σ_e is already known by estimating the reduced-form VAR model. However, there are only $7(7-1)/2$ independent equations on the upper diagonal elements of Σ_u because of a symmetry. As a result, $7(7+1)/2$ more equations are needed to solve for A_0. In this framework, the diagonal elements of A_0 are set to unity, so that the coefficients of variable of order j in y_t in Equation (5) are normalized to one. Such restriction makes ς_{jj}^2 equals to the variance of structural shock in variable of order j in y_t. Consequently, the remaining equations or restrictions that must be identified are $7(7-1)/2$, or 21, for this model. The matrix A_0 can be expressed as $[a_{ij}]_{7x7}$, where $a_{ij} = 1$ when $i = j$, and the model becomes structural $A_0 y_t$ as defined in Equation (5).

The next step is to impose a set of restrictions on the contemporaneous relations among the endogenous variables. Starting with discussion on money, Benati (2020) econometrically show that M1 - velocity is approximately always in equilibrium and the movement of short-term rate reflects its reaction to disequilibria. In this paper, it is assumed that the same can be inferred for the case of broad money because advance in payment technology makes deposit and other accounts to be as liquid as M1. Thereby, the quantity of money is only contemporaneously affected by the shock in real output and price level. Structural shocks from other variables affect money stock with lag. Consequently, money supply shock (u_m) that is attributed to money issuers such as the central bank and other financial institutions can be determined from the following equation.

$$m_t - cpi_t = b_{10} - a_{12}cei_t + f_1(L(y_t)) + u_{m,t} \tag{8}$$

The rest of restrictions mostly follow the rationales from Li et al. (2010) and Belke et al. (2010). A structural shock to real output (u_{cei}) is interpreted as exogenous changes in productivity, unexpected shutdown of plant, and other factors from a supply-side. To identify this, the real output in Thailand is specified to only react contemporaneously with global factor such as exchange rate.

$$cei_t = b_{20} - a_{27}er_t + f_2(L(y_t)) + u_{cei,t} \tag{9}$$

A structural shock to short-term rate (u_R) presumably reflects the monetary policy shock which can be attributed to an exogenous change to the decision of central bankers. The interest rate is assumed to react instantaneously to the quantity of broad money, real output, and exchange rate. This should be in line with the central bank's decision who sets the policy rate by observing these variables.

$$R_t = b_{30} - a_{31}m_t - a_{32}cei_t - a_{37}er_t + f_3(L(y_t)) + u_{R,t} \quad (10)$$

An aggregate domestic demand shock (u_{cpi}) reflects an exogenous spending shock resulted from fiscal policy, wage-price setting relation, and other factors on a demand-side. It can be identified by allowing price level in Thailand to react contemporaneously to real output, interest rate and exchange rate. It should be noted that the contemporaneous effect of interest rate on goods price is also supported by Phiromswad (2015).

$$cpi_t = b_{40} - a_{42}cei_t - a_{43}R_t - a_{47}er_t + f_4(L(y_t)) + u_{cpi,t} \quad (11)$$

A structural shock to house price (u_{hpi}) can be identified by allowing the house price to instantaneously adjusts to a shock in current real output and consumer price level. Global factor, exchange rate and other variables only affect the house price with lag.

$$hpi_t = b_{50} - a_{52}cei_t - a_{54}cpi_t + f_5(L(y_t)) + u_{hpi,t} \quad (12)$$

Stock price is highly sensitive to shocks and is likely to instantaneously react to all variables in the system. Therefore, a structural shock in stock price (u_{set}) reflects an exogenous change in demand for equities.

$$set_t = b_{60} - a_{61}m_t - a_{62}cei_t - a_{63}R_t - a_{64}cpi_t - a_{65}hpi_t - a_{67}er_t$$
$$+ f_6(L(y_t)) + u_{set,t} \quad (13)$$

An exchange rate, as similar to stock price, is formulated from all sets of public and private information. Thus, the exchange rate should be instantaneously affected by all other variables in the system except stock market, whose price also relies on the same set of information. A structural shock (u_{er}) is modeled to capture an exogenous change in trade balance such as unexpected demand for certain product in Thailand.

$$er_t = b_{70} - a_{71}m_t - a_{72}cei_t - a_{73}R_t - a_{74}cpi_t - a_{75}hpi_t$$
$$+ f_7(L(y_t)) + u_{er,t} \quad (14)$$

A complete set of the restrictions in the form of $A_0 e_t = u_t$ is shown below:

$$\begin{bmatrix} 1 & a_{12} & . & -1 & . & . & . \\ . & 1 & . & . & . & . & a_{27} \\ a_{31} & a_{32} & 1 & . & . & . & a_{37} \\ . & a_{42} & a_{43} & 1 & . & . & a_{47} \\ . & a_{52} & . & a_{54} & 1 & . & . \\ a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & 1 & a_{67} \\ a_{71} & a_{72} & a_{73} & a_{74} & a_{75} & . & 1 \end{bmatrix} \begin{bmatrix} e_m \\ e_{cei} \\ e_R \\ e_{cpi} \\ e_{hpi} \\ e_{set} \\ e_{er} \end{bmatrix} = \begin{bmatrix} u_m \\ u_{cei} \\ u_R \\ u_{cpi} \\ u_{hpi} \\ u_{set} \\ u_{er} \end{bmatrix} \tag{15}$$

(Dots represent zero-restriction on each a_{ij})

It can be noticed that there are 21 unknowns, while the number of independent equations is also 21. Thus, the model is exactly identified.

4.5 Impulse-Response Functions and Forecast Error Variance Decompositions

The structural impulse response functions are used to study the responses of each element of y_t to a one-time impulse in $u_t = (u_m, u_{cei}, \dots, u_{FFR})'$,

$$\frac{\partial y_{t+i}}{\partial u_t} = \Theta_i, \qquad i = 1,2,3, \dots, H \tag{16}$$

where Θ_i is a $K \times K$ matrix. The purpose of these functions is to plot the responses of each variable to each structural shock over time horizon of H. The economic meaning of Equation (16) is that y_{t+i} increases by Θ_i when the size of the shocks $\boldsymbol{u_t}$ increases by one unit. If y_{t+i} and u_t are transformed variable, then Eq. (16) can be rearranged as

$$\frac{dy_{t+i}}{du_t} = \frac{d\ln(Y_{t+i})}{d\ln(U_t)} = \frac{dY_{t+i}/Y_{t+i}}{dU_t/U_t} = \Theta_i \tag{17}$$

Thus, its meaning becomes Y_{t+i} increases by Θ_i% when the size of the shocks U_t increases by 1%, which is similar to the definition of an elasticity.

The three hypotheses of this paper greatly rely on the analysis of impulse-response functions. To answer the first hypothesis, the positive (negative) structural innovation $u_{R,t}$ is imposed on $m_{t+1}, m_{t+2}, \dots, m_{t+H}$ to see whether the response of

m_{t+i} is significantly lower (higher) than zero using the 95% confidence interval band generated by bootstrapping method based on Efron and Tibshirani (1993). The second hypothesis looks at the response of $cei_{t+i}, R_{t+i}, cpi_t, hpi_t$ and set_{t+i} to the positive impulse of $u_{m,t}$ whether they are consistent with the economic theory. The last hypothesis compares the response of cpi_{t+i} and hpi_{t+i} to the positive impulse of $u_{m,t}$ to see whether hpi_{t+i} significantly increases faster and higher than cpi_{t+i}.

The forecast error variance decompositions are used to analyze the proportion of forecast error variance of y_{t+h} at horizon $h = 0,1,\dots,H$ that is due to each structural shock u_t. To illustrate, the h-steps prediction of y_t is.

$$y_t = B_0 + B_1 y_{t-1} + B_2 y_{t-2} + \cdots + B_p y_{t-p} + e_t$$
$$y_{t+h|t} = E[y_{t+h}|y_t, y_{t-1}, \dots] = B_0 + B_1 y_{t+h-1|t} + \cdots + B_p y_{t+h-p|t}, \quad (18)$$

where $y_{t+j|t} = y_{t+j}$ for $j \leq 0$. The forecast error of 1-step and 2-step ahead prediction are

$$y_{t+1} - y_{t+1|t} = e_{t+1} \quad (19)$$
$$y_{t+2} - y_{t+2|t} = \left(B_0 + B_1 y_{t+1} + B_2 y_t + \cdots + B_p y_{t+2-p} + e_{t+2}\right) - \left(B_0 + B_1 y_{t+1|t} + B_2 y_{t|t} + \cdots + B_p y_{t+2-p|t}\right)$$
$$= B_1 e_{t+1} + e_{t+2} \quad (20)$$

With some algebra, the h-step ahead forecast error can be expressed as

$$y_{t+h} - y_{t+h|t} = \sum_{i=0}^{h-1} \Phi_i e_{t+h-i} = \sum_{i=0}^{h-1} \Theta_i u_{t+h-i} \quad (21)$$

where $\Theta_i = \Phi_i A_0$. Therefore, the forecast error variance at horizon h is

$$FEV(h) = \sum_{i=0}^{h-1} \Theta_i {\Theta'}_i \quad (22)$$

The contribution of shock j to the FEV of y_{kt}, at horizon h is $FEV_j^k(h) = \sum_{i=0}^{h-1} \theta_{kj,i}^2$ where $\theta_{kj,i}$ is the kj^{th} element of Θ_i. The total FEV of y_{kt} at horizon h is $FEV^k(h) = \sum_{j=1}^{k} FEV_j^k(h)$. The fraction of variance from shock j relative to total variance is $FEV_j^k(h) / FEV^k(h)$.

The role of shock in the policy interest rate in explaining the unexpected movement in broad money can be observed by first computing the $FEV_j^m(h)/FEV^m(h)$ for all variables in the system. If the short-term interest rate is relatively important, the fraction $FEV_R^m(h)/FEV^m(h)$ will be a major source of volatility in forecast error of broad money. The result from this approach provides important evidence for the first hypothesis that tests whether the unexpected movement in short-term interest rate is one of the determinants in explicating the movement of broad money.

5. Empirical Results

5.1 Data Structure and Model Selection

The augmented Dickey-Fuller test using two lags provides strong evidence that all variables are at most $I(1)$. In particular, the test with drift term shows that only cpi is $I(0)$, while another test which features no constant term suggests that all variables are $I(1)$. These variables in level are then fitted into VAR system to determine the optimal lag length. The AIC framework indicates that the optimal number of lags should be two. However, when VAR(2) model is estimated, the auto-correlation function (ACF) and partial auto-correlation function (PACF) show that the error terms of each variable are correlated. Therefore, the total number of lags is kept increasing until there is no autocorrelation in the system. Eventually, the total number of lags used in the VAR model is four. The detailed process of model construction can also be found in Appendix A.

The stability test for the VAR(4) model is conducted. There is one root that lies outside the unit circle. This implies that the system is unstable and may contain cointegration relationships among variables. The Johansen's test is then performed based on the VAR(4) model while the federal fund rate is controlled as exogenous. The test statistics from the trace test, based on eigenvalues, provides evidence that there can be up to 3 cointegrations in the system. With this result, if one uses VAR in difference form to estimate the coefficients between variables, it will be biased as the error-correction term is omitted.

Therefore, the main analysis of this paper will be based on VAR model in level which is also suggested by Killian and Lutkepohl (2017). Alternatively, one could switch to structural vector error correction model (SVECM), but then it is necessary to deal with controversial issue of which cointegration relations to be restricted and how to specify short-run and long-run effects. Some examples of identification under SVECM framework can be found in Arwachanakarn (2019), Lutkepohl and Netsunajev (2018), and Ivrendi and Guloglu (2010). Another deterrent is that the engine for SVECM estimation is quite limited. The author tried using an R-programming to solve for the SVECM parameters. However, large number of variables in the system make it more difficult for R-programming to provide the reliable result. In fact, the model cannot be solved if the lags in SVECM is greater than one, which is not enough to provide useful information for this study. As a result, the author opts to rely on the result from SVAR model which will be discussed in subsequent section.

5.2 Forecast Error Variance Decomposition in Broad Money Equation

After the SVAR model is estimated, the forecast error variance decomposition is computed as shown in Figure 2. It demonstrates that the variance of shock in goods price is the main factor that always contributes more than 95% to the total variance of forecast error in broad money equation. This is not a surprising result because goods price usually has direct link to money level. For short-term period, the forecast error of broad money is also exposed to the variance of shocks in real output and policy interest rate. But, for longer period, the importance of real output is faded and is replaced by exchange rate. This can be explained by the postulation that the variation of shock in exchange rate, due to unexpected change in trade balance, can lead to unexpected inflow of foreign currency into Thailand. This currency is then exchanged to Thai currency which result in a change in level of broad money. Another important finding is shocks in house price and stock price have no effect on the forecast error of broad money. The result suggests that the impact of these two shocks on broad money may not be as important as shocks from other variables, which is in line with the hypotheses proposed in this paper.

5.3 Impulse Response Functions to Shock in Policy Interest Rate

For the first hypothesis, the responses of all variables when the impulse variable is the policy interest rate are shown in Figure 3. In the first figure, there is slight immediate impact of shock in interest rate on the level of money holding. The response of money becomes insignificant during month 2 and month 5. However, broad money starts to significantly decrease in response to interest rate shock in month 6. Specifically, the level of money decreases by 0.037% when the magnitude of the interest rate increases by one percentage point. The direction of movement of broad money conforms to the theory, but the size of its change is quite small.

The shock in policy interest rate has no effect on real input, house price, and stock price within a period of one year. It is possible that real output needs longer time to adjust to new level of interest rate as many firms are reluctant to change their production schedule before their planned date. Next, the policy interest rate does not have significant impact on house price. This may result from the borrowing rate faced by homebuyers, which composes of long-term risk-free rate plus premium, is unaffected by change in policy interest rate. Lastly, the response of stock price implies that market participants may put more weight on expected future cash flow and the discount rate to value their stock. Thus, the shock in policy interest rate does not matter much for stockholders.

There is also an instantaneous small decrease in goods price following the interest rate shock. Overall, this result conforms to the theory. To illustrate, when people realize that their short-term borrowing cost is higher, they immediately reduce their demand and investment. Given that the supply side is unchanged, the drop in demand must be followed by a decrease in price level. However, the effect of the short-term rate is just transitory as the response of goods price becomes insignificant after month 6. The same pattern also exists in the response of exchange rate, which immediately appreciates following the contractionary policy shock, but then becomes insignificant after two months, which is consistent with the uncovered interest rate parity.

Period	m	cei	R	cpi	hpi	set	er
1	0.5%	2.3%	1.2%	95.5%	0.0%	0.0%	0.6%
2	0.2%	1.8%	1.1%	95.7%	0.0%	0.0%	1.1%
3	0.2%	1.8%	1.1%	95.8%	0.0%	0.0%	1.1%
4	0.2%	1.5%	1.0%	96.2%	0.0%	0.0%	1.0%
5	0.2%	1.1%	0.9%	96.6%	0.0%	0.0%	1.1%
6	0.1%	0.7%	0.9%	96.9%	0.0%	0.0%	1.3%
7	0.1%	0.5%	0.9%	97.0%	0.1%	0.0%	1.5%
8	0.1%	0.4%	0.9%	97.0%	0.1%	0.0%	1.6%
9	0.0%	0.4%	1.0%	97.0%	0.1%	0.0%	1.6%
10	0.0%	0.4%	1.0%	96.9%	0.1%	0.0%	1.6%
11	0.0%	0.4%	1.0%	96.9%	0.0%	0.0%	1.6%
12	0.0%	0.4%	1.0%	96.9%	0.0%	0.0%	1.6%

Figure 2. The forecast error variance decomposition of broad money

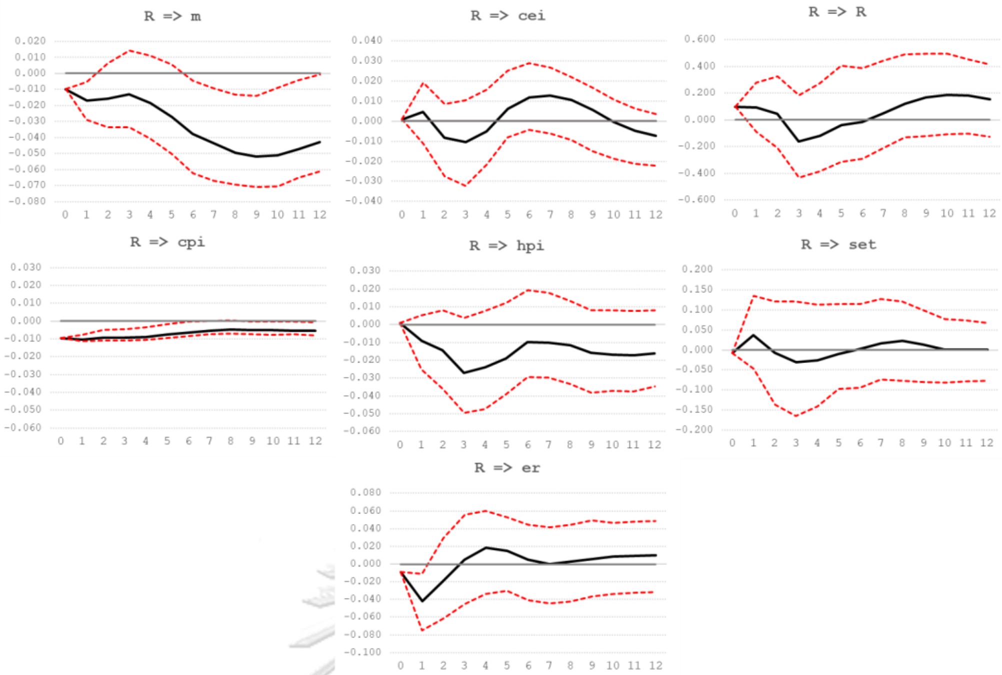

Figure 3. The IRFs to one percentage point increase in the magnitude of shock in interest rate

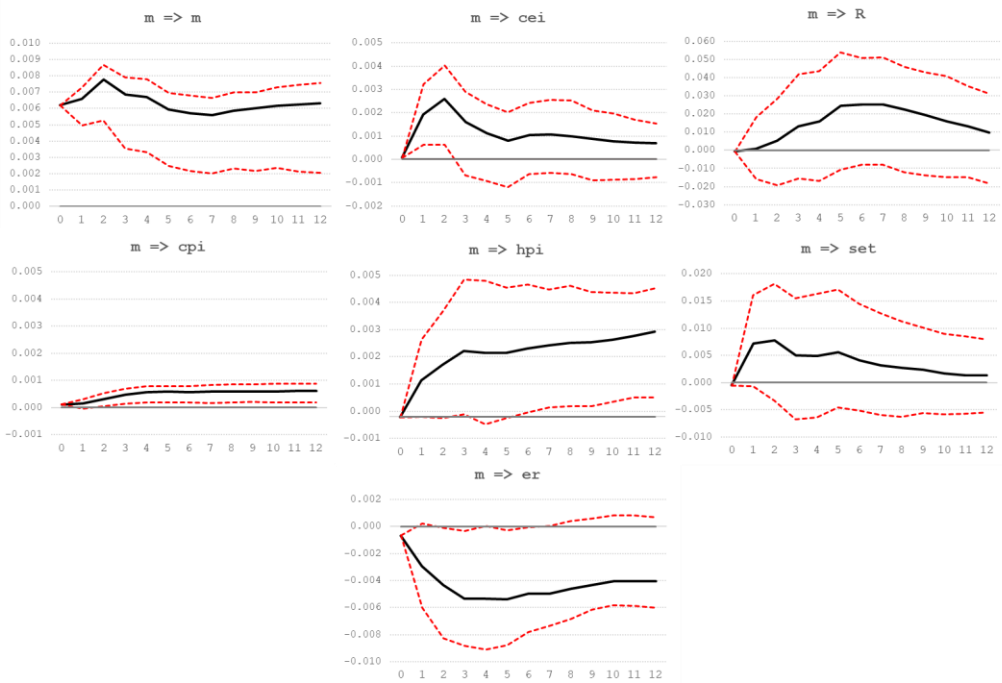

Figure 4. The IRFs to one percent increase in the magnitude of shock in broad money

5.4 Impulse Response Functions to Shock in Broad Money

According to Figure 4, real output significantly increases in response to shock in broad money within a period of 2 months. After that, real output is no longer affected by the shock. The response of goods price also increases and is more persistent than that of the output. Economically, when the size of the shock increases by 1%, unexpectedly, the output and price level will increase within 2 months by 0.0026% and 0.0003%, respectively. This is in line with IS/LM framework in a way that when people have additional liquidity, they can invest and consume more and so the output rises. However, in the long run, the price level will increase until it brings down the demand back to initial level, that is before the shock in money supply had occurred.

The exchange rate quoted in THB per one USD slightly appreciates following the money supply shock before being unaffected by it after 7 months. This is counterintuitive response because, when there is more money put into the economy, Thai currency should depreciate. On the other hand, the policy interest rate and the stock price (SET) barely move in response to the shock in liquidity. As previously mentioned, stock market participants gather information from various sources, so shock in money supply may not affect their stock price valuation. For policymakers, it is possible that they will increase the rate when there is too much liquidity in the system. However, the result shows that the response of policy interest rate is still insignificant which can be because policymakers look at other macroeconomic variables as well before adjusting their rate.

The house price in Thailand only significantly increases in response to the shock after 6 months while the goods price takes only 2 months. This result just provides strong evidence to statistically reject the hypothesis that the money supply shock has less effect on goods price than asset price with inelastic supply. One possible explanation is that housing market in Thailand has been overly supplied for years. The excess housing inventories therefore act as a buffer to absorb rising demand due to shock in liquidity. As a result, the response of house price is slower than the good prices. However, the hypothesis can still be partly appreciated by the fact that the magnitude of change in house price is much larger than the goods price. To illustrate, the 95% upper bound of the response of CPI in month 12 economically means that the CPI in month 12 will not increase by more than 0.0009% when the magnitude of the shock in money supply increase by 1.0%. On the contrary, the same magnitude of the shock can lead to an increase in house price from 0.0007% to 0.0047%, which is much larger than the response of the goods price.

6. Conclusion

In this paper, an SVAR model is developed to capture the dynamic relationship between broad money and other macroeconomics variables using Thai data. The novel structural restriction imposed on the model involves the finding that broad money does not react contemporaneously to a shock in short-term rate. In addition, this study controls for the wealth transmission through three forms of assets including bonds, stocks, and housings. The contemporaneous relationship in the SVAR model is exactly identified based on macroeconomic theories.

It is observed from the forecast error variance decomposition that the variance of shock in goods price is the main factor contributing most to the total variance of forecast error in broad money. The fraction of variance due to shock in interest rate is only about 1%. In addition, the impulse response function displays that one percentage point shock in policy interest rate leads to a slight decrease in broad money for just one month. In contrast, large significant movement in broad money only starts after a period of six months.

In response to an unexpected change in broad money, the real output significantly increases within two months while goods price and house price move in line with the real output. The policy interest rate and stock price have no significant response to shock in broad money. There is one counterintuitive response as Thai currency slightly appreciates following the shock. Therefore, it can be concluded that the model contains exchange rate puzzle but no price puzzle when the impulse variable is broad money.

The difference response of house price and goods price to a shock in money supply is observed in this study. Statistically, the goods price will significantly increase within three months while house price takes up to six months to materially increase. This seems to be in contrast with the hypothesis that the response of house price is faster than the goods price. However, the magnitude of response of the house price is much larger than that of goods price. Thus, the theory that house price is more affected by the liquidity shock can still be partly appreciated.

In summary, this paper provides alternative structural restrictions for SVAR model using Thai macroeconomic data. It contributes new findings on the role of money supply shock, which can be particularly important in the future as the policy interest rate is not far from zero now. There are also many areas left for future research from this paper. One could adjust the model to include other assets, such as gold or cryptocurrencies, to study its price response. Another potential topic could be allowing the SVAR model to have time-varying coefficients or SVAR with GARCH effect.

Appendix A

Model Construction

The process of selecting the appropriate model for this paper will be illustrated. At first, there are two models to be considered, namely Baseline Model, which is eventually employed in this paper, and Model B. The difference between each model is shown in Table A-1. Generally, Model B has eight endogenous variables in the system whereas the other contains only seven. The process of choosing the optimal number of lags is preliminarily done by using AIC criterion. The VAR models are estimated, and their error terms are tested for serial correlation using ACF and PACF. Eventually, the models need four lags to eliminate serial correlation in the error terms.

Next, the VAR stability test suggests that all models contain one root that lies outside unit circle. The Johansen's cointegration test provides evidence that three cointegrations exist in baseline model and Model B as illustrated in Figure A-1. On the contrary, seven cointegrations are reported for Model B as displayed in Figure A-2. The identifications for contemporaneous relationships are shown by matrix A for each model. Specifically, Model B does not allow short-term rate to contemporaneously affect the goods price. In addition, all other variables have no immediate effect on the federal fund rate.

Table A-1. Specification of models under consideration

Specification	Baseline	Model B
Endogenous Variables	$m, cei, R, cpi, hpi, set, er$	$m, cei, R, cpi, hpi, set, er, FFR$
Exogenous Variable	FFR	-
Number of Lags	4	4
Number of Unstable Root	1	1
Number of Cointegration	3	7
Identification Type	Exact-identification	Over-identification
Matrix $\boldsymbol{A}$	$\begin{bmatrix} 1 & a_{12} & . & -1 & . & . & . \\ . & 1 & . & . & . & . & a_{27} \\ a_{31} & a_{32} & 1 & . & . & . & a_{37} \\ . & a_{42} & a_{43} & 1 & . & . & a_{47} \\ . & a_{52} & . & a_{54} & 1 & . & . \\ a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & 1 & a_{67} \\ a_{71} & a_{72} & a_{73} & a_{74} & a_{75} & . & 1 \end{bmatrix}$	$\begin{bmatrix} 1 & a_{12} & . & -1 & . & . & . & . \\ . & 1 & . & . & . & . & a_{27} & a_{28} \\ a_{31} & a_{32} & 1 & . & . & . & a_{37} & . \\ . & a_{42} & . & 1 & . & . & a_{47} & a_{48} \\ . & a_{52} & . & a_{54} & 1 & . & . & . \\ a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & 1 & a_{67} & a_{68} \\ a_{71} & a_{72} & a_{73} & a_{74} & a_{75} & . & 1 & a_{78} \\ . & . & . & . & . & . & . & 1 \end{bmatrix}$
Over-identification Test	-	Invalid

```
######################
# Johansen-Procedure #
######################

Test type: trace statistic , without linear trend and constant
 in cointegration

Eigenvalues (lambda):
[1]  3.617827e-01  2.453347e-01  2.158870e-01  1.546539e-01
[5]  1.180988e-01  6.874806e-02  2.796574e-02 -4.432049e-16

Values of teststatistic and critical values of test:

          test  10pct   5pct   1pct
r <= 6 |   3.63   7.52   9.24  12.97
r <= 5 |  12.75  17.85  19.96  24.60
r <= 4 |  28.83  32.00  34.91  41.07
r <= 3 |  50.34  49.65  53.12  60.16
r <= 2 |  81.47  71.86  76.07  84.45
r <= 1 | 117.50  97.18 102.14 111.01
r = 0  | 174.98 126.58 131.70 143.09
```

Figure A-1. Johansen test for baseline model

```
######################
# Johansen-Procedure #
######################

Test type: trace statistic , without linear trend and constant
 in cointegration

Eigenvalues (lambda):
[1]  3.465432e-01  2.696564e-01  2.276302e-01  1.836129e-01
 1.424302e-01
[6]  1.305619e-01  1.057513e-01  4.576470e-02 -1.315750e-15

Values of teststatistic and critical values of test:

          test  10pct   5pct   1pct
r <= 7 |   6.00   7.52   9.24  12.97
r <= 6 |  20.30  17.85  19.96  24.60
r <= 5 |  38.21  32.00  34.91  41.07
r <= 4 |  57.88  49.65  53.12  60.16
r <= 3 |  83.85  71.86  76.07  84.45
r <= 2 | 116.91  97.18 102.14 111.01
r <= 1 | 157.13 126.58 131.70 143.09
r = 0  | 211.59 159.48 165.58 177.20
```

Figure A-2. Johansen test for Model B

There are two reasons that Model B is dropped from the consideration. First, the over-identification test is rejected which means that the imposed restrictions are not valid. Second, the impulse response generates counterintuitive result as shown in Figure A-3. To illustrate, the federal fund rate immediately increases following the shock in house price and stock price. This does not seem to be possible that the movement of variables from small open country can affect the interest rate in US.

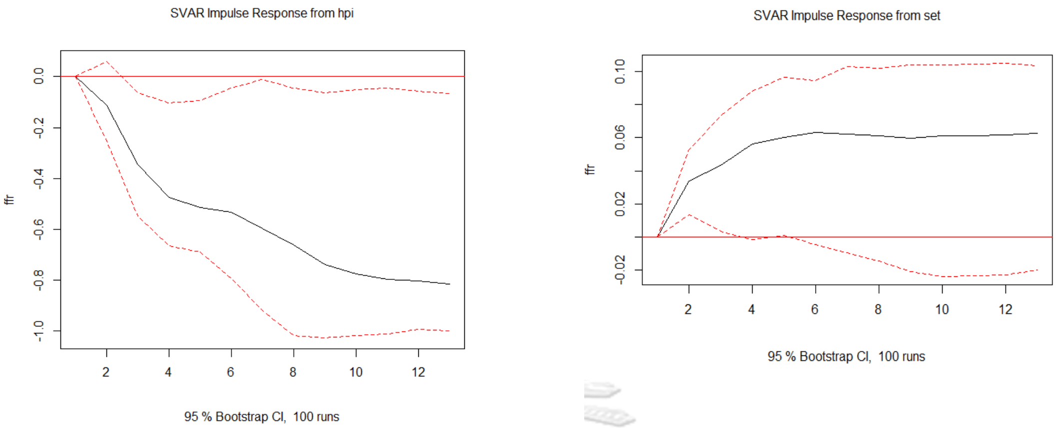

Figure A-3. The response of federal fund rate when impulse variables are house price and stock price.

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