วารสารเศรษฐศาสตร์ธรรมศาสตร์ Thammasat Economic Journal
ปีที่ 27 ฉบับที่ 2 มิถุนายน 2552 Vol.27, No.2, June 2009

An Analysis of the Real Interest Rate and Monetary Policy under Regime Shifts

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Abstract

The real interest rate plays a central role in macroeconomic theory and the transmission mechanism of monetary policy. This paper extends Garcia and Perron's (1996) time series analysis of the U.S. real interest rate to better understand its dynamics over the postwar period. Using a three-state Markov Switching model and a Hamilton filter estimation approach, the means and variances of the real interest rate series are found to be different over the time periods 1954-1973, 1973-1981, 1981-1986, 1986-2002, and 2002-2006. To examine whether a change in the conduct of monetary policy might have been the major driving force behind these shifts in the real interest rate series, a three-variable recursive Vector Autoregression (VAR) model comprising of the unemployment rate, price inflation and the short term interest rate is used to examine the nature of monetary policy over the five different time periods. Based on the impulse response analyses of the VAR, we cannot conclude that monetary policy is the main determinant

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Email: pymm@u.washington.edu. The author would like to thank Professor Chang-jin Kim, Department of Economics, University of Washington for his insightful comments and suggestions, as well as making available his computer program for the estimation of the three-state model. Her special thanks go to Professor Supachit Manopimoke, Ritsumeikan Asia Pacific University, Japan for the encouragement, valuable comments and continuing support she provided during the course of preparing the paper. Any errors are the sole responsibility of the author.

behind real interest rate fluctuations. As shifts in preferences and technology have been suggested to affect the dynamics of the real interest rate as well, a joint investigation of the real interest rate, monetary policy, and output trend growth rate might be able to better explain the causes for regime shifts in the U.S. real interest rate.

Keywords: Nonstationary series, real interest rate, unit root, stochastic process, vector autoregressions, monetary policy.

JEL Classification System: C22, C32, E52, E58.

บทคัดย่อ

ค่าอัตราดอกเบี้ยที่แท้จริง (Real interest rate) เป็นประเด็นที่สำคัญในทฤษฎีเศรษฐศาสตร์มหภาคและมีบทบาทเด่นมากในนโยบายทางการเงิน บทความนี้ขยายจำนวนเวลาของข้อมูล (Time Series) ที่ Garcia and Perron (1996) ใช้ในการวิเคราะห์อัตราดอกเบี้ยที่แท้จริงของสหรัฐอเมริกา โดยมีจุดประสงค์จะตรวจสอบผลการศึกษาของบทความดังกล่าว และต้องการเพิ่มความเข้าใจเกี่ยวกับลักษณะเชิงพลวัตของค่าอัตราดอกเบี้ยที่แท้จริงในช่วงหลังสงครามโลกครั้งที่สอง การประมาณการค่าของตัวกลางทางคณิตศาสตร์ (Mean) และความเบี่ยงเบน (Variance) ของอัตราดอกเบี้ยที่แท้จริงในบทความนี้ใช้แบบจำลอง Three-State Markov Switching และ Hamilton Filter ส่วนการพิจารณาว่าการปรับเปลี่ยนนโยบายทางการเงินจะมีผลกระทบต่อการเปลี่ยนแปลงของค่าของอัตราดอกเบี้ยที่แท้จริงหรือไม่นั้น ใช้แบบจำลอง Three-Variable Recursive Vector Autoregression (VAR) ซึ่งประกอบด้วยตัวแปรอัตราการว่างงาน อัตราเงินเฟ้อ และอัตราค่าดอกเบี้ยระยะสั้น

บทความนี้พบว่าค่าของตัวกลางทางคณิตศาสตร์ (Mean) และความเบี่ยงเบน (Variance) ของอัตราดอกเบี้ยที่แท้จริง มีค่าที่แตกต่างกันในช่วงปี 1954-1973, 1973-1981, 1981-1986, 1986-2002 และ 2002-2006 อย่างไรก็ตาม เมื่อพิจารณาจาก Impulse Response Analysis ของ VAR บทความนี้ยังสรุปไม่ได้ว่านโยบายทางการเงินเป็นตัวแปรหลักที่ทำให้เกิดการปรับค่าของอัตราดอกเบี้ยที่แท้จริง ควรจะมีการศึกษาเพิ่มเติมเพื่อวิเคราะห์และพิจารณาถึงสาเหตุการปรับค่า

ของค่าอัตราดอกเบี้ยที่แท้จริงโดยใช้แบบจำลองร่วมที่ประกอบด้วย ค่าของอัตราดอกเบี้ยที่แท้จริง นโยบายทางการเงิน และแนวโน้มของอัตราเพิ่มของผลผลิต (Output trend growth rate) ในการอธิบายลักษณะเชิงพลวัตของค่าอัตราดอกเบี้ยที่แท้จริงให้ดียิ่งขึ้น ทั้งนี้เนื่องจากมีผลการศึกษาที่ชี้ให้เห็นว่าการเปลี่ยนแปลงของความพอใจ (Preference) และเทคโนโลยีมีผลต่อลักษณะเชิงพลวัตของค่าอัตราดอกเบี้ยที่แท้จริงด้วย

1. Introduction

The real interest rate is one of the most important variables in economics. It is essential that we understand the dynamics of the real interest rate, as it plays a prominent role in the transmission mechanism of monetary policy and is a central element in business cycle theory. Moreover, the investment behavior of firms and the consumption-savings behavior of households depend crucially on the real cost of borrowing or the real rate of return.

To gain a better understanding of the U.S. real interest rate behavior over the postwar period, this paper extends Garcia's and Perron’s work (1996) titled, “An Analysis of the Real Interest Rate Under Regime Shifts”. In their paper, Garcia and Perron used the Hamilton filter to characterize the time series behavior of the ex-post U.S. real interest rate during the period 1961 to 1986. The Markov switching model is used to allow for an arbitrary number of changes occurring at unknown dates in the real interest rate series, and by employing a thorough testing procedure, the authors show that the real interest rate series during this time period would be best characterized by three states. By allowing three regime shifts, the authors find that the ex-post real interest rate in each period is random with means and variances that are different for the periods 1961-1973, 1973-1981, and 1981-1986.

The timing and source of the fluctuations in the real interest rate series during the time period studied by Garcia and Perron is somewhat contentious. Garcia and Perron attribute the endogenously determined shifts in the real interest rate series in 1971 and in the middle of 1981 to the sudden jump in oil prices and the rise of the federal budget deficit respectively. The exact date and interpretation of the second shift however, contrasts with Huizinga’s and Mishkin’s (1986) study. By using the maximum likelihood approach suggested by Quandt (1958, 1960), they identify the shifts to be at October 1979 and October 1982. The authors argue that their reported regime shifts in the real interest rate are a monetary phenomenon rather than a fiscal one, as these dates correspond with the well-documented changes in the Federal Reserve's operating procedures. Although the authors are merely ascribing a historical event to fit their results, they looked towards other similar "controlled experiments" that have caused a change in the characteristics of the real interest rate series to support their claim. They find that there is a regime shift that corresponds to a similar disinflationary monetary policy regime enacted by the Federal Reserve Board (Fed) in the 1920s. Huizinga and Mishkin argue that the striking correspondence between the impact of the change in monetary policy on the real interest rates in 1920 and later in 1979 provides strong support for the view that the latter shift in the real interest rate behavior is due to changes in monetary policy, especially because high deficits were not a feature of the 1920s.

Following Huizinga's and Mishkin's study, Walsh (1988) criticizes their approach as flawed, in the sense that their model cannot distinguish between shifts in the real rate process and shifts in the inflation process. He modifies the equation estimated by Huizinga and Mishkin, and finds the dates of the shift in the real interest rate to be October 1979 and April 1983. Walsh argues that changes in the conduct of monetary policy may not be the only force at work as Huizinga and Mishkin have claimed. Alternative explanations may be the rise in the level of federal budget deficits in the 1980s or a shift in the inflation process in 1983. In fact, Garcia's and Perron's study of the inflation series supports Walsh's argument to some extent, as they find that the inflation rate process shifted from the high state to the intermediate state in the fourth quarter of 1982 with a probability of 0.62.

The unresolved debate surrounding the source of fluctuations in the real interest rate is the focus of this paper. Competing explanations for the change in the behavior of the real interest rates include changes in monetary policy, high budget deficits, investment booms, favorable changes in business taxation, or declining relative price of energy. To this date however, endogenously dated shifts determined by econometric models are merely given an economic interpretation by associating them with coinciding economic events. This paper will investigate whether changes in monetary policy can explain changes in the real interest rate series by examining the focus of the Fed within each time period following a shift in the real interest rate series. The three-variable recursive VAR approach of Stock and Watson (2001) that comprises of a short term interest rate, price inflation, and the unemployment rate will be used to examine policy responses to inflation and unemployment shocks. Under the assumption that the federal funds rate is an appropriate tool to measure monetary policy, if the response of the federal funds rate to inflation and unemployment shocks is observed to be different in each real interest rate regime, then changes in the real interest rate behavior may be attributed to shifts in monetary policy conduct.

The contents of the paper are organized into five sections. Following the introduction, Section 2 presents the statistical methodology used to characterize the ex-post real interest rate, as well as the estimation method followed by Garcia and Perron (1996). Section 3 reports estimation results for the quarterly ex-post real interest rate from 1961 to 1986, and compares it to Garcia's and Perron's findings. It also discusses the estimation results for the quarterly ex-post real interest rate for the extended time period of 1954 to 2006. Section 4 describes the three-equation VAR approach of Stock and Watson (2001), used to examine the nature of monetary policy within the different time periods following a shift in the real interest rate. Results are then presented and discussed. Section 5 concludes the paper.

2. The Model and the Estimation Method

Garcia and Perron (1996) describe the ex-post real interest rate with the following autoregressive specification of order 2[1]:

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[1] The authors performed various tests to verify that the autoregressive structure of order 2 is most suitable. They also showed that it was unnecessary to allow the autoregressive parameters ϕ_1 and ϕ_2 to differ in the three states.

$$y_t - \mu_{S_t} = \phi_1[y_{t-1} - \mu_{S_{t-1}}] + \phi_2[y_{t-2} - \mu_{S_{t-2}}] + e_t \qquad e_t \sim i.i.d.N(0, \sigma^2_{S_t}) \qquad (1)$$

where the mean μ and the variance σ^2 of the process depend on the regime at time t, indexed by S_t, a discrete valued state variable. The authors assume that the roots of $1 - \phi_1 z - \phi_2 z^2 = 0$ lie outside the unit circle[2].

The stochastic process of the variable S_t is defined as a three-state, first-order Markov process, where S_t can take on the values 1, 2 or 3[3]. The transition probability matrix can be written as:

$$P^* = \begin{bmatrix} P_{11} & P_{12} & P_{13} \\ P_{21} & P_{22} & P_{23} \\ P_{31} & P_{32} & P_{33} \end{bmatrix} \qquad (2)$$

where $P_{ij} = \Pr[S_t = j \mid S_{t-1} = i]$ with $\sum_{j=1}^{3} P_{ij} = 1$ for all i.

The state-dependent means and variances are defined linearly as:

$$\mu_{S_t} = \alpha_1 S_{1t} + \alpha_2 S_{2t} + \alpha_3 S_{3t} \qquad (3)$$

$$\sigma^2_{S_t} = w_1 S_{1t} + w_2 S_{2t} + w_3 S_{3t} \qquad (4)$$

where S_{it} takes the value 1 when S_t is equal to i and 0 otherwise.

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[2] The authors used the ex-post real interest rate from the Citibase data bank as one of their data sets. Perron (1990) rejected the unit root hypothesis for this series allowing for one change in regime at 1980:3.

[3] The choice of number of regimes was formally tested by the authors and they verified that the series was best characterized by three states, and not by one, two, or four states.

If the sequence of states $\{S_t\}$ from t=0,…,T were known, it would be possible to write the joint conditional log likelihood function of the sequence $\{y_t\}$ as:

$$\ln L = \sum_{t=1}^{T} \ln(f(y_t \mid I_{t-1}, S_t, S_{t-1}, S_{t-2})) \tag{5}$$

where

$$f(y_t | S_t, S_{t-1}, S_{t-2,} I_{t-1}) = \frac{1}{\sqrt{2\pi\sigma_{S_t}^{\;2}}} \exp(-\frac{\{(y_t - \mu_{S_t}) - \phi_1(y_{t-1} - \mu_{S_{t-1}}) - \phi_2(y_{t-2} - \mu_{S_{t-2}})\}^2}{2\sigma_{S_t}^{\;2}}) \tag{6}$$

in which the log-likelihood function could be used to estimate the 14 parameters

$\mu_1, \mu_2, \mu_3, \sigma_1^2, \sigma_2^2, \sigma_3^2, \phi_1, \phi_2, p_{11,} p_{12}, p_{21}, p_{22}, p_{31}, p_{32}$.

However, S_t is unobserved and therefore the Hamilton filter is employed to make an optimal inference about the current state based on the history of observed values for $y_{t.}$ In a recursive fashion, the Hamilton filter yields the following log-likelihood function:

$$f(y_T, \ldots, y_2) = \prod_{t=2}^{T} f(y_t \mid y_{t-1}, y_{t-2}, \ldots, y_0) \tag{7}$$

If given a specified number of states, the Hamilton filter can be used to estimate the parameters $\mu_1, \mu_2, \mu_3, \sigma_1^2, \sigma_2^2, \sigma_3^2, \phi_1, \phi_2, p_{11,} p_{12}, p_{21}, p_{22}, p_{31}, p_{32}$. In the three-state case, the limiting unconditional probabilities for each state is used for the construction of the probabilities in the first 2 observations (see Appendix). This can be specified as:

$$\pi_t = (A'A)^{-1} A' \begin{bmatrix} 0_3 \\ 1 \end{bmatrix} \tag{8}$$

where A = I-P, I is a 3x3 identity matrix, and 0_3 is a 3 x 1 matrix of zeros. P is as defined in (2), The Hamilton filter also provides a sequence of joint probabilities $P(S_t, S_{t-1}, S_{t-2}|y_t, y_{t-1},\ldots,y_0)$ which are the probabilities that the series is in state i, j, or k (i=1, j=2, k=3) at times t, t-1 and t-2 respectively, conditional upon the information available at time t. The filter probabilities, which are the probabilities of being in state 1, 2, or 3 at time t given the information available at time t, can be obtained by summing over the joint probabilities:

$$
\begin{aligned}
&P(S_t = j \mid y_t, y_{t-1},\ldots, y_0) \\
&\quad = \sum_{i=1}^{3}\sum_{k=1}^{3} p(S_t = j, S_{t-1} = i, S_{t-2} = k \mid y_t, y_{t-1},\ldots, y_0) \qquad j = 1,2,3.
\end{aligned}
\tag{9}
$$

The filter probabilities provide information about the regime in which the series is most likely to be at every point in the sample. They are therefore used to endogenously determine the dates of the various switches in the series.

3. Empirical Results and Discussion

The empirical analysis uses the ex-post real interest rate, which is the difference between the nominal interest rate (i_t) and the inflation rate (π_t), $r_t = i_t - \pi_t$. The ex-ante real interest rate is defined as $i_t - \pi^e_t$ where π^e_t is the market's expectation of inflation. If agents use available information efficiently to form expectations about the ex-ante real interest rate, the ex-post real interest rate is equivalent to the ex-ante real interest rate except for independent forecast errors. The ex-post real interest rate series thus allows us to investigate the dynamics of the ex-ante real interest rate under the assumption of rational expectations.

This section presents the estimation results obtained from the Hamilton filter[4] for the ex-post real interest rate series as specified by the model described in Section 1. For comparative

[4] The three-state model was estimated by Professor Chang-jin Kim's computer program. This Hamilton filter algorithm was written in the GAUSS programming language.

purposes, two data sets were used to examine the real interest rate series during Garcia's and Perron's (1996) period of study. The first data set was supplied by the authors, and is a quarterly series (1961:1-1986:3) at annual rates drawn from the Citibase data bank. It uses the U.S. 90-day Treasury bill rate for the nominal interest rate and a quarterly inflation rate series constructed from the U.S. CPI non-seasonally adjusted[5]. The second data set was also constructed from monthly series of the U.S. 90-day Treasury bill rate and the non-seasonally adjusted U.S. CPI, but these data sets were obtained from the Federal Reserve Bank of St. Louis (FRED). As mentioned above, the ex-post real interest rate is defined as $r_t = i_t - \pi_t$, and therefore, to construct the quarterly real interest rate series, the following steps were followed. First, the monthly nominal interest rate series and the U.S. CPI index series were converted into a quarterly data set by extracting end-of-quarter figures. Next, the annual inflation rate was calculated from the quarterly U.S. CPI series via the formula $\pi_t = \ln(CPI_{t+1}/CPI_t)*400$. Last, the inflation rate was subtracted from the nominal interest rate to form the real interest rate series. The real interest rate series for the extended data set of 1954:1 – 2006:4 was also constructed in the same fashion. Figures 1a and 1b presents the ex-post real interest rate over Garcia's and Perron's period of study (1961:1 – 1986:3) for the two data sets, and also the series constructed for the extended data set (1954:1 – 2006:4) respectively.

From the visual evidence in Figure 1a, the real interest rate series constructed from the monthly series obtained from FRED is very similar to the authors' data set. Since the nominal interest rate should be the same for both series, discrepancies in the values of the real interest rate might have been caused by a revision of the U.S. CPI series, especially since Garcia and Perron's paper was published 10 years ago. The similarity of the real interest rate series in Figure 1a gives confidence to the construction method used for the extended data set as shown in Figure 1b.

The estimation results of the quarterly ex-post real interest rate for the two data sets during the period 1961:1 – 1986:3 are shown in Table 1 with standard errors of estimates in

[5] They also estimated the model with seasonally adjusted data and found that their results were qualitatively similar and the conclusions were unchanged.

parentheses. Figure 2 shows the ex-post real interest rate series obtained from the Hamilton filter. From Table 1, it can be seen that the replicated results in this paper obtained from the Hamilton filter are satisfactory. There are some small discrepancies which could have been due to a different numerical optimizer used by the authors. The estimation results that differs the most are the variances in the low and high states (ω_1 and ω_3), which are slightly higher than the results reported by Garcia and Perron, but are reported with a large standard error.

An analysis of the estimation results in Table 1 include:

1) The volatility of the ex-post real interest rate is about the same in the low and high states, but significantly smaller in the middle state. Hence, volatility increases after 1973, irrespective of the level of the real interest rate. This heteroskedastic behavior of the series contrasts with some findings in previous literature (Bollerslev, 1988).

2) The parameters ϕ_1 and ϕ_2 are both close to zero, which suggests an absence of autocorrelation in the series once the shifts in mean and variance have been taken into account. Therefore, within each regime, the real interest rate is a random process around a mean. This finding resolves some debate regarding the constancy and stationarity of the real interest rate (Fama, 1975; Walsh, 1987; Rose, 1988).

Figure 3 shows the filter probabilities corresponding to the three states for the constructed real interest rate series with data obtained from FRED. They indicate the probability of being in the different states at each point in the sample. From the filter probabilities, it is evident that the real interest rate series switches between three distinct states over the time period 1961:1 – 1986:3. During 1961 to 1973, the series is in the middle state with a mean of 1.3%, from 1973 - mid 1981 the mean is a negative level of -1.6%, and from mid-1981 to the end of the sample the mean of the real interest rate is 5.5%. As mentioned in the introduction, Garcia and Perron (1996) attribute the 1973 shift to rising oil prices, and the shift in mid 1981 to rising budget deficits. The timing and interpretation of the second shift however, is subject to some controversy. Walsh (1988) contends that the rise in the real interest rate series in the 1980s could have been caused by a restrictive monetary policy, with a starting point in the last quarter of 1979.

This view was also supported by Huizinga and Mishkin (1986). The second cause of the rise in the real interest rate in the 1980s could have been due current and expected federal budget deficits, especially from the 1981-1982 recession. Garcia and Perron favor this second argument. Walsh also mentions that a shift in the inflation rate process could be responsible for the change of real interest rate behavior in the 1980s. Garcia and Perron's mention in the latter part of their paper that the filter probabilities obtained from their characterization of the inflation rate series as a 3-state Markov switching model seem to somewhat support this notion.

Next, the estimation results for the extended data set are presented in Table 2. Estimation results from the extended data set are quite satisfactory as they are fairly close to the authors' original estimates for the 1961:1-1986:3 period, with some discrepancies in the variances of all the three states and the mean in the low state. However, they are reported with large standard errors and with consistent trends; that is, the volatility is almost the same and is higher in the low and high states compared to the middle state, and the mean in the low state has the same sign and is generally at the same level.

Figure 4 shows the estimated ex-post real interest rate series obtained from the Hamilton filter for the extended data set, and Figure 5 shows the filter probabilities for the three states. The filter probabilities above suggest that the real interest rate for the extended time period can still be characterized well by three states. The real interest rate switches between the three distinct states as summarized in Table 3.

From the filter probabilities for this extended data set, the dates of the shifts in 1973 and mid 1981 correspond exactly to Garcia's and Perron's (1996) findings. Garcia and Perron attribute the 1973 shift to rising oil prices, and the shift in mid 1981 to rising budget deficits. The two additional shifts in this extended data set are the ones in 1987, in which the shift in the real interest rate series could have been caused by the Tax Reform Act of 1986, the stock market crash of 1987, or the brief recession in 1987, and in 2002, in which the change in behavior of the real interest rate could be explained by the collapse of the dot com bubble, the recession of 2001, or the terrorist attacks of September 11.

4. Investigating the Shift in the Real Interest Rate as a Monetary Phenomenon

Over the 1954-2006 period, the real interest series can be divided into five time periods. These periods correspond to the regimes following each shift in the real interest rate series, and are as described in Table 3 of Section 2. To date, endogenously dated shifts found in the real interest rate series are merely given an ad hoc interpretation by associating them with coinciding historical events. In this section, the three-variable VAR approach of Stock and Watson (2001) will be used to examine whether changes in the conduct of monetary policy can explain shifts in the real interest rate series. The VAR approach uses the effective federal funds rate as a tool to measure monetary policy, and therefore it allows us to investigate the nature of monetary policy by observing how the federal funds rate responds to inflation and unemployment shocks. The goal of this exercise is twofold; first, if the focus of the Fed in each period following a shift in the real interest rate series is different, this might suggest that monetary policy was a major cause for the change in real interest rate behavior. Second, if the nature of monetary policy for each reoccurring state, such as the two medium regimes of 1954-1973 and 1987-2002, are the same, this should strengthen the argument that the dynamics of the real interest rate could be described as a monetary phenomenon.

This section proceeds as follows. First, the recursive VAR setup of Stock and Watson (2001) will be described. Second, data descriptions and the methodology of recursive VAR estimation will be presented. Last, estimation results are reported and discussed. The main findings of the paper will also be compared to the results reported in Stock and Watson (2001).

4.1 The Recursive VAR Approach

The VAR is an econometric model used to capture the dynamics and interdependencies between multiple time series by using its own past values and the lags of other variables of interest to make forecasts. They have been widely used as a coherent and credible approach to data description, forecasting, structural inference and policy analysis. There are three VAR approaches; reduced form, recursive, and structural. One of the approaches estimated in Stock and

Watson (2001) is a three-variable VAR system of interest rates, unemployment, and inflation based on a recursive VAR method.

A recursive VAR constructs the error terms in each regression equation as uncorrelated with the error terms in the preceding equations. The error terms are considered to be the "surprise" movements in the variables after taking its past values into account. This is done by carefully including some contemporaneous values as regressors. To achieve this, Stock and Watson orders the three variables from least to most endogenous as i) inflation, ii) the unemployment rate, and iii) the interest rate. By ordering the equations in this fashion, the first equation has inflation as the dependent variable, with regressors as lagged values of all three variables. In the second equation, the unemployment rate is the dependent variable, and the regressors are the lags of all three variables plus the current value of the inflation rate. The last equation has the interest rate as the dependent variable, and the regresssors are the lagged three variables, the current value of the inflation rate, and also the current value of the unemployment rate. The three equations can then be estimated by ordinary least squares which produces residuals that are uncorrelated across equations. Note that the results are highly dependent on the ordering of the variables. Here, the federal funds rate is assumed to be most endogenous as monetary policy is influenced by both the inflation and unemployment rate.

Since the error terms in a recursive VAR are uncorrelated across equations, it is natural to consider the impulse response analyses of the three-equation recursive VAR system. Impulse responses trace out the response of current and future values of each of the variables to a one-unit increase in the current value of one of the VAR errors, assuming that this error returns to zero in subsequent periods and that all the other errors are equal to zero. Therefore, impulse responses of the federal funds rate to inflation and unemployment gives information about the nature of monetary policy. More specifically, it outlines how the Fed utilizes the monetary policy tool to respond to changes in inflation and unemployment.

Another useful statistics calculated from the recursive VAR approach in Stock and Watson (2001) which can provide insight into the nature of monetary policy and interaction among the three variables in the system are the variance decomposition results. It shows the percentage of the variance of the error made in forecasting a variable due to a specific shock.

4.2 Data Description and Methodology

The Stock and Watson (2001) three-variable VAR model comprising of price inflation, the unemployment rate, and a short term interest rate employs quarterly data. Their study employs quarterly data to study the dynamics of the three variables over the time period 1960-2000. In this paper, the length of each time period is very short, and therefore monthly data is used instead for the longer time period 1954-2006. The annual inflation rate in Stock and Watson's paper is calculated via the formula $\pi_t = \ln(P_t/P_{t-1})*400$, where P_t is a quarterly series of the chain-weighted GDP price index. As this price index is only available as a quarterly series, to avoid a coarsely constructed monthly series, monthly data of the seasonally adjusted U.S. CPI price index is used for estimation[6]. For the unemployment and interest rate data, this paper follows Stock and Watson approach and uses the civilian unemployment rate and effective federal funds rate respectively. All data is obtained from FRED. Plots of the annual inflation rate, unemployment rate, and federal funds rate for the time period of 1954 to 2006 are displayed in Figure 6.

The VAR system is estimated with 6 lags[7]. The ordering of the equations in the system follows Stock and Watson, that is, from least to most endogenous is inflation, unemployment, and the federal funds rate. The monthly data from 1954-2006 is split into five time periods as shown in Table 4. As a reminder, the state corresponds to the level of the real interest rate mean.

4.3 VAR Estimation Results and Discussion

In the three-variable VAR system as described above, the federal funds rate is used as a tool to measure monetary policy. Several economists agree that movements in the level of the federal funds rate provide a better indicator for monetary policy than changes in the quantity of

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[6] VAR estimation was also performed with the inflation rate constructed from the seasonally adjusted U.S. CPI for all items less food and energy. However, the results were qualitatively unchanged.

[7] The appropriate number of lags were tested for in EViews.

money (McCallum, 1983; Laurent, 1988; Bernanke and Blinder, 1992; Goodfriend, 1992). They argue that this is because other than the 1979-1982 period, the Federal Reserve appears to have implemented its monetary policy by targeting the federal funds rate. Also, changes in the quantity of money depend on the prevailing conditions of the economy as well, and it is therefore not solely influenced by monetary policy.

The variance decomposition results and impulse responses of the federal funds rate to inflation and unemployment shocks calculated from the recursive VAR in the five time periods are shown in Table 5 and Figure 7 respectively. During the first period of 1954-1973, the impulse response analyses suggests that the Fed utilized the federal funds rate to systematically respond to both inflation and unemployment, and gave both issues equal amounts of attention. The monetary policy observed in this time period fits well with one that is often described as a policy that "leans against the wind", that is, it reacts countercyclically to the business cycle – with unexpected rises in inflation, the federal funds rate rises, and with unexpected increases in unemployment, the federal funds rate falls. Furthermore, the variance decomposition results in Table 5 suggest that, an almost equal and substantial portion of the forecast error variance in the federal funds rate is caused by uncertainty about the future values of unemployment and inflation. That is, knowledge about future states of the economy indeed contains information about the future movements in the federal funds rate. It could also be observed however, that the uncertainty about the future values of the federal funds rate does not contribute much to the uncertainty about the future values of inflation or unemployment. Overall, it may be concluded that in this period, the federal funds rate had important predictive content for unemployment and inflation.

Bernanke and Blinder (1992) specified the same recursive VAR system with also 6 lags to study the nature of monetary policy during the period of July 1959 – September 1979. They report that the Fed's actions fits well to the "lean against the wind" policy behavior, and the federal funds rate may be a good indicator of monetary policy during this period. The period of this study covered by Bernanke and Blinder combines the first time period discussed above, and also overlaps with the second time period of 1973 – mid 1981. Bernanke's interpretation of the federal funds rate as being an appropriate measure of monetary policy seems consistent with the findings for the 1954 – 1973 period, but not necessary for the 1973 – mid 1981 period[8]. From Figure 7 above, it is evident that the Fed did not always implement the "lean against the wind" policy, and in this period, the Fed seemed to have focused more on the real sector. Therefore, the Fed's neglect on inflation seems to explain well why the economy experienced high inflation levels at that time. Also, more than half of the forecast error variance in the federal funds rate is caused by uncertainty about the future values of unemployment, and the portion attributing to inflation uncertainty decreased dramatically from the earlier time period.

Following the 1981 period, results run counterintuitive, especially during the mid 1981-1987 period which correspond to a puzzling high level of real interest rates. Following the high inflation period of the 1970s, it was expected to see from impulse responses that the Fed would use the federal funds rate to combat inflation under its tight monetary policy regime (Ball, 1990; Alogoskoufis and Smith, 1991). If the federal funds rate is a good measure of monetary policy, then inflation shocks should have had a significant effect on the federal funds rates movements. However, in Figure 7, it is evident that the Fed did not respond much to inflation at all, and is consistently the case for all reaction functions of the federal funds rates to inflation for the post 1980s. The variance decompositions for all periods in the post 1980s also show that inflation shocks account for no variability in the federal funds rate. This result is one that is consistent with other findings in literature, and has raised the question about the validity of using the federal funds rate as an instrument to measure monetary policy.

As for the real sector in the post 1980s, assuming that the federal funds rate is a good indicator of monetary policy, the Fed has chosen to focus more on unemployment, especially in the 2002-2006 period. Even though the 2002-2006 periods is similar to the prior two post 1980s regimes in the sense that the federal funds rate was not very responsive to inflation shocks, the variance decomposition evidence indicates that the 2002-2006 period is quite distinct from its previous two periods as almost all the forecast error variance of the federal funds rate can be

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[8] The VAR system was estimated for the 1973-1979 period as well, but results were not much different.

attributed to unemployment. This is in contrast to the other two post 1980s regimes, as their variance decompositions indicate that a larger percentage of the forecast variance in the federal funds rate can only be attributed to uncertainty about innovations to the federal funds rate itself. In other words, the federal funds rate has become more independent of the other variables in the VAR system in the 1981-1986 and 1986-2002 time periods.

The above observations may be summarized as follows. In 1954-1973, the federal funds rate may have been a good instrument to measure monetary policy, and results suggest that the Fed paid equal attention to inflation and unemployment. However, in the 1973-1981 period, the Fed has chosen to focus more on the real sector, which explains the high inflation levels during that time. Following this high-inflation period, if the federal funds rate was still an appropriate instrument to measure monetary policy, results should have shown monetary policy as being very responsive to inflation shocks, but clearly this was not the case observed. Instead, in the post 1980s, the Fed seemed to have focused more on the real sector. However, there is doubt upon whether the federal funds rate is a good indicator for monetary policy in the post 1980s, especially in the 1981-1987 and 1987-2002 periods where the federal funds rate was almost an independent instrument from inflation and unemployment.

This observation for the 1981-2002 period is indeed consistent with other findings in literature. In the post 1980s period, many economists find that the structure of monetary policy has changed considerably, and the federal funds rate may not have been a good indicator of monetary policy (Balke and Emery, 1994; Bernanke and Blinder, 1992). Some explanations for this include; financial innovation and deregulation during the 1980s may have changed the effectiveness and transmission mechanism of monetary policy (Bosworth, 1989; Kahn, 1989), the high inflation period of the 1970s may have changed the way the public reacts to inflation (Balke and Emery, 1994), or the Fed may have focused more of its policy on controlling inflation before it had the chance to accelerate. In other words, the last explanation translates to the Fed choosing to conduct monetary policy in a more forward-looking manner (Stock and Watson, 2001)[9] by increasing the federal funds rate in anticipation of inflation so as to not get behind the curve with respect to fighting inflation. Other measures for monetary policy that have been tested in a VAR context include the quantity of money, unexpected changes in money (Sims, 1986), unexpected changes in the federal funds rate (McCallum, 1983; Laurent, 1988), and the spread between the federal funds rate and the ten-year U.S. Treasury bond rate (Bernanke and Blinder, 1992). Balke and Emery (1994) also propose using the real federal funds rate as a measure of monetary policy.[10] However, results are generally unsatisfactory and economists are still unable to explain precisely how monetary policy has changed since the 1980s.

From these findings, under the assumption that the federal funds rate is a good measure of monetary policy, the five time periods following a shift in the real interest rate regime correspond to different monetary policy regimes[11]. It is also observed that for each reoccurring real interest rate regime state, such as the two medium regimes of 1954-1973 and 1987-2002, the focus of monetary policy was clearly not the same, which contradicts with Romer's and Romer's (2002) argument that monetary policies in the 1950s was similar to the ones in the 1980s and 1990s. Therefore, based on these analyses alone, there is not enough supporting evidence that monetary policy may have been the cause for the shift in the behavior of the real interest rate. However, the results from this split sample VAR exercise does highlight the importance of taking into account policy shifts when conducting VAR analyses. In the study of Stock and Watson (2001) the three-variable recursive VAR was estimated for the entire sample 1960-2000. The impulse response analyses and variance decomposition results are examined under the assumption that the nature of monetary policy was constant throughout the entire sample period. The findings

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[9] Balke and Emery (1994) point out that implementing a forward looking monetary policy with low-dimensions VARs might not be appropriate as the VAR system does not capture all available information used by monetary authorities in their decision process.

[10] This was implemented in this study but yielded unsatisfactory results.

[11] The time periods of 1981-1987 and 1987-2002 could be viewed as one monetary policy regime, but keep in mind that the early 1980s was a problematic and experimental time period for the Fed.

of Stock and Watson (2001) was that, for the entire period of study, there is strong interaction between the three variables in the recursive VAR system. Monetary policy behavior fit well with one that "leans against the wind" and the Fed utilized the federal funds rate to systematically respond to both inflation and unemployment with equal amounts of attention. However, from the findings of this paper, it has been shown that the nature of monetary policy has changed over different time periods, and is not always one that "leans against the wind". Across different sample periods, the Fed has also displayed varying amounts of attention towards changes in inflation and unemployment. As VARs are often used for forecasting, structural inference, and also policy analysis, much caution should thus be paid to statistics from a VAR that does not take into account policy shifts or instabilities that may have occurred in the system of equations.

5. Conclusion

The real interest rate behavior during 1954 – 2006 can be well described by a Markov Switching model with three distinct means and variances. Changes in the real interest rate series are found to occur in 1973, 1981, 1987, and 2002. In literature, regime shifts in the real interest rate series are often explained by associating the dates of shifts with coinciding historical events. However, this method is ad hoc, and therefore this paper proposes a more formal investigation of real interest rate regime shifts.

Monetary policy has close ties to the nominal interest rate and inflation dynamics. This paper examines whether changes in the conduct of monetary policy can explain shifts in the U.S. real interest rate. A three-variable recursive VAR model is used to investigate the conduct of monetary policy in each of the five time periods following shifts in the real interest rate series, under the assumption that the short term interest rate is an appropriate measure for monetary policy. Based on the impulse response analyses of the VAR, there is weak evidence that regime shifts in the real interest rate is a monetary phenomenon.

The findings in this paper suggest many areas for future research on the source of regime shifts in the real interest rate series. The results from the three-equation VAR model are obtained under the assumption that the federal funds interest rate is an appropriate measure of monetary policy over the entire sample period. However, it is plausible that during this time, the conduct of monetary policy has changed as well. In this case, the federal funds rate may not be able to properly or completely characterize monetary policy over the entire sample period. In addition, there may be additional factors other than monetary policy that have affected the dynamics of the real interest rate such as variations in preferences and technology or changes to fiscal policy. An investigation of a system of equations characterizing the joint dynamics of the real interest rate, monetary and fiscal policy, and output trend growth rate might be able to better explain the causes for regime shifts in the U.S. real interest rate.

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Appendix

The transition probabilities matrix for a first order, 3-sate Markov-switching process S_t from equation (2) is:

$$P^* = \begin{bmatrix} P_{11} & P_{12} & P_{13} \\ P_{21} & P_{22} & P_{23} \\ P_{31} & P_{32} & P_{33} \end{bmatrix} \quad (1)$$

where $i_3' P^* = i_3'$ with $i_3 = [1 \quad 1 \quad 1]'$. If we let π_t be a vector of 3x1 steady-state probabilities, we have

$$\pi_t = \begin{bmatrix} \Pr[S_t = 1] \\ \Pr[S_t = 2] \\ \Pr[S_t = 3] \end{bmatrix} = \begin{bmatrix} \pi_{1t} \\ \pi_{2t} \\ \pi_{3t} \end{bmatrix} \quad (2)$$

$$i_3' \pi_t = 1 \quad (3)$$

According to the definition of steady-state probabilities, we have

$$\pi_{t+1} = P^* \pi_t \Rightarrow (I_3 - P^*)\pi_t = 0_3 \quad (4)$$

where 0_3 is a 3x1 matrix of zeros. Combing equations, we have

$$\begin{bmatrix} I_3 - P^* \\ i_3' \end{bmatrix} \pi_t = \begin{bmatrix} 0_3 \\ 1 \end{bmatrix}, \quad or \quad A\pi_t = \begin{bmatrix} 0_3 \\ 1 \end{bmatrix} \quad (5)$$

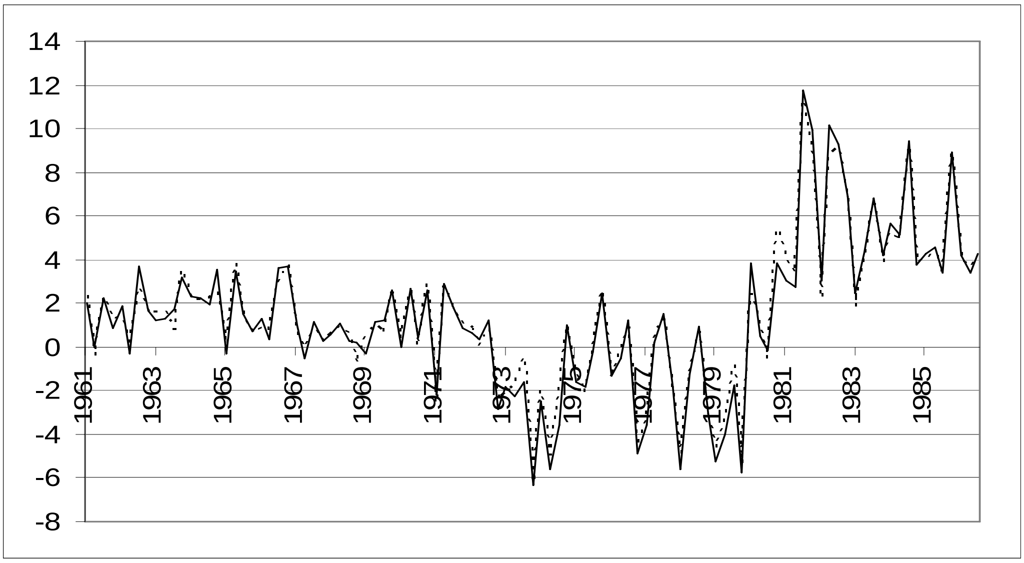
Multiply both sides by $(A'A)^{-1} A'$, to get:

$$\pi_t = (A'A)^{-1} A' \begin{bmatrix} 0_3 \\ 1 \end{bmatrix} \quad (6)$$

That is, the matrix of steady-state probabilities π_t, is the last column of the matrix $(A'A)^{-1} A'$.

Figures and Tables

Figure 1a. Ex-post Real Interest Rate, 1961:1 – 1986:3



Note: The solid line is the authors' data set, and the dotted line is the constructed data set.

Figure 1b. Ex-post Real Interest Rate, 1954:1 – 2006:4

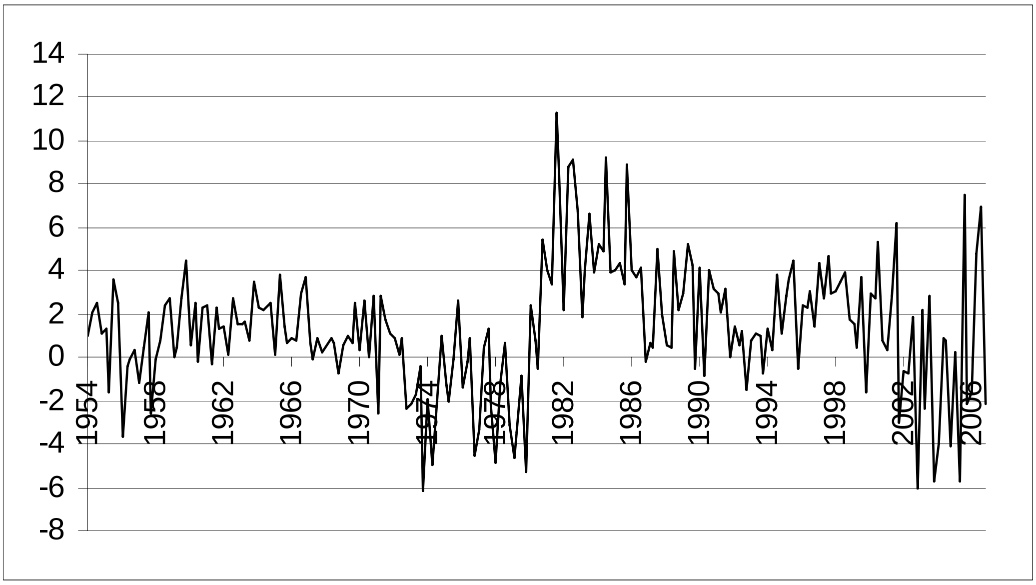


Table 1. Estimation Results, 1961:1 – 1986:3

Parameter	**Constructed Data Set**	**Authors' Data Set**	**Results Reported in Garcia's and Perron's Paper**
P_{11}	0.965 (0.031)	0.964 (0.032)	0.968 (0.024)
P_{12}	0.000 (0.000)	0.000 (0.000)	0.013 (0.011)
P_{21}	0.011 (0.013)	0.011 (0.013)	0.011 (0.000)
P_{22}	0.989 (0.013)	0.989 (0.014)	0.988 (0.000)
P_{31}	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
P_{32}	0.015 (0.021)	0.015 (0.021)	0.017 (0.000)
ϕ_1	-0.078 (0.102)	-0.027 (0.115)	-0.020 (0.111)
ϕ_2	-0.075 (0.105)	0.008 (0.117)	0.013 (0.116)
ω_1	5.089 (1.282)	6.386 (1.715)	6.355 (0.339)
ω_2	1.573 (0.339)	1.637 (0.360)	1.6129 (0.367)
ω_3	6.059 (1.844)	7.926 (2.513)	8.1567 (0.335)
α_2	1.314 (0.161)	1.375 (0.189)	1.379 (0.516)
α_3	5.499 (0.448)	5.518 (0.661)	5.488 (0.691)
Likelihood Value	213.804	217.608	Not reported

Note: In Garcia and Perron's (1996) paper, they labeled the three states 0, 1, and 2, whereas in this paper, they are relabeled as states 1, 2, and 3. The states are referred to as low (state 1), medium (state 2), and high (state 3) according to the level of the mean. Also, the authors estimated the state-dependent standard deviations, whereas in this paper, the original model was rewritten to estimate the state-dependent variances ω_1 , ω_2 , and ω_3 instead. This also applies to the estimation results of the extended data as shown in Table 2.

Figure 2. Ex-post Real Interest Rate, 1961:1-1986:3

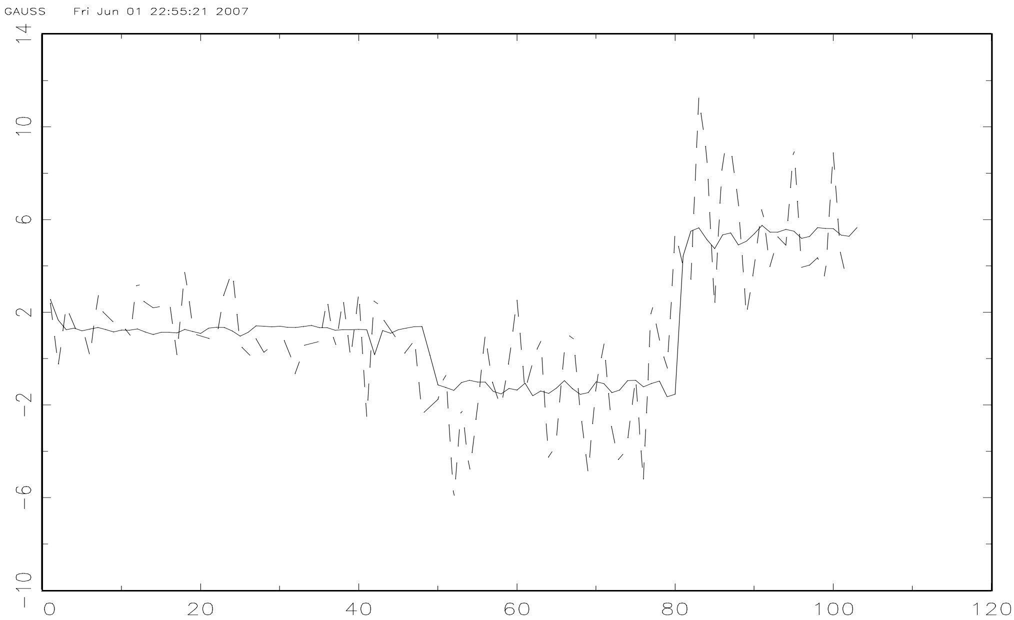


Figure 3. Filter Probabilities, 1961:1-1986:3

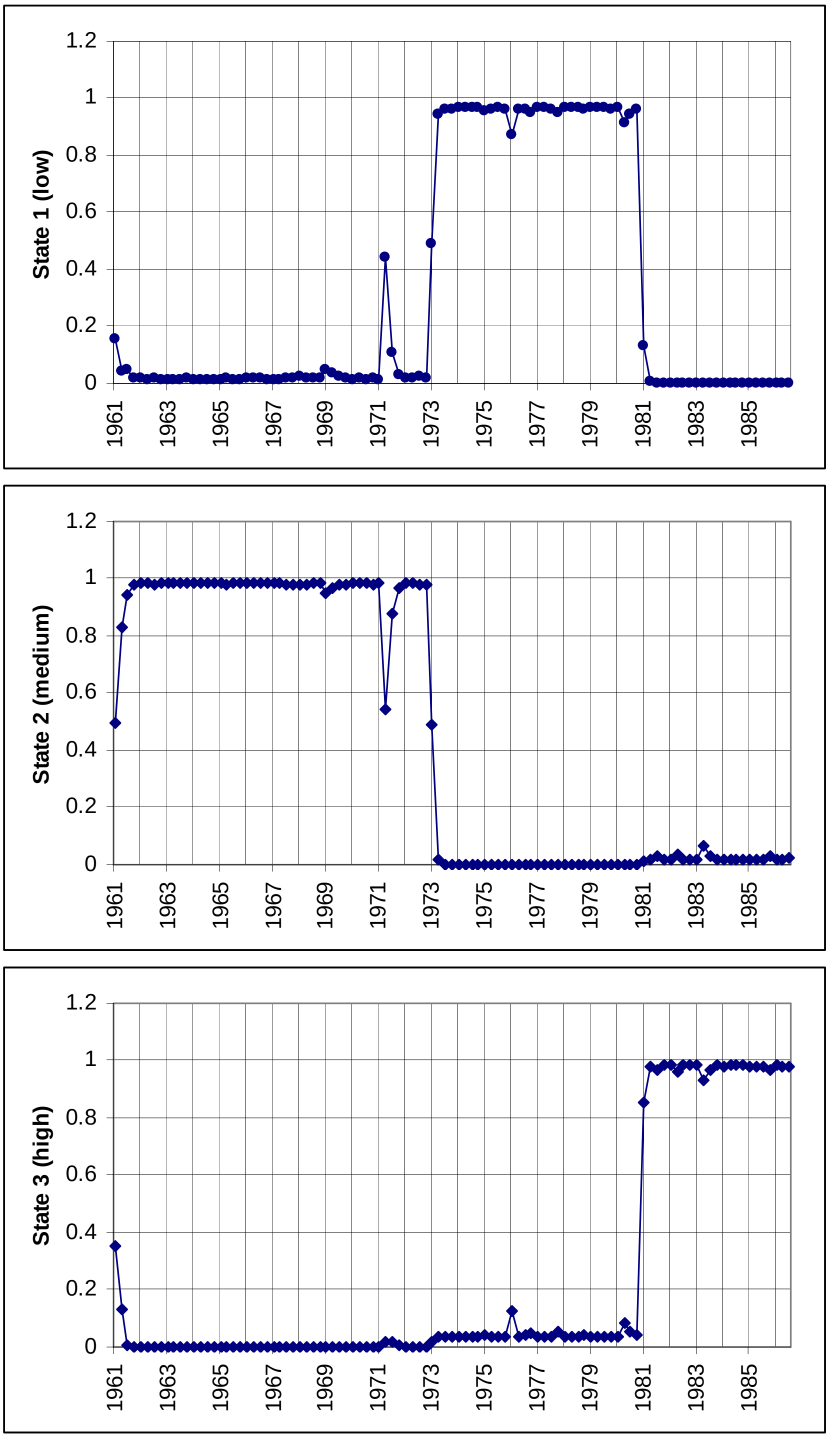


Table 2. Estimation Results, 1954:1 – 2006:4

Parameter	**Estimates for the Extended Data Set (1954:1 – 2006:4)**	**Estimates Reported in Garcia and Perron's Paper (1961:1 – 1986:3)**
P_{11}	0.974 (0.022)	0.968 (0.024)
P_{12}	0.000 (0.000)	0.013 (0.011)
P_{21}	0.0121 (0.009)	0.011 (0.000)
P_{22}	0.988 (0.009)	0.988 (0.000)
P_{31}	0.000 (0.000)	0.000 (0.000)
P_{32}	0.051 (0.044)	0.017 (0.000)
ϕ_1	0.003 (0.000)	-0.020 (0.111)
ϕ_2	0.092 (0.077)	0.013 (0.116)
ω_1	9.641 (1.983)	6.355 (0.339)
ω_2	2.854 (0.368)	1.6129 (0.367)
ω_3	7.499 (2.528)	8.1567 (0.335)
α_1	-0.920 (0.505)	-1.781 (0.492)
α_2	1.593 (0.167)	1.379 (0.516)
α_3	5.401 (0.691)	5.488 (0.691)
Likelihood value	471.060	Not reported

Figure 4. Ex-post Real Interest Rate, 1954:1-2006:4

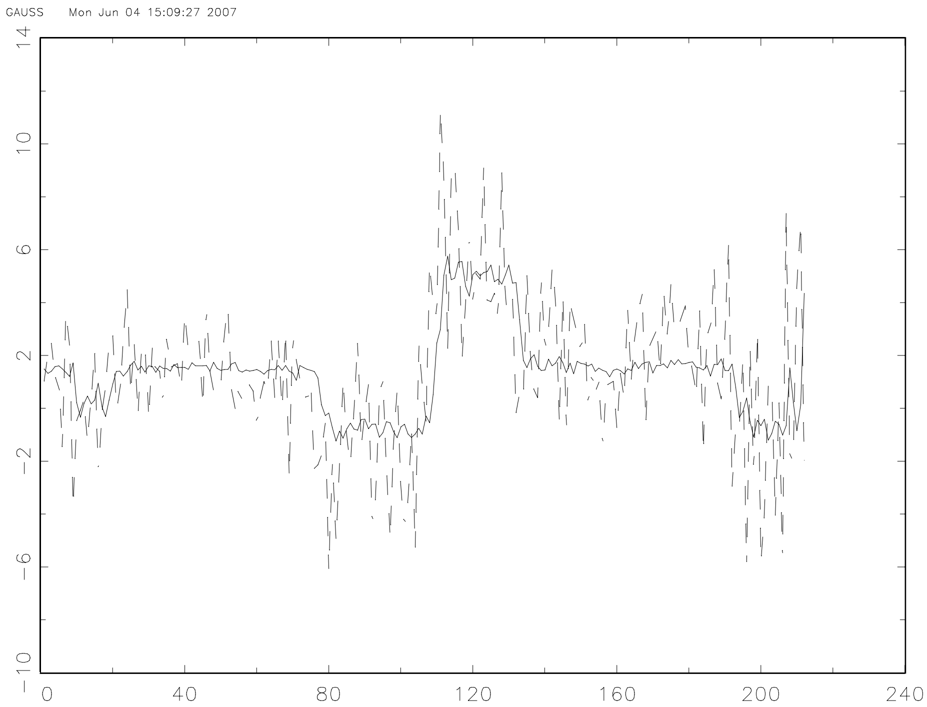
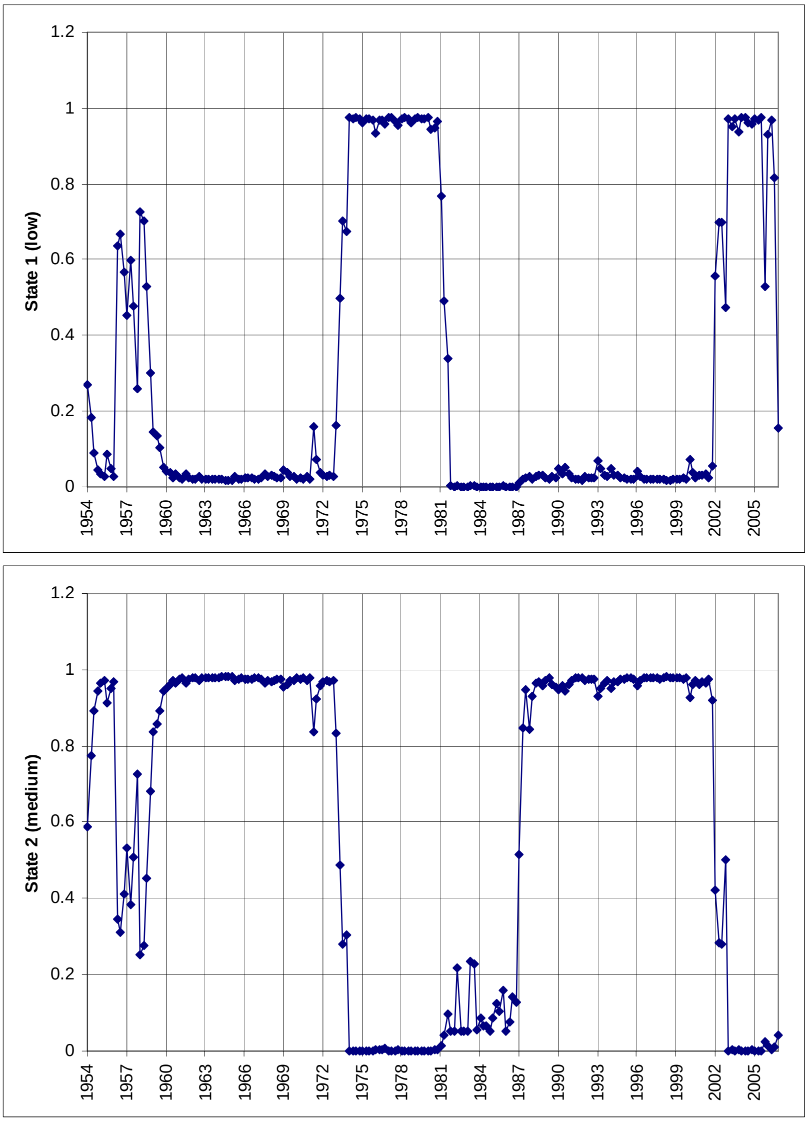


Figure 5. Filter Probabilities, 1954:1-2006:4



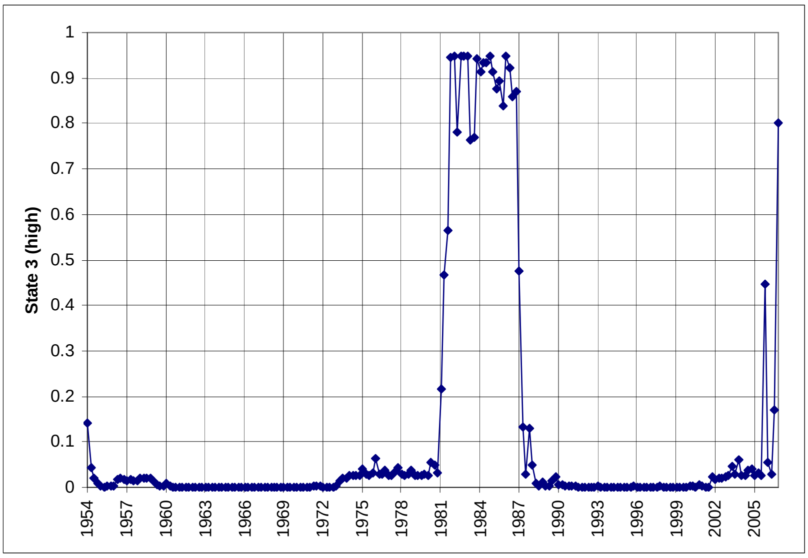

State 3 (high)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1954
1957
1960
1963
1966
1969
1972
1975
1978
1981
1984
1987
1990
1993
1996
1999
2002
2005

Table 3. The Three States of the Ex-Post Real Interest Rate, 1954:1-2006:4

Time Period	State	Mean (Volatility)
1954 – 1973	Medium	1.6% (2.9%)
1973 – mid 1981	Low	-0.9% (9.6%)
Mid 1981 – 1987	High	5.4% (7.5%)
1987 – 2002	Medium	1.6% (1.6%)
2002 – 2006	Low Note: From 2005:4, the series alternates between the low and the high state.	-0.9% (9.6%)

Figure 6. Monthly Series for the Three-variable VAR System, 1954:7 – 2006:12

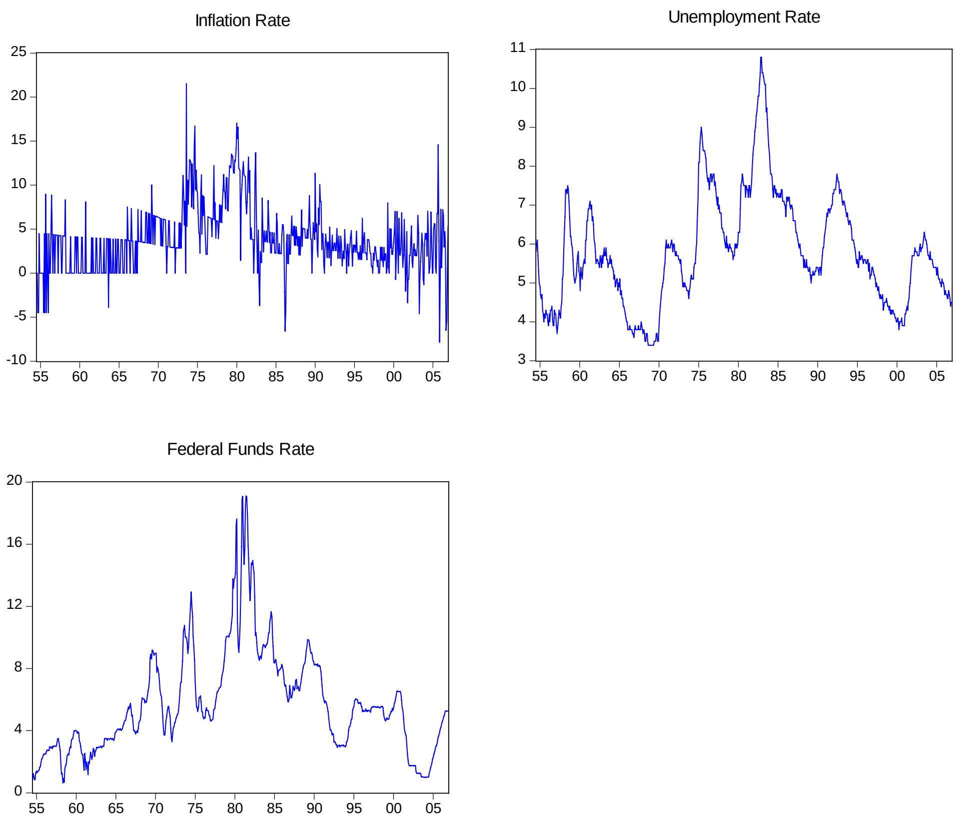


Table 4. Description of the Five Time Periods, 1954:7 – 2006:12

Time period	State	No. of Observations
1954:7 – 1973:6	Medium	228
1973:9 – 1981:9	Low	97
1981:12 – 1987:3	High	64
1987:6 – 2001:12	Medium	175
2002:3 – 2006:12	Low Note: Alternates between the low and high states from late 2005.	58

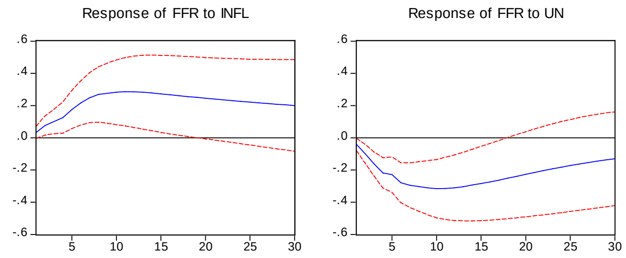
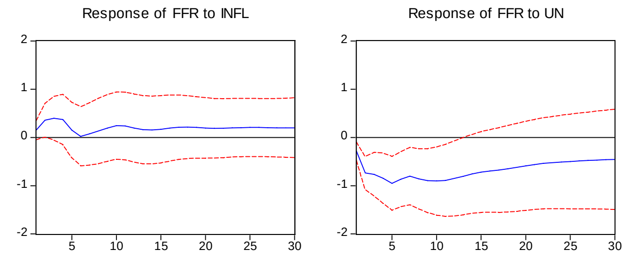
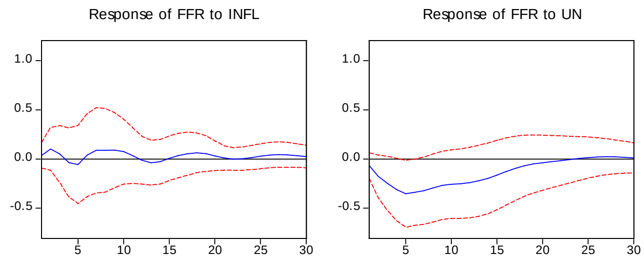
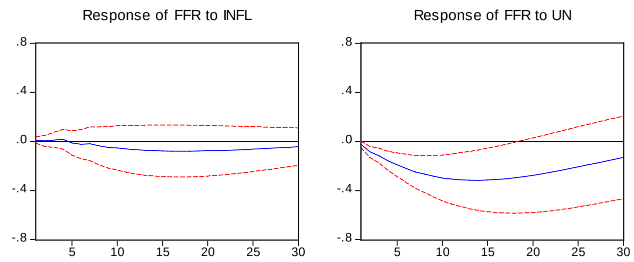
Note: Since the dates of the shifts in the real interest rate series were endogenously determined from quarterly data, the start and end points of each regime corresponds to end-of-quarter months. The first data point starts as far back as data from FRED permits.

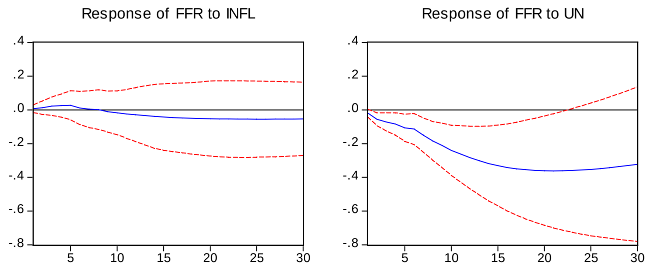
Table 5. Variance Decomposition Results, 1954:7 – 2006:12

Variables/ Time Period (State)	1954 – 1973 (Medium)	1973 – 1981 (Low)	1981– 1987 (High)	1987 – 2002 (Medium)	2002 – 2006 (Mostly Low)
infl Variance	75% by infl 15% by un 10% by ffr	55% by infl 35% by un 10% by ffr	75% by infl 5% by un 20% by ffr	20% by ffr 5% by un 75% by infl	90% by infl 0% by un 10% by ffr
un Variance	0% by infl 100% by un 0% by ffr	5% by infl 80% by un 15% by ffr	0% by infl 50% by un 50% by ffr	10% by infl 85% by un 5% by ffr	5% by infl 90% by un 5% by ffr
ffr Variance	25% by infl 30% by un 45% by ffr	5% by infl 55% by un 40% by ffr	0% by infl 30% by un 70% by ffr	0% by infl 30% by un 70% by ffr	0% by infl 90% by un 10% by ffr

Note: These observations were made at approximately lag 25. Inflation is denoted by infl, unemployment by un, and federal funds fate by ffr.

Figure 7. Impulse Response Analyses of the Three-Variable VAR, 1954:7 – 2006:12

Time Period (State)	Impulse Response Analysis
1954:7 – 1973:6 (Medium)	
1973:9 – 1981:9 (Low)	
1981:12 – 1987:3 (High)	
1987:6– 2001:12 (Medium)	

2002:3 – 2006:12 (Predominantly low)	

Note: The solid line shows the impulse responses, and the dotted lines are the asymptotic standard errors for the impulse responses.