MONETARY POLICY SHOCK ANALYSIS USING

STRUCTURAL VECTOR AUTOREGRESSION

(Digital Signal Processing Project Report)

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Abstract

A wide variety of theoretical and empirical models have been employed to analyse the relationship between monetary policy and stock prices. These have provided some evidence to justify that monetary policy can impact asset prices and vice versa. We aim to analyse the interaction between monetary policy and asset prices in India, using structural VARs, as given in Bjornland and Leitemo (2009). Their results indicate great interdependence between stock prices and interest rate in the United States. We follow a similar methodology here because the behaviour of the US Stock Index is similar to the Indian Stock Indices, over the years. Annual frequency of data is used. The first data is the Stock Index of India, which we've taken to be NIFTY. The second data is the MIBID or the Mumbai Interbank Bid Rate. This is the interest rate that a bank participating in the Indian interbank market would be willing to pay to attract a deposit from another participant bank.This paper seeks to explore the extent of interdependence that exists between stock prices and monetary policies in India. A structural VAR model is employed in the study.

Introduction

This paper estimates the relationship between monetary policy and stock prices for the Indian economy. The present literature has studied the response of changes in monetary policy to asset prices in the United States of America. No significant work has been done to capture the relation of monetary policy and stock prices for the Indian economy.

Central Banks are known to keep inflation in check and decide the Interest Rate at which other banks accept loans known as Repo Rate in the Indian economy. Interest rate and Inflation are closely linked; Interest rates are used by central banks to control Inflation and as Interest rates are lowered, more people are able to borrow more money which results in surplus money to spend for consumers causing increase in inflation and economic growth. Basically by lowering the interest rates, Central Banks attempts to increase the supply of money by making it easier to obtain.

On the other hand if Central banks increase the interest rates, it becomes more expensive for banks to borrow money from central banks as a result banks increase the rates that they charge their customers which leaves consumers with less money to spend. Not Just individuals but businesses also get affected because if a business is left with lower sum of money to spend and cuts back on growth or makes less profit, then future cash flow will drop which lowers the stock price of the company. If enough companies experience declines in their stock prices, the whole market or index like NIFTY goes down.

The financial crisis of 2007 -2008 saw the worst damage to world market caused by inflated asset price values, asset prices fizzled out of control largely because of insufficient monitoring of asset price movements. Any crisis raises questions of why and how we got there and what lessons should be drawn to avoid repetition of past developments without laying the ground for a new disaster.

The entire paper pans out as follows section three details a literature review of the previous work done on monetary policy and asset pricing .The next section explains in detail the Structural Vector Auto Regressions implemented on monthly data sets of MIBID(Interest

Rate),Market Closing Price, Gross Domestic Product and Inflation Rates. The next section summarizes data, data sources inferences derived from Vector Auto Regressions Implemented. Appendix collects the graphs and figures.

Literature Survey

Bernanke and Gertler (1999) estimated that goal of monetary policy should be price stability .But this notion was soon countered by Cecchetti, Genberg, Lipsky, and Wadhwani (2000) who recommended to central banks are responsible for stock price changes , But Cecchetti et al. (2000) suggested asset pricing must not be a direct goal of monetary policy decided by Central Banks whereas Goldhart(1999) says asset pricing contributes directly to price stability.

S. Gilchrist, J.V. Leahy (2002)[1] recommended asset prices and the economy as a whole can exhibit large fluctuations in response to these shocks. They did not find a strong case for including asset prices in monetary policy rules. Research by Hilde C. Bjørnland , Kai Leitemo (2005)[2] supports the idea that monetary policy making is indeed important for the stock market N. Cassola, C.

Morana (2004)[3] estimated that asset prices contain information that is useful for the conduct of monetary policy in the euro area and a price stability oriented monetary policy may have a beneficial impact also on the stock market.

Modelling using VARs

To study the interdependence of the monetary policy in India and the stock prices, we make use of the mathematical models known as Structural VARs. We make use of and estimate this model using four variables, namely, Real GDP, Inflation, Stock Market Index (NIFTY in this case) and the MIBID, the Mumbai Interbank Bid Rate. This is the rate that banks involved in the Indian interbank market are willing to pay for the purpose of attracting

deposits from other participating banks.

Mathematical Background

We start with an underlying structural equation of the form

$$Ay_t = C(L)y_t + Bu_t$$

where the structural shocks u_t are normally distributed, i.e, $u_t \ N(0, I)$. Unfortunately, we cannot estimate this equation directly due to identification issues, but instead we have estimated an unrestricted VAR of the form:

$$y_t = A^{-1}C(L)y_t + A^{-1}Bu_t$$

Matrices A, B and the Cj's are not separately observable. So, we impose restrictions on our VAR to identify an underlying structure. The restrictions are a causal ordering of shock propagation; the Choleski decomposition.

Imposing short-run restrictions

To impose short-run restrictions, we use equation

$$y_t = A^{-1}C(L)y_t + A^{-1}Bu_t$$

We estimate the random stochastic residual

$$A^{-1}Bu_t$$

from the residual ϵ_t of the estimated VAR:

$$A^{-1}Bu_t = \epsilon_t$$

Reformulating equation (3), we have $A^{-1}Bu_tu_tB(A^{-1}) = \epsilon_t\epsilon_t$, and, since $E(u_tu_t) = I$, we have:

$$A^{-1}BB'(A^{-1})' = E(\epsilon_t\epsilon_t') = \Omega$$

Equation (4) says that for K variables in y_t, the symmetry property of $E(\epsilon_t\epsilon_t')$ imposes $K(K + 1)/2$ restrictions on the $2K^2$ unknown elements in A and B. Thus, an additional $K(3K - 1)/2$ restrictions must be imposed on A and B to identify the full model. Such restriction schemes must be of the form:

$$A\epsilon_t = Bu_t$$

This is also known as the AB model. We use an A-model, where $B = I$, in which case

$$A\epsilon_t = u_t$$

. For example, the restrictions may be imposed as follows:

$$A = \begin{bmatrix} 1 & 0 & 0 \\ a_{21} & 1 & 0 \\ a_{31} & a_{32} & 1 \end{bmatrix}, B = \begin{bmatrix} b_{11} & 0 & 0 \\ 0 & b_{22} & 0 \\ 0 & 0 & b_{33} \end{bmatrix}$$

Structural VAR

We first define a vector of variables. Let X_t be the vector of the four macroeconomic variables. Then,

$$X_t = [y_t, \pi_t, \Delta s_t, r_t]'$$

where y_t is the log of the differenced Real GDP, π_t is the change in the log of the consumer price index - otherwise known as inflation, Δs_t is the log of the differenced NIFTY index, deflated by the CPI, and r_t is the MIBID. The order of the variables in this vector is paramount. This has to do with the interdependence of the variables. Changing the order changes the results vastly.

The VAR can be written as a reduced-form, in the following moving average (MA) notation as,

$$X_t = A(L)v_t \tag{1}$$

where

$$A(L) = \sum_{j=0}^{\infty} A_j L^j = I + a_1 L + a_2 L + ... + a_\infty L^\infty$$

is the matrix lag polynomial in the lag operator L. v_t is a $4 - dimensional$ vector of reduced-form residuals with covariance matrix Ω. We assume that the orthogonal structural disturbances (ϵ_t) can be written as linear combinations of the innovations v_t. Hence, $v_t = D\epsilon_t$ where

$$\epsilon_t = [\epsilon_t^y, \epsilon_t^\pi, \epsilon_t^s, \epsilon_t^r]'$$

is the vector of uncorrelated structural shocks; ϵ_t^s is the stock price shock ϵ_r^t is the monetary policy shock, ϵ_y^t output shock and ϵ_π^t is the shock from inflation. Since we have a 4-variable VAR, we can identify these four structural shocks. D is a lower diagonal (4×4) contemporaneous impact matrix. This model will be identified using a diagonal form on the variance-covariance matrix of the structural shocks and a lower triangular form on the contemporaneous impact matrix D.

Substituting v_t in equation (1), we get,

$$A_t = B(L)e_t \tag{2}$$

where

$$B(L) = A(L)Q$$

Assuming e_t is normalised with variance 1, the matrix D can be identified. The VAR model can now be written in terms of these structural shocks stated above. In this model, we make the assumption that the Real GDP and Inflation can respond with a lag to monetary policy and stock price shocks while stock prices and monetary policy can respond to one other contemporaneously. We can identify the monetary policy shock by putting output and inflation before interest rates and stock prices in the VAR and impose two zero restrictions on the relevant coefficients in the third and fourth columns of the D matrix below. This is why the order of the variables in the vector was deemed important. Changing the order changes the interdependence of the variables and hence the structural shocks of the model. Therefore,

$$
\begin{bmatrix} y_t \\ \pi_t \\ \Delta s_t \\ r_t \end{bmatrix} = A(L) \begin{bmatrix} D_{11} & 0 & 0 & 0 \\ D_{21} & D_{22} & 0 & 0 \\ D_{31} & D_{32} & D_{33} & 0 \\ D_{41} & D_{42} & D_{43} & D_{44} \end{bmatrix} \begin{bmatrix} \epsilon_t^y \\ \epsilon_t^\pi \\ \epsilon_t^s \\ \epsilon_t^r \end{bmatrix} \tag{3}
$$

We follow Bjornland and Leitemo (2009) by imposing the restriction that monetary policy has no effect on real stock prices in the long run. We apply this restriction by setting an infinite number of lag coefficients in equation (2). Therefore, in the long run, $\sum_{j=0}^{\infty} A_j D = \sum_{j=0}^{\infty} B_j$. This means the additional restriction that $\sum_{j=0}^{\infty} B_{34,j} = 0$. Hence, the equation $A_{31}(1)D_{14} + A_{32}(1)D_{24} + A_{33}(1)D_{34} + A_{34}(1)D_{44} = 0$. Since $D_{14} = D_{24} = 0$, equation becomes $A_{33}(1)D_{34} + A_{34}(1)D_{44} = 0$. Now, Cholesky decomposition can be applied.

Results and Data

Data

The data that has been used is of annual frequency, because of lack of availability of more frequent data, from 2000 to 2015. The graphs of the variables with respect to time are given below. Here $t = 0$ represents starting date.
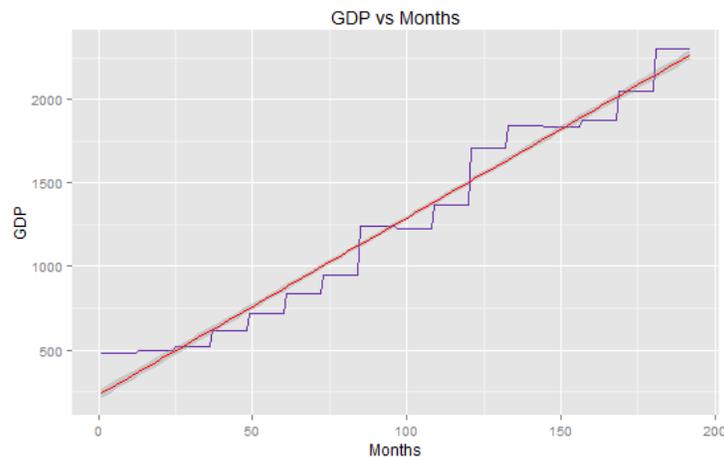
Figure 1: NIFTY Index

Figure 2: GDP

The variables whose time series' were not stationary were differenced to achieve stationarity. The Augmented Dickey Fuller and the Phillips Perron unit root tests are used to
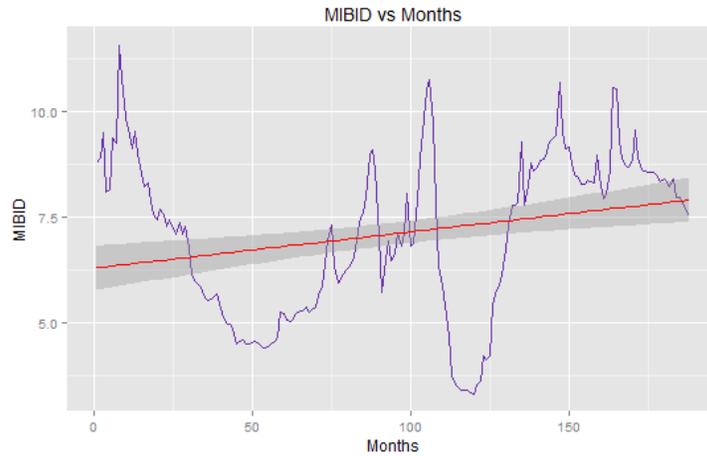
9

Figure 3: MIBID

ensure that the variables are stationary, which is a necessary condition to guarantee that the MA representation of the VAR model converges. The variables were stationary after first differencing. The appropriate lag lengths were chosen according to the Akaike Info Criterion, Final Prediction Error, Hannan-Quinn Criterion and Schwarz Criterion information criterions. Real GDP and Inflation data were annual, whereas the NIFTY index and MIBID were averaged over a year. The estimated value of the coefficients of the VARs and SVARs are given in Appendix 2.

As can be seen from the graph below, the NIFTY Index has a definite upward trend, which implies non-stationarity of the data,

This non-stationarity can be removed by removing the upward trend, which gives the following data

Empirical results

The analysis in this section is done through the Impulse Response functions that were obtained. The Impulse response estimates are given in Appendix 1 and their corresponding graphs are given in Appendix 2. To look at the changes in the variables according to monetary policy shocks, we look at the graphs where the impulses are MIBID and to look at

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Figure 4: NIFTY Index with upward trend

Figure 5: Detrended NIFTY Index

the changes in the variables in response to a stock price shock, we look at the graphs where the impulse variable is MIBID. The graphs show the impulse responses of a monetary policy shock with a standard error band.

Figure 3(a), Figure 3(b), Figure 3(c), Appendix 2 show the responses to monetary policy shocks. A monetary policy shock first increases the output, which then decreases back to its mean value. However, the response of the output to stock price shocks, though similar in behaviour is smaller in comparison and approaches its mean quicker. The stock prices respond to monetary policy shocks with an initial increase, after which it moves back to its mean. This is different from the results obtained in the USA (see Bjornland and Leitemo, 2009); a positive monetary policy shock causes stock prices to fall in the short run and increase in the long run in the USA. Even though the short-run effect is different, the long-run effect is similar A monetary policy shock also decreases the inflation, but in the long run the inflation slowly approach its mean.

Figure 4(a), Figure 4(b), Figure 4(c) graph the responses to stock price shocks. The output behaves much like it behaves to monetary policy shocks. Since NIFTY is smaller Index, the percentage change compared to monetary policy shock is also smaller. Inflation increases initially with a stock price shock and then approaches the mean in the long run, which is expected because positive changes in the stock prices have a chain effect which ultimately causes inflation to rise, but this increase in the inflation wears out over time. A shock in the stock prices decreases the interest rate, which is an expected result, consistent with the findings in the USA(see Bjornland and Leitemo, 2009).This is an inverse result of the one found out as the response of stock price to a interest rate impulse.
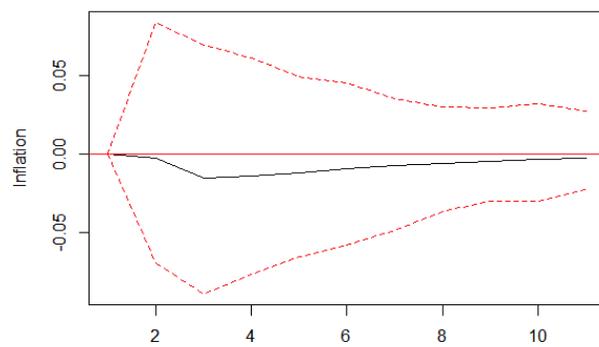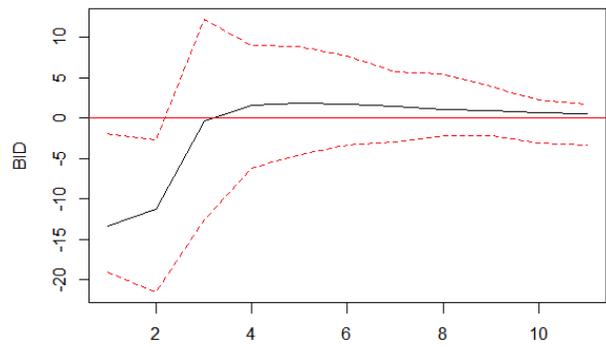
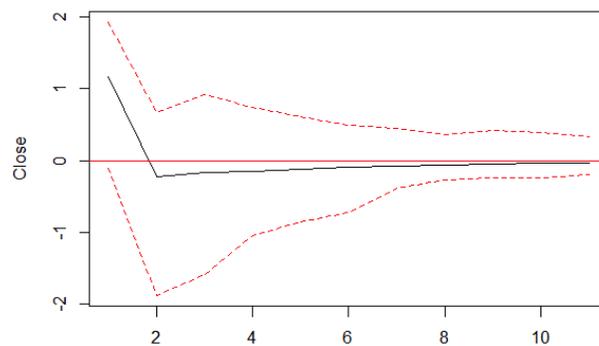# Appendix 1: Graphs
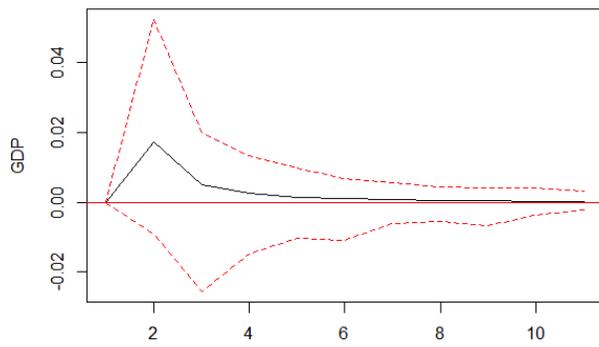
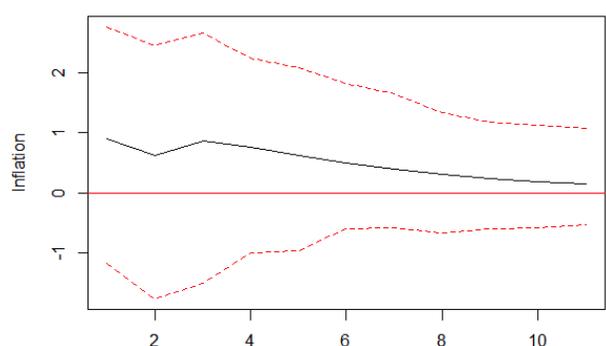(a) Impulse:MIBID Response:Real GDP
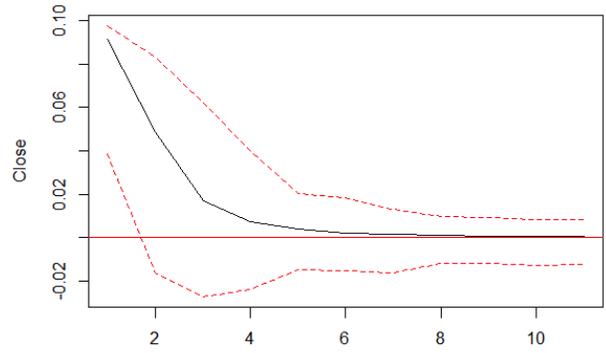
(b) Impulse:MIBID Response:NIFTY Index

(c) Impulse:MIBID Response:Inflation

(d) Impulse:GDP Response:BID
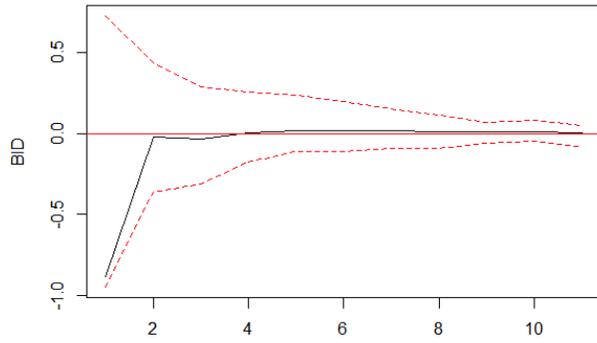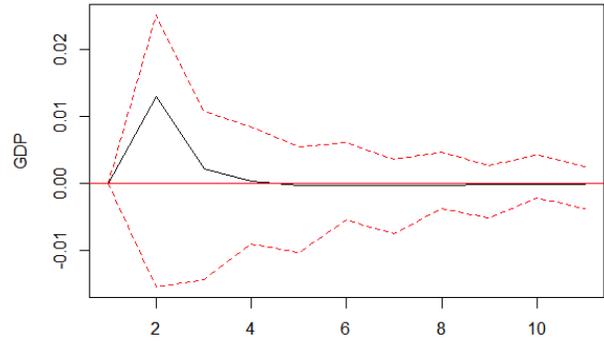
(e) Impulse:GDP Response:NIFTY Index

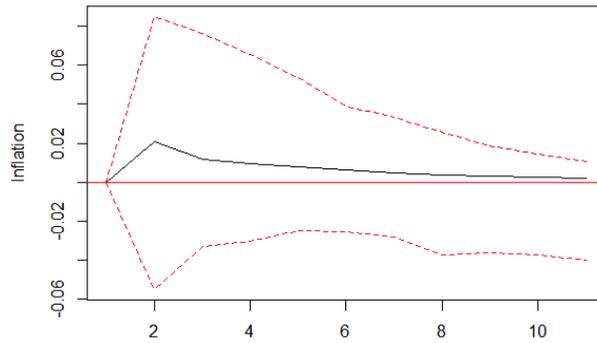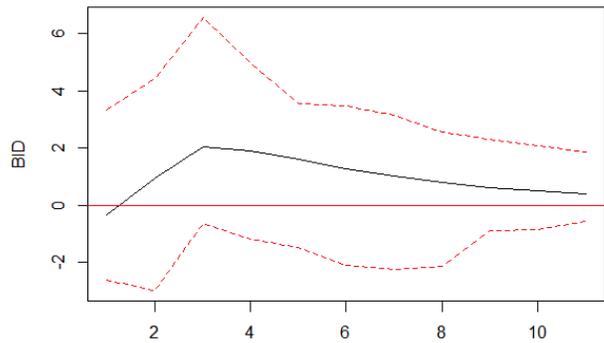(f) Impulse:GDP Response:Inflation

Figure 6: Impulse Response Graphs
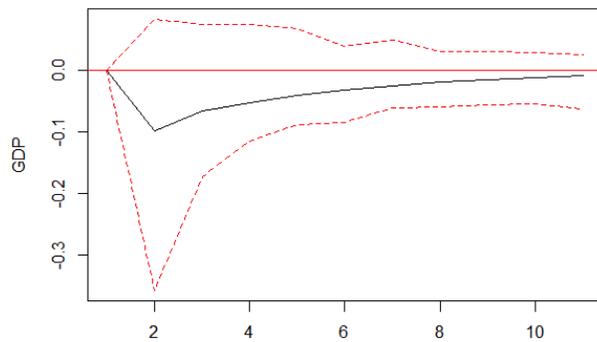
(a) Impulse:NIFTY Index Response:MIBID
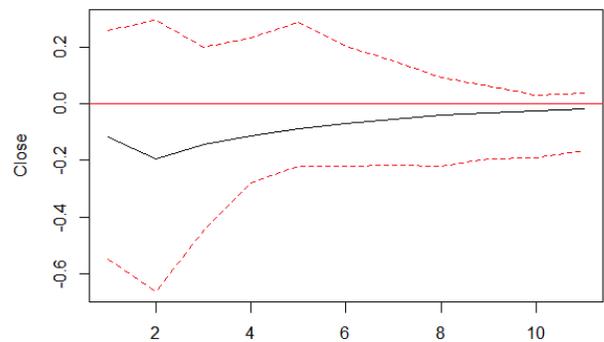
(b) Impulse:NIFTY Index Response:Real GDP

(c) Impulse:NIFTY Index Response:Inflation

(d)Impulse:Inflation Response:MIBID

(e) Impulse:Inflation Response:Real GDP

(f) Impulse:Inflation Response:NIFTY Index

Figure 7: Impulse Response Graphs

Appendix 2: Estimates and Tables

The graphs and the estimates have been calculated using R. The scripts and the methodology are available at the following Github repository: `https://github.com/ronitkishore/MonetaryPolicy-StructuralVARs-R`

```
VAR Estimation Results:
=======================

Estimated coefficients for equation GDP:
========================================
Call:
GDP = GDP.l1 + Inflation.l1 + Close.l1 + BID.l1 + const

      GDP.l1 Inflation.l1     Close.l1       BID.l1        const
-0.288102246 -0.075141468  0.184253789  0.003930588  0.229217505


Estimated coefficients for equation Inflation:
==============================================
Call:
Inflation = GDP.l1 + Inflation.l1 + Close.l1 + BID.l1 + const

      GDP.l1 Inflation.l1     Close.l1       BID.l1        const
-0.445864156  0.828736955 -0.002913912 -0.023586596  0.557706004


Estimated coefficients for equation Close:
==========================================
Call:
Close = GDP.l1 + Inflation.l1 + Close.l1 + BID.l1 + const

      GDP.l1 Inflation.l1     Close.l1       BID.l1        const
-0.622500377 -0.131553963  0.525476740  0.007185057  0.339300311


Estimated coefficients for equation BID:
========================================
Call:
BID = GDP.l1 + Inflation.l1 + Close.l1 + BID.l1 + const

      GDP.l1 Inflation.l1     Close.l1       BID.l1        const
 -11.6490751    1.3198160    2.2962439    0.2561764    3.6268386
```

Figure 8: VAR Estimates

```
SVAR Estimation Results:
========================


Estimated A matrix:
              GDP Inflation Close    BID
GDP        1.0000    0.0000 0.000  0.000
Inflation -0.9015    1.0000 0.000  0.000
Close    -14.7821   -0.2288 1.000 -1.031
BID        0.4747    1.5221 9.949  1.000

Estimated B matrix:
          GDP Inflation Close BID
GDP         1         0     0   0
Inflation   0         1     0   0
Close       0         0     1   0
BID         0         0     0   1
```

Figure 9: SVAR Estimates

```
$BID
               GDP     Inflation        Close          BID
 [1,] 2.816468e-18  0.000000000 0.0915796974   0.08884060
 [2,] 1.722310e-02 -0.002362302 0.0487613257   0.23304819
 [3,] 5.115968e-03 -0.015275791 0.0168867898  -0.03208166
 [4,] 2.659279e-03 -0.014233149 0.0074680056  -0.04919990
 [5,] 1.485979e-03 -0.011842516 0.0037877842  -0.04521877
 [6,] 9.819273e-04 -0.009421356 0.0022984003  -0.03582653
 [7,] 7.077087e-04 -0.007407304 0.0015785068  -0.02777323
 [8,] 5.343840e-04 -0.005803772 0.0011638276  -0.02151064
 [9,] 4.120369e-04 -0.004544091 0.0008878641  -0.01672308
[10,] 3.206018e-04 -0.003557716 0.0006876958  -0.01304252
[11,] 2.504117e-04 -0.002785731 0.0005361138  -0.01019231
$Close
               GDP    Inflation        Close          BID
 [1,] -7.510582e-18 0.000000000  0.0888406013 -0.883907145
 [2,]  1.289494e-02 0.020589487  0.0403327461 -0.022436494
 [3,]  2.081086e-03 0.011725550  0.0102969772 -0.036173700
 [4,]  2.744324e-04 0.009612725  0.0023128922  0.005610358
 [5,] -3.531677e-04 0.007704992 -0.0001797446  0.016238351
 [6,] -4.465084e-04 0.006160393 -0.0007715533  0.018030394
 [7,] -4.055525e-04 0.004881400 -0.0008083564  0.016179282
 [8,] -3.353036e-04 0.003846959 -0.0006982343  0.013455428
 [9,] -2.682290e-04 0.003022284 -0.0005675840  0.010826902
[10,] -2.118449e-04 0.002370556 -0.0004510810  0.008583765
[11,] -1.664682e-04 0.001857874 -0.0003553403  0.006759661
```

Figure 10: Impulse response coefficients

References

(1) Gilchrist, S.; Leahy, J. V. *Journal of Monetary Economics* **2002**, *49*, 75–97.

(2) Bjørnland, H. C.; Leitemo, K. *Journal of Monetary Economics* **2009**, *56*, 275–282.

(3) Cassola, N.; Morana, C. *Journal of Policy Modeling* **2004**, *26*, 387–399.