Discussion Papers In Economics And Business

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An Application of Identified Markov Switching Vector Autoregression to the Impulse Response Analysis When the Nominal Interest Rate is Almost Zero

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Discussion Paper 03-08

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Abstract

I study whether the effect of monetary policy has changed during 1990s and the zero bound of nominal interest rate may have some distortional effect on macroeconomic dynamics. In order to check the existence of structural change without any prior knowledge on break point and to be able to compare the effect of monetary policy before and after the break without any distortion from the difference in degrees of freedom caused by the different estimated periods, the identified Markov switching vector autoregression model is estimated.

The result shows that there is a structural change in 1990s and the effect of monetary policy has become weaker since then. As obvious, traditional interest rate channel is not functioning and therefore the role of monetary expansion is limited now.

Another intriguing by-product is that the conventional puzzles with identified VAR, namely price puzzle and liquidity puzzle, are often resolved in one regime, but not in the whole sample. This finding may have some implication for the cause of those puzzles, the coexistence of equilibrium dynamics and disequilibrium dynamics in economic time series.

JEL Classification: C33; E50.

Key words: Markov Switching Model; VAR; Monetary Policy; Price Puzzle; Liquidity Puzzle; Bootstrapping; Zero Bound of Nominal Interest Rate

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1 Introduction

It is often argued that the effect of monetary policy has significantly weakened during 1990s. Looking at the Japanese macroeconomy since 1990 carefully, indeed, monetary policy does not seem to have obvious stimulating effect on the "lost decade."[1] Several preceding research such as Miyao (2000) points out three reasons for this event; "(i) the yen appreciation to over 80 yen per dollar, (ii) the Bank of Japan's actions to lower the official discount rate or the call rate to a record low below 1%, and (iii) the series of bank failures that disclosed the serious bad loan problem in Japan's financial sector." Moreover, as mentioned in Kimura, Kobayashi, Muranaga and Ugai (2002), the introduction of the zero nominal interest rate should have made the effect of monetary policy further less effective as there has been less room to ease from interest rate policy, namely due to the lack of traditional interest rate channel of monetary policy transmission.

The principal aim of this paper is to check whether there was a structural change in monetary policy effect on real economy during 1990s due to the backgrounds as mentioned above and if so, to understand the current state of relationship between monetary instruments and other economic variables especially when the nominal interest rate is almost zero.

The easiest way to test the structural break is perhaps to conduct a conventional break point test and compare the impulse responses before and after the break separately. However, the degree of freedom usually differs between two periods due to the difference in estimated periods. This may distort the proper comparison of the outcome from two periods. In order to find out a resolution for this problem, the newly introduced econometric technique, identified Markov Switching Vector Autoregression, is employed in this paper. With this method, the model is computed without any prior knowledge about break point, since the structural break is expressed as Markovian regime shift which is determined by estimation. Further, as the estimation is conducted for the whole period, there is no distortions from the difference in degrees of freedom. As long as the regimes derived by Markov switching estimation are long-lived and distinct, it is appropriate to compare the impulse responses between different regimes as the analysis on the structural break.

The paper consists as the following. Section one reviews the prior research concerning the interest mentioned above. First part is about the developments in Markov switching regressions, and the latter is on the research with VAR on monetary policy transmission mechanism. In section two, the VAR model for monetary policy analysis with explicit interest rate channel is constructed. It will also explain how to estimate the Markov switching model, how to derive the impulse response and how to draw the confidence interval by bootstrapping method. Further, results are also summarised. In response to the consequences attained in the previous section, the VAR model with implicit interest rate channel is built in section three so that the analysis with the current policy

[1] Hayashi and Prescott (2002) uses this word and seeks for the cause of the lost decade. Researchers become paying more attention to Japan's unusual experiences after the bubble economy, as found in Bayoumi and Collyns (2000) and Ramaswamy and Rendu (2000).

scheme employed by the bank of Japan, namely "Quantitative Easing" policy, could be possible. Section four is to conclude.

2 Prior Research

In this section, prior research on Markov switching model is reviewed, then the VAR on the monetary policy transmission mechanism.

2.1 Markov Switching Model

Hamilton (1989) is the first research to introduce Markov switching model in time series econometrics. Based on the stylised fact of nonlinearity in economic time series, especially asymmetric business cycle established by Neftci (1984) and others, which find that US business cycle is characterised by the combination of long but gradual expansion and short but sudden recession, Hamilton (1989) presents an alternative method for dating the expansion and recession to the conventional NBER method by recognising the periodic shift from a positive growth rate to a negative growth rate as a recurrent feature of US business cycle.

Since this seminal research, Markov switching model has been widely applied to analyse various economic phenomena such as the Phillips curve with regime shift and the comovement of the European business cycle since the introduction of EMI system etc. The various application of this Markov switching model and how to estimate these models in detail are shown in Krolzig (1996) and Kim and Nelson (1999).

Krolzig (1998) develops **MSVAR** with user friendly application which runs on the **Ox**.[2] It enables many researcher to be very accessible to the Markov switching model, the programme for which is normally very complicated. The econometric analysis below uses **MSVAR**.

Krolzig and Toro (1999) first recongnises the existence of impulse response function in Markov switching vector autoregression model. It tries to derive the impulse response functions which can account for the endogenous regime shift. However, since my research interest lies in the comparison of the impulse responses between different regimes, regime dependent impulse responses, namely impulse response function in each period, need to be computed. Recently, Ehrmann, Ellison and Valla (2003) shows how to derive regime dependent impulse response functions.[3] The analysis below follows their methodology.

2.2 Analysis on Monetary Policy with VAR

The researches on monetary policy transmission mechanism using VAR is quite vast. Indeed, the seminal paper on identified VAR of Sims (1980), which is well

[2] You can download the **MSVAR** for **Ox** at www.econ.ox.ac.uk/people/members/krolzighm.htm.

[3] Minor extension which enables the analysis on the five variables system is made by the author.

known for the "Sims critique" on traditional large macromodels for their implausible identifications, is also about monetary transmission. Since then, quite a large number of researches with various identification schemes have been published. Among them, it is popular to identify the system for contemporaneous relationships between macroeconomic variables. In this context, some such as Christiano, Eichenbaum and Evans (1999) use Choleski decomposition, which is referred to as the recursive framework, and the other such as Leeper, Sims and Zha (1996) employ non-recursive framework[4] for identifying monetary policy shocks.

As it is strongly craved for to obtain the robust results which will not change significantly with the different estimated period so that the results obtained in this paper could be used as the reference to check the validity of theory based macromodel which is sometimes called as dynamic stochastic general equilibrium (DSGE) model as indeed suggested by Christiano, Eichenbaum and Evans (1999),[5] several estimations are conducted with different starting date. For this purpose, the simple identification framework which is thought to be robust throughout the time is better to be implemented. Therefore, the model considered in this paper is based on the simple recursive framework for identification.[6]

As for the research on Japanese monetary policy, Teruyama (2001) well summarises the developments in this field with very good introduction for how to identify as well. Concerning the possibility of structural change in the monetary transmission mechanism, Miyao (2000) estimates three variables (industrial production, call rate and monetary base) and four variables (plus nominal exchange rate) VAR where all the non-financial variables are expressed as log difference value. Miyao (2000) concludes that according to testing procedure suggested by Christiano (1986) and Cecchetti and Karras (1994), the effect of monetary policy has significantly weakened during 1990s. Further, on the impulse responses to monetary expansion under the zero nominal interest rate, Kimura, Kobayashi, Muranaga and Ugai (2002) estimates time-varying VAR and concludes that the response of the inflation rate to the monetary base expansion becomes weaker now than before.

Although the aim is similar to that of Miyao (2000), what is new in this paper is first that the model is estimated with levels. Sims (1980) and other related research recommend against differencing even if the variables are not stationary.[7] As the main purpose of the study using VAR is not to determine the parameter estimates but to know the inter-relationship among the variables, differencing should not be employed because it throws away important informa-

[4]Identification in the non-recursive framework is established by Bernanke (1986) and Sims (1986).

[5]Teruyama (2001) claims that this suggestion by CEE is implicitly assuming the righteousness of indentification structure, which is not neccesarily always right.

[6]I am not saying that the simple structure is more robust, rather that the comparison becomes very difficult if identifications are different in each estimated periods. Hence, the simple recursive structure is employed in this paper.

[7]Non-stationarity in data has no problem in estimation since the residuals behave quite reasonably. Further, Sims, Stock and Watson (1990) claims that even if the system includes non-staionary variables, the estimator pocesses consistency in level estimation.

tion concerning the comovements in the data.[8] Therefore, the impulse response obtained in this research may be rich in information. Further, as stated above, by including the Markovian regime shifts, the model is not estimated separately for each regimes. Hence, impulse responses for each regime can be directly comparable without any distortion from the differences in degrees of freedom.

3 Model with Explicit Interest Rate Channel

In this section, two models are estimated. One is the four variables VAR consisted of output, price level, call rate and money supply. The other is five variables VAR. It consists of the above four plus whole price index (WPI), the leading indicator for the price level. All are monthly data[9]. This is a quite standard form of analysing monetary policy as described in Christiano, Eichenbaum and Evans (1999) and Teruyama (2001).

Perhaps, the latter may be more common as it has been recognised to escape the "price puzzle." Price puzzle is a phenomenon that the price level tends to increase right after the tightening of monetary policy, rise in the nominal interest rate, in impulse response analysis.[10] As described in Walsh (1998), "the most commonly accepted explanation for the price puzzle is that it reflects the fact that the variables included in the VAR do not span the information available to the FED in setting the funds rate." Since Sims (1992) finds that the inclusion of commodity price, which are supposed to be sensitive to changing forecasts of future inflation and therefore serves as an additional information for the monetary policy decision making, tends to mitigate this problem as this is due

[8]Doan (1996), which is the user's manual for RATS, one of the most commonly used software for time series analysis, claims that "Should I difference? Our advice is no, in general. In Box-Jenkins modeling, appropriate differencing is important for several reasons: i) It is impossible to identify the stationary structure of the process using the smaple autocorrelations of an integrated series; ii) Most algorithms used for fitting ARIMA models will fail when confronted with integrated data. Neither of these applies to VAR's. In fact, the result in Fuller (1976, Theorem 8.5.1) shows that differencing produces no gain in asymptotic efficiency in an autoregression, even if it is appropriate. In VAR, differencing throws infomatin away (for instance, a simple VAR on differences cannot capture a co-integrating relationship), while it produces almost no gain." Further, it recommends not to use a deterministic trend term as the most economic time series are best represented as a random walk with trend.

[9]The details for the data employed here are as follows; output: Seasonally adjusted Industrial production (Ministry of Economy, Trade and Industry), price level: Seasonally adjusted Consumer Price Index at 2000 price (Ministry of Public Management, Home Affairs, Posts and Telecomunications) , Call rate: with collateral bases before 1995 and without collateral bases after 1995 (Bank of Japan), money supply: seasonally adjusted M2+CD, however disconnection due to the different difinition is solved by using quartely growth rate (Bank of Japan), and WPI: at 1995 price (Bank of Japan).

[10]Another famous puzzle concerning identified VAR is "liquidity puzzle". Liquidity puzzle is a symptom that the increase in interest rate occurs after the increase in monetary aggregates. Bernanke and Mihov (1998) conjectures that the misspecification for the choice of the variables of the monetary instruments. However, their approach is based on non-recursive assumption unless Strongin (1995) identification is employed. Further, the number of the variables included tends to be large in those specification and this brings considerable decrease in the degrees of freedon in Markov switching estimation. Hence, in this analysis, no prescription is made to tackle this puzzle.

to the misspecification of central bank's information set, five variables VAR has been a standard approach.[11] As for the analysis on monetary policy in Japan, WPI is often used to fulfil this role as a proxy variable.

Two estimated periods with different starting dates are chosen, from January 1980 and January 1985. The ending date is always set at August 2002. The choice of the estimated period may have a significant effect on the results in Markov switching estimation as regimes are estimated automatically within the estimated period[12] and therefore different estimated periods may suggest different composition of regimes. Hence, in order to keep the robustness of the results, estimated periods with quite different starting date as above are chosen to estimate.

Number of lags are chosen as the majority of the suggested optimal length of lags according to the three information criteria: Akaike information criteria (AIC), Hannan Quinn criteria (HQ) and Schwarz Bayesian information criteria (SBIC).[13]

Since this is the regime switching model, the number of regimes needs to be fixed beforehand. It is true that the likelihood ratio test which is embedded in **MSVAR** may be used for the decision of the optimal number of regimes. However, Krolzig (1997) claims that due to the existence of nuisance parameters, the likelihood ratio test against the null hypothesis of linearity or more number of regimes has no asymptotic standard distribution.[14] Furthermore, it is desirable for each regime to last a while as opposed to frequently changing so that the existence of structural breaks could be monitored.[15] Therefore, the model should be kept as parsimonious as possible. Considering these information into account, the number of regimes are fixed at two.

[11] However, recently, several new research can be found against this common view. Hanson (2000) deals with the price puzzle seriously and concludes that the inclusion of leading indicator to price level does not necessarily resolve the puzzle. Further, Barth and Ramey (2001) states that if thinking about cost channel of monetary policy, the price puzzle does not have to be a puzzle any more. It concludes that the tightening of monetary policy may increase the cost of the firm and therefore it is quite possible to have the increase in price level immediately after the increase in nominal interest rate.

[12] Precisely, regime probabilities and transition probabilities are directly estimated.

[13] As more parameters such as the transition matrix need to be estimated in Markov switching model, the optimal number of lags tends to be smaller than in the case of linear model.

[14] One of the regularity condition for the likelihood ratio test to have an asymptotic Chi square distribution is that the information matrix is non-singular. However, this condition fails to hold if an m state model is to be fitted when the true process has m-1 state because the parameters which describe mth state are unidentified under the null hypothesis.

[15] Indeed, Ehrmann, Ellison and Valla (2001) claims "Regime-dependent impulse response functions are conditional on a given regime prevailing at the time of the disturbance and throughout the duration of the response. The validity of regime conditioning depends on the time horizon of the impulse response and the expected duration of the regime. As long as the time horizon is not excessive and the transition matrix predicts regimes which are highly persistent then the conditioning is valid and regime-dependent impulse response function are a useful analytical tool. For a longer time horizon or frequently switching regimes, it would be more attractive to condition on the expected path of the regime throughout the response."

3.1 Identified Markov Switching Vector Autoregression Model

In this analysis, all the parameters including intercept, coefficients and variance covariance matrices for the reduced-form VAR are assumed to switch according to the hidden Markov chain.[16] Denoting the number of regimes and of lags by m and p respectively, the equation to be estimated is expressed as follows.

$$Y_t = v(s_t) + B_1(s_t) Y_{t-1} + \cdots + B_p(s_t) Y_{t-p} + A(s_t) U_t \tag{1}$$

$$s_t = 1, \cdots, m$$

$$U_t \tilde{} N(0, I_K)$$

K is the dimension of the coefficient matrix B_p, namely the number of endogenous variables. U_t, the vector of fundamental disturbances, is assumed to be uncorrelated at all leads and lags. In case when the number of regimes m is two[17], equation (1) is reduced to

$$Y_t = \{ \begin{matrix} v_1 + B_1^1 Y_{t-1} + \cdots + B_p^1 Y_{t-p} + A^1 U_t, \text{ if } s_t = 1 \\ v_2 + B_1^2 Y_{t-1} + \cdots + B_p^2 Y_{t-1} + A^2 U_t, \text{ if } s_t = 2 \end{matrix}. \tag{2}$$

s_t is assumed to follow the discrete time and discrete state hidden stochastic process of Markov chain. The probability in regime i next period conditional on that current regime is j[18] is fixed. This stochastic process is defined by transition matrix P as follows.

$$P = \begin{pmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{pmatrix} \tag{3}$$

$$p_{i,j} = \Pr(s_{t+1} = j \mid s_t = i), \ \sum_{j=1}^{2} p_{ij} = 1 \ \forall i, j \in (1, 2) \tag{4}$$

3.1.1 Estimation

The estimation of the Markov switching model is conducted by applying EM (Expectation-Maximisation) algorithm.[19] As mentioned in Ehrmann, Ellison and Valla (2003), "since the Markov chain is hidden, the likelihood function has a recursive nature: optimal inference in the current period depends on the optimal inference made in the previous period. Under such conditions the likelihood cannot be maximised using standard techniques." Under the procedure of EM

[16] According to the terminology by Krolzig (1997), this specification is called as MSIAH(m)-VAR(p).

[17] Superscripts denote the regime.

[18] i may equal to $j.i$ and j are either 1 or 2 in this case.

[19] For the details on the estimation, see Hamilton (1994) and Krolzig (1997).

algorithm, first, the hidden Markov chain is inferred in the expectation step for a given set of parameters, then the parameters for the hidden Markov chain is re-estimated in the maximisation step. These two steps are continued until convergence.

This procedure estimates coefficient matrix, variance-covariance matrix for each regime, transition matrix, and the optimal inference for the regimes throughout the sample period, which is called regime probabilities $\widehat{\xi}_t^i$, where T denotes the ending period for estimation.

$$\widehat{\xi}_t^i = \Pr\left(s_t = i\right) \text{ for } i = 1, 2 \text{ and } t = 1, \cdots T$$

There exist three types of regime probabilities depending on the differences in the information. The following analysis uses smoothed probabilities which are defined as below.

$$\widehat{\xi}_{t|\tau}^i, \; t < \tau \leq T$$

3.1.2 Identification

Matrix A^i is computed from the regime dependent variance covariance matrix from reduced form VAR Σ^i.

$$\Sigma^i = E\left(A^i U_t U_t' A^{i\prime}\right) = A^i I A^{i\prime} = A^i A^{i\prime} \tag{5}$$

Matrix A^i has K^2 elements, on the other hand Σ^i has only $\frac{K(K+1)}{2}$ elements. In order that A^i is defined from equation (5), there exist $\frac{K(K-1)}{2}$ missing restrictions. Sims (1980) introduces additional restriction based on recursive structure so that A^i is just identified from equation (5). If A^i is restricted to be a lower triangular matrix, A^i is easily recovered by applying Choleski decomposition to equation (5).

When using the Choleski decomposition, the order of the variables in VAR may have significant effect on the shape of impulse response function since, for example, disturbance to the second variables has no contemporaneous effect on the first variables. In the analysis below, I choose the very conventional order of the variables according to such researches as Christiano, Eichenbaum and Evans (1999) and Teruyama (2001). For the four variables VAR, the order is output, price level, call rate and money supply. For the five variables VAR, the order is output, price level, leading indicator to the price level, call rate and money supply.

3.1.3 Impulse Response

Regime-dependent impulse response functions depict the relationship between endogenous variables and fundamental disturbances within a regime. As is standard approach for impulse responses, they draw expected changes in the endogenous variables after a one standard deviation shock to one of the fundamental disturbances. However, regime-dependent impulse response functions are conditional on regime prevailing at the time of the disturbance and throughout the duration of the responses. Therefore, as mentioned earlier, this concept is valid only when each regime is persistent.

Mathematically, this regime-dependent impulse response function at time $t+h$ for the case of the one standard error shock to kth fundamental disturbances at time t when the prevailing regime is i is expressed as follows.

$$\frac{\partial E_t Y_{t+h}}{\partial U_{k,t}}|_{s_t=\cdots=s_{t+h}=i} = \theta^i_{k,h}, \text{ for } h \geq 0$$

A series of K dimensional response vectors $\theta^i_{k,1}$,..., $\theta^i_{k,h}$ show the response of the endogenous variables to the shock to kth fundamental disturbances. Here, the duration for the impulse response is set at 48 months as this is reasonable length of time span judged from the expected duration of each regime estimated below.

These response vectors are computed by combining the unrestricted parameter estimates of reduced-form Markov switching vector autoregression model B and identified matrix A. The first response vector is easily computed since this is a case where a one standard shock is added to the kth fundamental disturbances which is shown as the initial disturbance vector U_0=$(0, \cdots, 1, \cdots, 0)$, namely a vector of zeros apart from the kth element which is one. Using equation (2), this is shown as

$$\widehat{\theta}^i_{k,0} = \widehat{A}^i U_0. \tag{6}$$

The remaining response vectors are also easily calculated by solving forward for the endogenous variables in equation (2).

$$\widehat{\theta}^i_{k,h} = \sum_{j=1}^{\min(h,p)} \left(\widehat{B}^i_j\right)^{h-j-1} \widehat{A}^i U_0, \text{ for } h > 0 \tag{7}$$

3.1.4 Confidence Interval

Bootstrapping is now widely used to gauge the precision of the impulse response function.[20] However, the bootstrapping in Markov switching model is complicated due to the existence of hidden Markov chain determining the regimes. Therefore, it needs to first compute artificial history for the regimes. I follow the procedure advocated by Ehrmann, Ellison and Valla (2003) as below.

1) Create a history for the hidden regimes s_t

This can be done recursively using the definition of a Markov process in equation (3) and (4), and replacing the transition matrix with its estimated

[20] It is widely recognised that bootstrapping method may be inconsistent for autoregressive models with unit roots. However, that for non-stationary VAR is not very clear. Although Choi (2002) reports that bootstrapping may be inconsistent for non-stationary bivariate AR process, I will not consider this point as nothing has been still very clear for VAR with more than two variables.

value $\widehat{P}$. At each time t we draw a random number from a uniform $[0,1]$ distribution and compare it with the conditional transition probabilities to determine whether there is a switch in regime.

2) Create a history for the endogenous variables

Again, this is done recursively, on the basis of equation (2). All parameters are replaced by their estimated values and new fundamental residuals are drawn from the normal distribution $U_t \tilde{} N(0, I_K)$. Equation (2) can then be applied recursively using the artificial regime history created in step one.

3) Estimate a Markov switching vector autoregression

Using the data from the artificial history created in step two, a Markov switching vector autoregression is re-estimated. Estimation gives bootstrapped estimates of the parameters $\left\{\widetilde{v}^i, \widetilde{B}_1^i, \cdots, \widetilde{B}_p^i, \widetilde{\Sigma}^i\right\}$ for $i = 1,2$, the transition matrix $\widetilde{P}$, and the smoothed probabilities $\widehat{\xi}_t^i$ for $i = 1,2$ and $t = 1, ..., T$.

4) Impose identifying restrictions

Applying the same restrictions as the data, recursive structure in this case, provides bootstrapped estimates of the matrices $\widetilde{A}^1$ and, $\widetilde{A}^2$.

5) Calculate the bootstrapped estimates of the response vectors

Substituting the new parameters $\widetilde{B}_1^i, \cdots, \widetilde{B}_p^i$ and $\widetilde{A}^i$ into equation (6) and (7) gives bootstrapped estimates of the response vectors $\theta_{k,1}^i$,..., $\theta_{k,h}^i$ for $k = 1, .., K$ and $i = 1,2$.

Applying the above five steps for a sufficiently large number of histories gives a numerical approximation to the distribution of the original estimates of regime vectors. In this analysis, bootstrapping is conducted 100 times. The distribution obtained from 100 times bootstrapping forms the basis for the adding confidence interval bands to the impulse response functions.

3.2 Results

First, we will see the impulse responses from the linear VAR model as a reference for further analysis. Then, the results from identified Markov switching vectorautoregression models are shown.

3.2.1 Linear model

The linear VAR as below is estimated for the periods of January 1980 to August 2002 and January 1985 to August 2002. As four and five variable VAR are estimated respectively, in total, four VAR models are estimated.

$$Y_t = v_1 + B_1 Y_{t-1} + AU_t$$

Lag length is chosen as one except for the VAR of the four variables system for the periods of January 1980 to August 2002, in which the number of lags are two. Although in linear case information criteria employed here, namely AIC, HQ and SBIC, usually suggest that the optimal lag length is longer than the non-linear case,[21] the lag length are set to be the same as the ones for the non-linear case so that the direct comparison of impulse responses is possible without any distortion from the difference in the models.

Table 1 shows the estimated parameters[22] for all four VAR models. It may be possible to show the matrix A, and reproduce monetary reaction function. However, Rudebusch (1998) claims that it is suspicious to consider the monetary reaction function derived from VAR model as the true one since the relationship between the parameters obtained from VAR and deep structural parameter in the true monetary reaction function is unclear.[23] Therefore, it will not be shown.

A shock to nominal interest rate Chart 1 draws the impulse responses from the four variable system to the positive shock on call rate. Almost similar results are obtained in both models with different starting date. Positive shock to call rate will lower the output level and money supply. However, as contrary to the theory, monetary tightening here is bringing higher price level initially. This is indeed the price puzzle mentioned earlier.

Chart 2 shows the impulse responses to the same shock from the five variable VAR which include the leading indicator for the future inflation in order to avoid price puzzle. As indeed suggested by prior researches, the degree of price puzzle is significantly mitigated compared to the four variables case as above. Other responses seem to be reasonable except for the persistent increase in money supply in the case of the estimated period from 1985.[24]

Although very rough, in both charts the effect of monetary policy seems to be weaker in the estimated periods from 1985. This may already suggest the declining trend in the effectiveness of monetary policy through interest rate channel.

A shock to money supply Chart 3 depicts the impulse responses to the shock on the money supply in the four variables VAR. A shock to money supply

[21] However, the results are almost same with reasonable lag length.

[22] Sims (1980) points out that "Because estimated AR coefficients are highly correlated, standard errors on the individual coefficients provide little of the sort of insight into the shape of likelihood we ordinarily glean from starndard errors of regression coefficients." Therefore, here just information about parameters are introduced.

[23] In its title and abstract, Rudebusch (1998) claims that "Do measures of monetary policy in a VAR make sence? No. In many vector autoregressions (VARs), monetary policy shocks are identified with the least squares residuals from a regression on the federal funds rate on an assortment of variables. Such regressions appear to be structurally fragile and are at odds with other evidence on the nature of the U.S. federal Reserve's reaction function; furthermore, the residuals from these regressions show little correlation across various VARs or with funds rate shocks that are derived from forward-looking financial markets."

[24] This may be due to the fact that the relationshp between the money supply and other macroeconomic variables becomes very unclear in 1990s.

increases the output and price level and at the same time is supposed to lower the interest rate according to the conventional LM theory.[25] However interest rate is initially increasing after the expansion of money supply. This is indeed the liquidity puzzle. From the reason mentioned earlier, no measure is taken against liquidity puzzle in this analysis.

As for chart 4 which shows the same impulse responses in five variables system, all the results are similar and reasonable except that liquidity puzzle is occurring.

Contrary to the conjecture above, no significant chronological tendency in the effect of monetary policy has been found in the case with the transmission mechanism through money supply.

3.2.2 Identified Markov switching model

To check the stability of the monetary policy effect and the conclusion advocated by Miyao (2000) and Kimura, Kobayashi, Muranaga and Ugai (2002). As in the case of linear VAR models, four identified Markov switching vector autoregression models are estimated. Results from all four models are shown below.

Estimated period: 1980-2000

Case with four endogenous variables Estimated parameters including coefficient, the transition matrix, the variance-covariance matrix for the unrestricted VAR and information criterion as well as the results from linearity tests are shown in Table 2.

The linearity test suggest that the model is non-linear and parameters switch significantly between regimes. Furthermore, each regime is very persistent according to transition matrix. Therefore, in this case regime dependent impulse responses will be a quite useful analytical tool.

Although not shown here, diagnostic tests in all cases mentioned later confirm that errors are considered to be normally independently distributed.[26] Hence, even if some of the endogenous variables are not stationary, this does not impose problems with the estimations.

Chart 5 shows smoothed regime probabilities, which suggest that the economy is in regime one throughout 1980s and regime two after 1995. The period between 1990 and 1995 can be considered as transition period.

Impulse responses to nominal interest rate shock are shown in Chart 6. Dotted lines are confidence interval for one standard error from bootstrapping. In

[25] Although conventional, recently McCallum and Nelson (1999) derives the LM curve, or money demand function equivalently, in an optimised framework.

[26] Results from all the other three models below show that the each regime is distinct and persistent, and further diagnostic tests support that they are all congruent. Hence, nothing will be mentioned for the usefulness of regime-dependent impulse responses and diagnostic tests hereafter.

regime one, impulse responses as expected[27] are obtained with slight price puzzle. However in regime two, the positive shock to nominal interest rate increases output and money supply.[28] This impulse responses are hardly understood by the standard macroeconomic theory.

As for the impulse responses to money supply shock in chart 7, theoretically consistent impulse response function is obtained without liquidity puzzle in regime one, but in regime two, a shock to money supply brings lower level of price levels.[29]

Case with five endogenous variables Table 3 summarises the estimated results.

Chart 8 shows smoothed regime probabilities which suggest that the economy is in regime one almost during 1980s and regime two in 1990s and after.

The impulse responses to nominal interest rate shock in chart 9 show that in regime one, theory consistent impulse responses are obtained without price puzzle. However in regime two, the positive shock to nominal interest rate raises the output and the leading indicator for the future inflation. Further it just has a slight restraining effect on the price level.

As for the impulse responses to money supply shock in chart 10, impulse responses as expected are obtained in both regimes with some odd responses of WPI which tend to decrease after monetary expansion shock. However, comparing the magnitude of the responses, while there is no significant difference in price level reaction between the two regimes, the response of output is much stronger in regime one than in regime two.

Estimated period: 1985-2002

Case with four endogenous variables Table 4 summarises the estimated results.

Smoothed regime probabilities in chart 11 show that the economy is in regime one throughout the 1980s and in regime two after 1995. Period between them can be considered as the transition period.

The impulse responses to nominal interest rate shock in chart 12 show that results as expected are obtained in both regimes with price puzzle solved in regime two. However, the increase in call rate raises the money supply in this case.[30]

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[27] "Impulse responses as expected" means the impulse responses with common features such as price puzzle or iquidity puzzle obtained in many prior researches.

[28] Notice that one root of the companion matrix is very slightly larger that unity in regime two, which is 1.0228.

[29] Kimura, Kobayashi, Muranaga and Ugai (2002) also states on the shape of recent impulse responses that "we seem to be witnessing something very unusual in the relationship between money and the economy.

[30] It should be noted that two roots from the companion matrix is slightly larger than unity(1.0081 and 1.0041) in regime two.

As for the impulse responses to money supply shock in chart 13, almost theoretically consistent impulse responses are obtained in regime one. However, in regime two, responses of all the endogenous variables are deviating to the wrong direction.

Case with five endogenous variables Table 5 summarises the estimated results.

Smoothed regime probabilities in chart 14 show that the economy is in regime one throughout the 1980s and in regime two after 1995. Period between them can be considered as the transition period.

The impulse responses to nominal interest rate shock in chart 15 shows that impulse responses as expected are obtained in regime one with slightly odd responses of money supply. Looking into the responses of price related variables, responses of CPI and WPI decrease in regime one, but they are increasing in regime two.

As for the impulse responses to money supply shock in chart 16, impulse responses as expected are obtained in regime one with liquidity puzzle. However, in regime two, responses of output and WPI are moving in the opposite direction to the prediction.

4 Model with Implicit Interest Rate Channel

The findings in the previous section suggest that 1) the interest rate channel since the introduction of *de-facto* zero nominal interest rate is collapsed as is expected, 2) the effect of monetary expansion may be smaller now than before. As for the second point, indeed, proper comparison of the effect of monetary expansion between in regime one and two is unfeasible since the interest rate channel is not functioning after 1996 but it is included in the whole sample.[31] Although VAR coefficients on call rate as a explanatory variable should not be significantly different from zero in statistical sense as it has been almost zero without any significant fluctuation since then, the parameters are not remarkably smaller in regime two than in regime one.

Reflecting these caveats, I here construct three variables VAR which consists of price level, output level and money supply, namely VAR with implicit interest rate channel. By doing this, we can learn about the consequences of non-negativity constraint of nominal interest rate on the effect of monetary expansion without any possible distortion on estimation from almost fixed interest rate since 1996 so that we could confirm the latter finding mentioned above.

That the analysis on the monetary transmission mechanism without explicit interest rate channel is useless is possible criticism. However, some prior researches suggest alternative channels where the money could have impact on

[31] Further, the monetary policy rule employed by the Bank of Japan must be quite different between before 1996 and after 1996 as the room for the further lowering the nominal interest rate is very limited.

other macroeconomic variables such as price level and output, even if the traditional interest rate channel, which is defined as LM curve, is not functioning due to the zero nominal interest rate bound. Koenig (1990) reports that empirically real money growth enters positively and significantly in consumption equation. Recently, the portfolio re-balancing effect,[32] supported by such researches as Meltzer (1995) McCallum (2000), and Orphanides and Wieland (2000), has become popular as one of the measure to combat deflation under zero nominal interest rate. According to this theory, as long as the money is not the perfect substitute for all other asset, monetary expansion affects nominal demand both through wealth and substitution effects on real assets, and through adjustments in a wide range of financial yields relevant to expenditure decisions. Further, Ireland (2001) constructs a model where the utility obtained from consumption and money holdings are non-separable so that the money could have a direct effect on consumption decision, although the effect through this channel turns out to be minuscule.

Although I here do not specify any candidate of transmission channel around monetary expansion as above but consider that such transmission mechanism is implicitly included, how the transmission channel of monetary expansion on other macroeconomic variables changed due to the introduction of zero nominal interest rate will be monitored in this three variables VAR estimated here.

4.1 Results

The estimated period for this three variables VAR is January 1985 to August 2002.[33] Again, the number of lags are chosen as the majority of the suggested optimal length of lags according to the three information criteria: AIC, HQ and SBIC and the number of regimes is fixed at two.

Table 6 shows the estimated results. Information Criteria suggests that the model should be estimated with two lags. That the parameters are quite different between regime one and two as well as each regime is quite long-lived suggest usefulness of the impulse response analysis with identified Markov Switching model.

Chart 17 shows smoothed regime probabilities, which seem to suggest that the economy is in regime one throughout 1980s and regime two after 1995 although there exists some short-lived switching. The period between 1990 and 1995 can be considered as transition period.

Impulse responses to nominal interest rate shock are shown in Chart 18. In both regimes, monetary expansion results in higher price level and output. However this positive effect is smaller and less long-lived in regime two than in regime one. This result indicates that the effect of monetary expansion becomes

[32]Kimura, Kobayashi, Muranaga and Ugai (2002) shows three candidates for the channels through which this effect is working: a relative asset-supply effect, a reduction of transaction cost by providing amply money, and the expectation effect.

[33]If we estimate the model from January 1980, the regime switches around 1990. As the aim of this section is to understand the effect of zero nominal interest rate bound on the monetary transmission mechanism, the analysis with the estimated period starting at 1980 is excluded.

significantly smaller when the nominal interest rate is almost zero.[34]

5 Conclusion

Several intriguing results are obtained from five identified Markov Switching Vector Autoregression models I have estimated. These are summarised as follows;

1) There seems to be at least one break point of macroeconomic dynamics, which depict the transmission mechanisms of monetary policy, during 1990s. Candidates for this break point are sometime around 1990 and around 1995 with more possibility.

2) Monetary policy's impact on macroeconomy, whether it be through nominal interest rate or money supply, becomes weaker than before or is not fulfilling the role as expected in the regime which is prevailing now. Its effects on output or price level tend to be smaller now. Furthermore, impulse responses which cannot be understood from standard macroeconomic theory has been found in the currently prevailing regimes when the break point is just the time when the Bank of Japan resumed the *de-facto* zero nominal interest rate policy in 1996.

3) The price puzzle and the liquidity puzzle, which usually happen when one estimates the impulse response functions of VAR and indeed are found in the linear VAR models estimated in this paper, are not observed in some impulse responses for regime one, namely before 1990s.

1) and 2) support the conclusions in Miyao (2000) and Kimura, Kobayashi, Muranaga and Ugai (2002). Although recent research by Boivin and Giannoni (2003) states that "Recent studies using vector autoregressions (VAR) find that the impact of monetary policy "shocks" - defined as unexpected exogenous changes in the Federal funds rate - have had a much smaller impact on output and inflation since the beginning of the 1980's. .... An alternative interpretation could thus be that monetary policy itself has come to systematically respond more decisively to economic conditions, thereby moderating the real effects of demand fluctuations. In this case, the change in the responses to monetary shocks would reflect an improvement in the effectiveness of monetary policy", observing that the possible break point is around 1995 when the de-facto zero nominal interest rate policy has started, it is not feasible to assume that the smaller responses to monetary shocks are due to the improvement in the effectiveness of monetary policy in Japan. Hence, it could be concluded that the effects of monetary policy have become weaker during 1990s.

Furthermore, 2) suggests that the Japanese economy may now be in the state where the conventional monetary transmission mechanism is not fully functioning and this seems to be due to the introduction of *de-facto* zero nominal interest

[34] Fujiwara (2003) confirms that the same results are obtained if the order of the variables are changed.

rate policy since 1996.[35] For example, if we look carefully at the impulse responses of all three models including explicit interest rate channel which further suggest that break point is around 1995, the impulse responses after the shock to the money supply is hard to be interpreted. Even if we interpret this finding as the failure of the proper estimation due to the almost fixed interest rate since 1996, the results from three variable VAR reports that the effect of monetary expansion is significantly smaller. These suggest that the current problem the Bank of Japan is facing, deflation under the almost zero nominal interest rate, is very tricky. If the Bank of Japan could control the money supply by quantitative easing, its role on other macroeconomic variables would be extremely limited. The monetary expansion without the transmission mechanism through nominal interest rate channel seems to have just inadequate impact on macroeconomic variables.

The existence of the break in the macroeconomic dynamics has some very important implication for the dynamic macro modelling, either in the form of VAR or DSGE. Needless to mention VAR, the analysis on macroeconomic dynamics without considering the possible structural break may lead to the misjudgment of the current state and wrongful monetary policy.[36] Even for the dynamic stochastic general equilibrium model either in the form of strong or weak econometric interpretation in the terminology of Geweke (1999),[37] the model with parameters which is set based on the whole sample, may have wrong explanation of the current state of economy. Tendency of the DSGE becoming more data-oriented, namely more in the strong econometric interpretation, as in Ireland (1999) and Smets and Wouters (2002) should be preferable as it makes DSGE more realistic and useful for the policy analysis. However, caution always needs to be paid to use the model for the analysis on the current economic state as there may have been some structural break and the economic dynamics might be quite different at the moment.

Probably, more intriguing finding is 3). This by-product hints another explanation for the famous puzzles in VAR models: price puzzle and liquidity puzzle. Concerning the former, as mentioned earlier, the conventional explanation is the incorrect specification of central bank's information set when deciding monetary policy as in Sims (1992). The recently established one is the effect through the cost channel of monetary policy in Barth and Ramey (2001). For the latter, as mentioned in Bernanke and Mihov (1998), the misspecification in

[35] Ueda (2003) further points out that the asset price deflation causes the "financial accelerator" to work by reducing the collateral value, and this results in the weaker monetary policy effects.

[36] Indeed, Kimura, Kobayashi, Muranaga and Ugai (2002) criticises Baig (2002) which argues that Japan's data support the existence of the monetary base channel even at zero interest based on the results obtained from time invariant VAR for the whole sample.

[37] The weak econometric interpretation is such that the parameters of DSGE model are calibrated in such a way that selected theoretical moments given by the model match as closely as possible those observed in the data, which is first adovocated by Kydland and Prescott (1982). On the other hand, the stong econometric interpretation attempts to provide a full characterisation of the observed data series. Details on the these two interpretations are found in Geweke (1999) or Smets and Wouters (2002).

the way of monetary policy conducted by central bank is the most persuasive clarification so far. However, the result in this paper proposes an integrated explanation to these two puzzles, each with quite different explanations so far. Results seem to suggest that the cause of these puzzles is the coexistence of equilibrium dynamics and disequilibrium dynamics in economic time series. As long as the usual economic time series contain the disequilibrium dynamics due to the bounded rationality of the economic agents to some extent, the derivation of impulse responses according macroeconomic theory tends to be impaired, although I admit that further research will be needed in order to establish this hypothesis more persuasive for the explanation of conventional puzzles.[38]

[38]One possible caveat on this point is that we may need to employ different identification when comparing the impulse responses between regimes.

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Table 1

Coefficients of the linear VAR models

VAR(4): 1980-

	Y	P	I	M
C	0.0695	0.0440	7.7055	0.1674
Y(-1)	0.5552	-0.0052	1.9159	0.0168
Y(-2)	0.4218	0.0108	-1.0152	-0.0041
P(-1)	0.6280	0.9127	12.5696	-0.1358
P(-2)	-0.6768	0.0650	-15.5834	0.0913
I(-1)	-0.0033	0.0012	1.2688	0.0000
I(-2)	0.0025	-0.0010	-0.3156	-0.0005
M(-1)	1.0428	-0.0022	-0.5851	1.2497
M(-2)	-1.0261	0.0043	0.7152	-0.2510

VAR(5): 1980-

	Y	P	W	I	M
C	-0.3882	0.0917	0.5258	5.8745	0.1201
Y(-1)	0.9447	0.0052	0.0118	1.1876	0.0148
P(-1)	-0.1715	0.9845	-0.0010	-5.0760	-0.0819
W(-1)	0.1082	-0.0109	0.9118	0.8545	0.0224
I(-1)	-0.0011	0.0004	0.0007	0.9457	-0.0009
M(-1)	0.0602	0.0003	-0.0111	0.5190	1.0057

VAR(4): 1985-

	Y	P	I	M
C	0.1768	0.0020	4.9806	0.2667
Y(-1)	0.9228	0.0100	0.9908	0.0056
P(-1)	-0.0951	0.9873	-3.1573	-0.0746
I(-1)	0.0006	0.0002	0.9706	-0.0005
M(-1)	0.0395	0.0007	0.3190	1.0034

VAR(5): 1985-

	Y	P	W	I	M
C	-0.3003	-0.1419	0.0254	-22.9849	0.4078
Y(-1)	0.9174	0.0083	0.0172	0.6704	0.0072
P(-1)	-0.1597	0.9678	-0.0375	-6.9472	-0.0555
W(-1)	0.1015	0.0306	0.9962	5.9529	-0.0300
I(-1)	-0.0005	-0.0001	-0.0001	0.9077	-0.0002
M(-1)	0.0610	0.0072	0.0054	1.5792	0.9971

Y: Output
P: Price level
I: Call rate
M: Money supply
W: Leading indicator to price

Table 2

Estimated results of MSVAR(4): 1980-

(1) Coefficients

Regime 1

	Y	P	I	M
C	-0.0408	-0.0140	17.1720	0.2692
Y(-1)	0.5173	-0.0138	4.2774	0.0247
Y(-2)	0.4262	0.0037	-1.1016	0.0041
P(-1)	0.4994	0.7764	22.7290	-0.1035
P(-2)	-0.5563	0.1955	-25.8130	0.0514
I(-1)	-0.0025	0.0016	1.2305	-0.0009
I(-2)	0.0018	-0.0009	-0.3213	-0.0002
M(-1)	1.2238	0.1311	-19.1590	1.0535
M(-2)	-1.1875	-0.1190	18.0260	-0.0638

Regime 2

	Y	P	I	M
C	0.5866	0.1886	1.4221	0.1084
Y(-1)	0.5307	0.0024	0.1981	-0.0016
Y(-2)	0.3992	0.0086	0.1291	0.0001
P(-1)	0.7208	0.9382	-2.1532	-0.0979
P(-2)	-0.7495	0.0276	1.0634	0.0815
I(-1)	0.0033	-0.0048	1.1232	0.0093
I(-2)	-0.0038	0.0046	-0.1150	-0.0089
M(-1)	0.6142	0.0359	0.4330	1.0575
M(-2)	-0.6227	-0.0411	-0.2999	-0.0591

(2) Transition Matrix

	Regime 1	Regime 2
Regime 1	0.95581	0.049179
Regime 2	0.04419	0.95082

Note that p[i][j]=Pr{s(t)=i|s(t-1)=j}

(3) Variance-covariance Matrix

Regime 1

	Y	P	I	M
Y	0.000175	-0.000002	-0.000102	0.000002
P	-0.000002	0.000007	0.000025	0.000000
I	-0.000102	0.000025	0.112750	-0.000054
M	0.000002	0.000000	-0.000054	0.000005

Regime 2

	Y	P	I	M
Y	0.000294	0.000003	0.000039	-0.000009
P	0.000003	0.000006	-0.000014	0.000000
I	0.000039	-0.000014	0.002149	0.000024
M	-0.000009	0.000000	0.000024	0.000006

(4) Information criteria

	AIC		HQ		SBIC	
	non-linear	linear	non-linear	linear	non-linear	linear
lag1	-23.8536	-22.6638	-23.5227	-22.5037	**-23.0295**	-22.265
lag2	**-24.0997**	-23.0714	**-23.5966**	-22.8252	-22.8469	-22.4583
lag3	-24.0603	-23.2027	-23.3841	-22.87	-22.3766	-22.3742

(5) Linearity test

LR linearity test: 373.6461 Chi(46)=[0.0000]** Chi(48)=[0.0000]** DAVIES=[0.0000]**

Table 3

Estimated results of MSVAR(5): 1980-

(1) Coefficients

Regime 1

	Y	P	W	I	M
C	-0.42758	0.025046	0.59212	48.92	0.36341
Y(-1)	0.71169	-0.005415	0.0096192	0.88083	0.010007
P(-1)	-0.5039	0.88947	-0.19915	-16.854	0.007324
W(-1)	0.082544	0.026607	0.98768	1.0253	-0.040242
I(-1)	-0.001135	8.50E-05	-0.000901	0.78122	-0.000758
M(-1)	0.23848	0.024525	0.020797	1.223	0.98384

Regime 2

	Y	P	W	I	M
C	-0.085371	-0.19993	0.40332	48.85	0.8577
Y(-1)	0.90721	0.007268	0.012851	1.1025	0.014648
P(-1)	-0.053213	0.95789	-0.006545	-1.7365	-0.035911
W(-1)	0.031685	0.045773	0.93667	-6.5443	-0.10673
I(-1)	0.000746	-0.000322	0.0004142	1.0166	0.000395
M(-1)	0.039241	0.009667	-0.009187	-1.0257	0.98276

(2) Transition Matrix

	Regime 1	Regime 2
Regime 1	0.97737	0.0055999
Regime 2	0.022627	0.9944

Note that p[i][j]=Pr{s(t)=i|s(t-1)=j}

(3) Variance-covariance Matrix

Regime 1

	Y	P	W	I	M
Y	0.000169	-0.000003	0.000001	-0.000243	0.000001
P	-0.000003	0.000007	0.000004	-0.000133	-0.000001
W	0.000001	0.000004	0.000018	0.000562	-0.000001
I	-0.000243	-0.000133	0.000562	0.120500	-0.000148
M	0.000001	-0.000001	-0.000001	-0.000148	0.000005

Regime 2

	Y	P	W	I	M
Y	0.000343	0.000007	0.000004	-0.000160	-0.000004
P	0.000007	0.000007	0.000002	0.000000	0.000000
W	0.000004	0.000002	0.000005	-0.000029	0.000000
I	-0.000160	0.000000	-0.000029	0.031529	0.000091
M	-0.000004	0.000000	0.000000	0.000091	0.000007

(4) Information criteria

	AIC		HQ		SBIC	
	non-linear	linear	non-linear	linear	non-linear	linear
lag1	-32.2633	-31.4575	**-31.7723**	-31.2174	**-31.0405**	-30.859
lag2	-32.5127	-31.9967	-31.7527	-31.6221	-30.6202	-31.064
lag3	-32.5713	-32.1453	-31.5409	-31.6355	-30.0055	-30.876

(5) Linearity test

LR linearity test: 312.3684 Chi(45) =[0.0000] ** Chi(47)=[0.0000] ** DAVIES=[0.0000] **

Table 4

Estimated results of MSVAR(4): 1985-

(1) Coefficients

Regime 1

	Y	P	I	M
C	0.10191	0.0074147	10.248	0.30894
Y(-1)	0.65916	-0.004709	3.6687	-0.003888
P(-1)	-0.50289	0.95779	-1.1131	-0.091206
I(-1)	0.00397	0.000467	0.94399	-0.000368
M(-1)	0.2428	0.013343	-1.4261	1.0083

Regime 2

	Y	P	I	M
C	1.392	0.095382	5.0982	0.38206
Y(-1)	0.89566	0.0067904	0.35374	0.0032747
P(-1)	-0.10815	0.98814	-1.7922	-0.074224
I(-1)	-0.001428	1.91E-05	1.0012	-0.000224
M(-1)	-0.02649	-0.004619	0.097018	0.99661

(2) Transition Matrix

	Regime 1	Regime 2
Regime 1	0.95776	0.028534
Regime 2	0.042243	0.97147

Note that p[i][j]=Pr{s(t)=i|s(t-1)=j}

(3) Variance-covariance Matrix

Regime 1

	Y	P	I	M
Y	0.000231	-0.000001	0.000024	-0.000003
P	-0.000001	0.000006	0.000009	0.000000
I	0.000024	0.000009	0.092869	0.000052
M	-0.000003	0.000000	0.000052	0.000005

Regime 2

	Y	P	I	M
Y	0.000358	0.000006	0.000037	-0.000009
P	0.000006	0.000006	-0.000009	0.000000
I	0.000037	-0.000009	0.002172	0.000022
M	-0.000009	0.000000	0.000022	0.000006

(4) Information criteria

	AIC		HQ		SBIC	
	non-linear	linear	non-linear	linear	non-linear	linear
lag1	**-33.9739**	-32.4835	**-33.3832**	-32.1945	**-32.5124**	-31.7686
lag2	-33.004	-32.7115	-32.089	-32.2605	-30.7407	-31.5958
lag3	-33.0054	-32.6285	-31.764	-32.0142	-29.9349	-31.1092

(5) Linearity test

LR linearity test: 322.3788 Chi(30) =[0.0000] ** Chi(32)=[0.0000] ** DAVIES=[0.0000] **

Table 5

Estimated results of MSVAR(5): 1985-

(1) Coefficients

Regime 1

	Y	P	W	I	M
C	-2.7892	-0.066981	0.22659	-37.171	0.4229
Y(-1)	0.51862	0.011168	0.060786	1.0719	0.007709
P(-1)	-1.0538	0.96667	0.029457	-11.243	-0.059449
W(-1)	0.60876	0.015462	0.95454	10.283	-0.025031
I(-1)	-0.000919	-7.67E-05	-0.000489	0.87223	-0.000313
M(-1)	0.45381	0.0063243	-0.027806	2.3517	0.99558

Regime 2

	Y	P	W	I	M
C	1.9582	-0.46163	0.53232	11.528	0.88541
Y(-1)	0.89788	0.0004474	0.0076759	0.40811	0.006486
P(-1)	-0.099399	0.96633	0.014411	-1.5283	-0.047127
W(-1)	-0.078493	0.081715	0.90963	-0.99393	-0.082133
I(-1)	-0.001232	-0.000348	0.0008973	1.0066	0.00033
M(-1)	-0.043014	0.015418	-0.014204	-0.11756	0.97948

(2) Transition Matrix

	Regime 1	Regime 2
Regime 1	0.9428	0.040416
Regime 2	0.057202	0.95958

Note that p[i][j]=Pr{s(t)=i|s(t-1)=j}

(3) Variance-covariance Matrix

Regime 1

	Y	P	W	I	M
Y	0.000215	0.000004	0.000005	-0.000361	-0.000001
P	0.000004	0.000009	0.000005	-0.000013	0.000001
W	0.000005	0.000005	0.000011	0.000097	0.000000
I	-0.000361	-0.000013	0.000097	0.085933	0.000071
M	-0.000001	0.000001	0.000000	0.000071	0.000005

Regime 2

	Y	P	W	I	M
Y	0.000355	0.000004	0.000004	0.000056	-0.000009
P	0.000004	0.000004	0.000000	-0.000002	-0.000001
W	0.000004	0.000000	0.000002	0.000000	0.000000
I	0.000056	-0.000002	0.000000	0.002252	0.000025
M	-0.000009	-0.000001	0.000000	0.000025	0.000007

(4) Information criteria

	AIC		HQ		SBIC	
	non-linear	linear	non-linear	linear	non-linear	linear
lag1	-23.8536	-22.6638	-23.5227	-22.5037	**-23.0295**	-22.265
lag2	**-24.0997**	-23.0714	**-23.5966**	-22.8252	-22.8469	-22.4583
lag3	-24.0603	-23.2027	-23.3841	-22.87	-22.3766	-22.3742

(5) Linearity test

LR linearity test: 408.4790 Chi(45) =[0.0000] ** Chi(47)=[0.0000] ** DAVIES=[0.0000] **

Table 6

Estimated results of MSVAR(4): 1980-

(1) Coefficients

Regime 1

	Y	P	M
C	-0.033628	0.23674	0.22428
Y(-1)	0.89938	-0.42752	-0.24083
Y(-2)	0.10595	0.20346	0.13481
P(-1)	0.017729	0.49619	-0.031192
P(-2)	0.0042932	0.45431	0.011571
M(-1)	0.096839	0.74418	1.1243
M(-2)	-0.10273	-0.67874	-0.10143

Regime 2

	Y	P	M
C	0.19879	-0.54708	-0.24824
Y(-1)	0.99354	2.5931	0.0038021
Y(-2)	-0.037222	-2.2468	0.066448
P(-1)	-0.0086305	0.45081	0.0067696
P(-2)	0.016762	0.3936	-0.015023
M(-1)	0.11904	0.62139	1.0813
M(-2)	-0.12134	-0.64253	-0.083541

(2) Transition Matrix

	Regime 1	Regime 2
Regime 1	0.93898	0.065057
Regime 2	0.061018	0.93494

Note that p[i][j]=Pr{s(t)=i|s(t-1)=j}

(3) Variance-covariance Matrix

Regime 1

	Y	P	M
Y	0.0000090	0.0000021	0.0000002
P	0.0000021	0.0001497	-0.0000058
M	0.0000002	-0.0000058	0.0000085

Regime 2

	Y	P	M
Y	0.0000021	0.0000027	-0.0000004
P	0.0000027	0.0003369	-0.0000102
M	-0.0000004	-0.0000102	0.0000027

(4) Information criteria

	AIC		HQ		SBIC	
	non-linear	linear	non-linear	linear	non-linear	linear
lag1	-23.4159	-23.1424	-23.1718	-23.0269	**-22.8122**	-22.8565
lag2	**-23.6227**	-23.3873	**-23.2618**	-23.2133	-22.7301	-22.9569
lag3	-23.4204	-23.3837	-22.9419	-23.1509	-22.237	-22.8079

(5) Linearity test

LR linearity test: 107.4325 Chi(27) =[0.0000] ** Chi(29)=[0.0000] ** DAVIES=[0.0000] **

Chart 1

Impulse responses to nominal interest rate shocks: Linear VAR(4) models

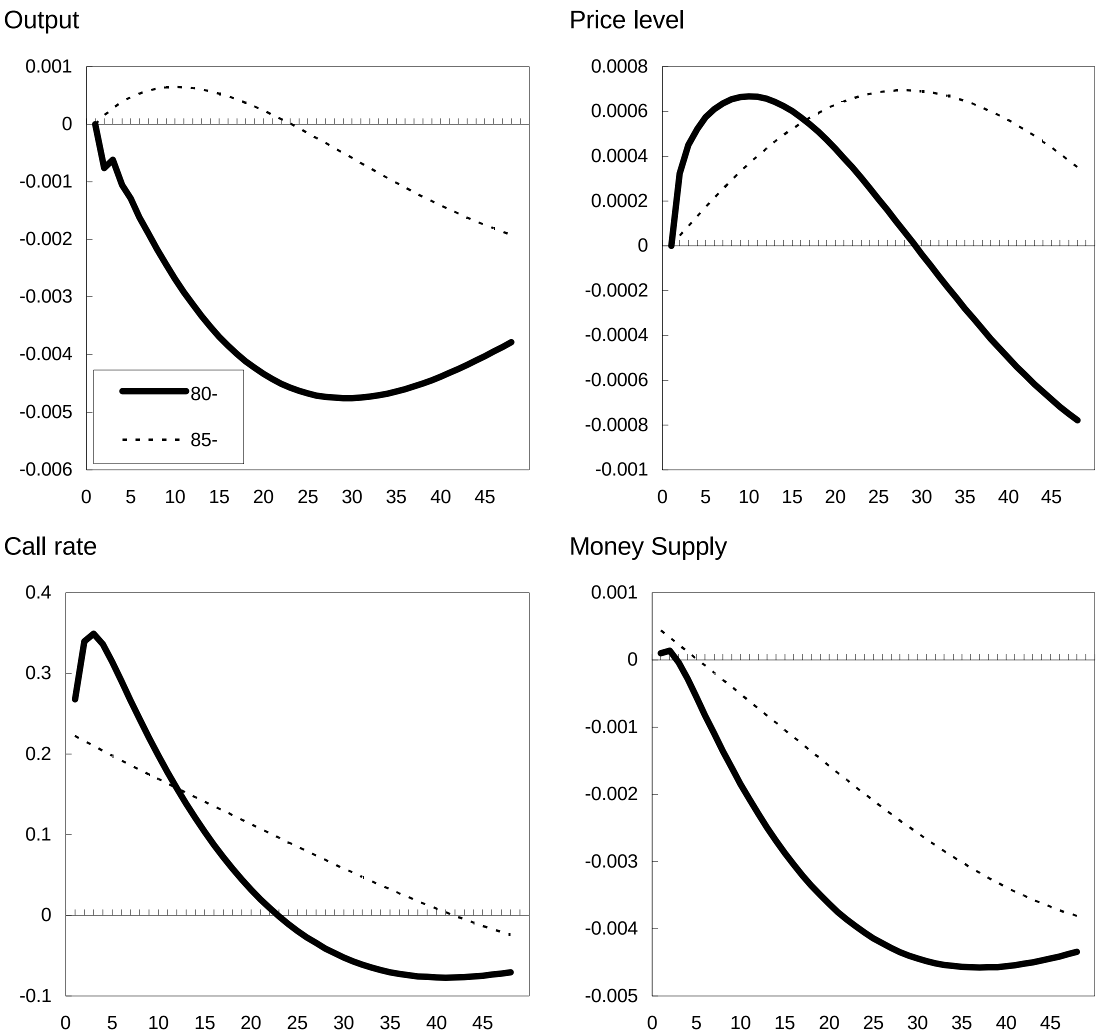


Chart 2

Impulse responses to nominal interest rate shocks: Linear VAR(5) models

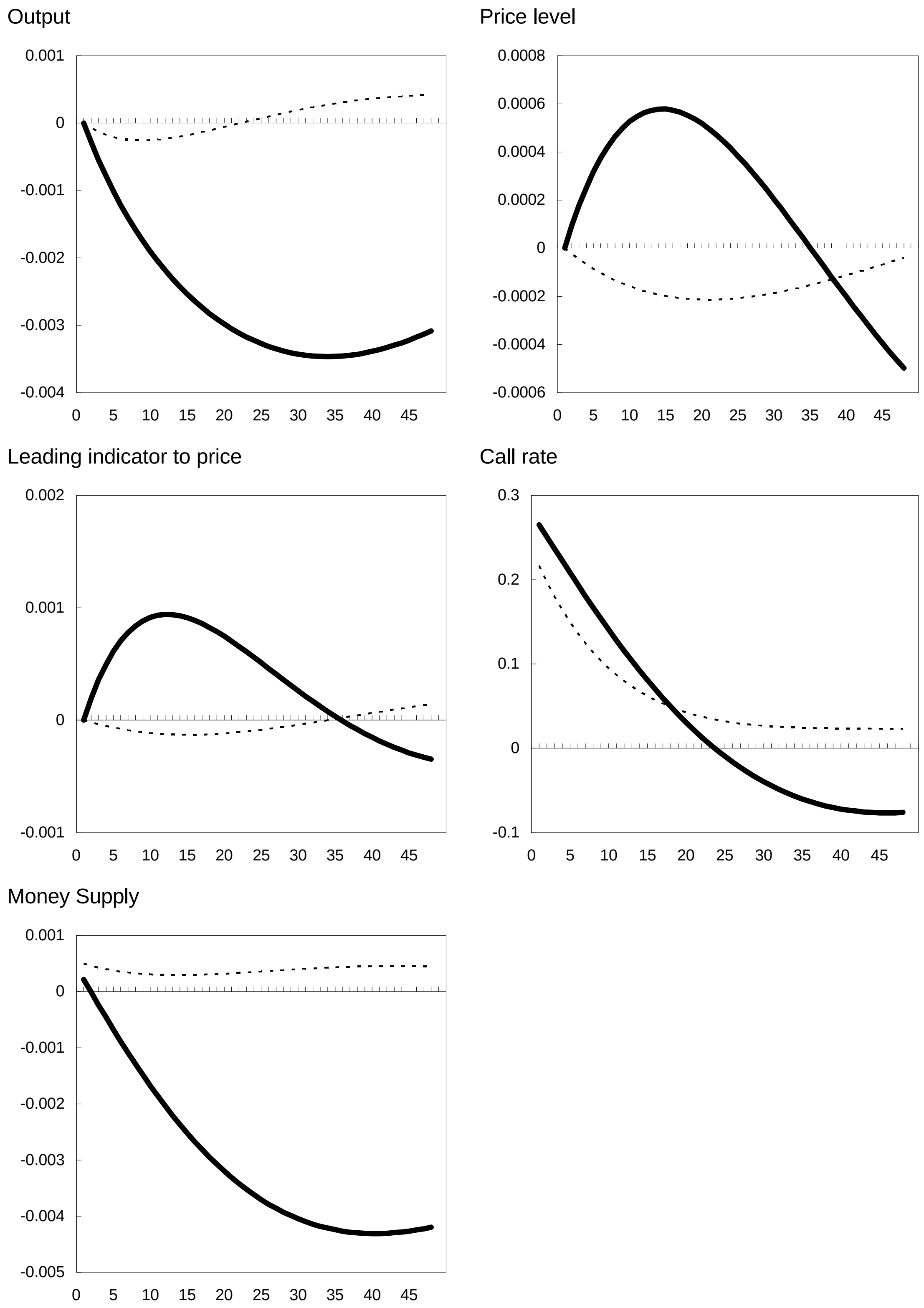


Chart 3

Impulse responses to monetary shocks: Linear VAR(4) models

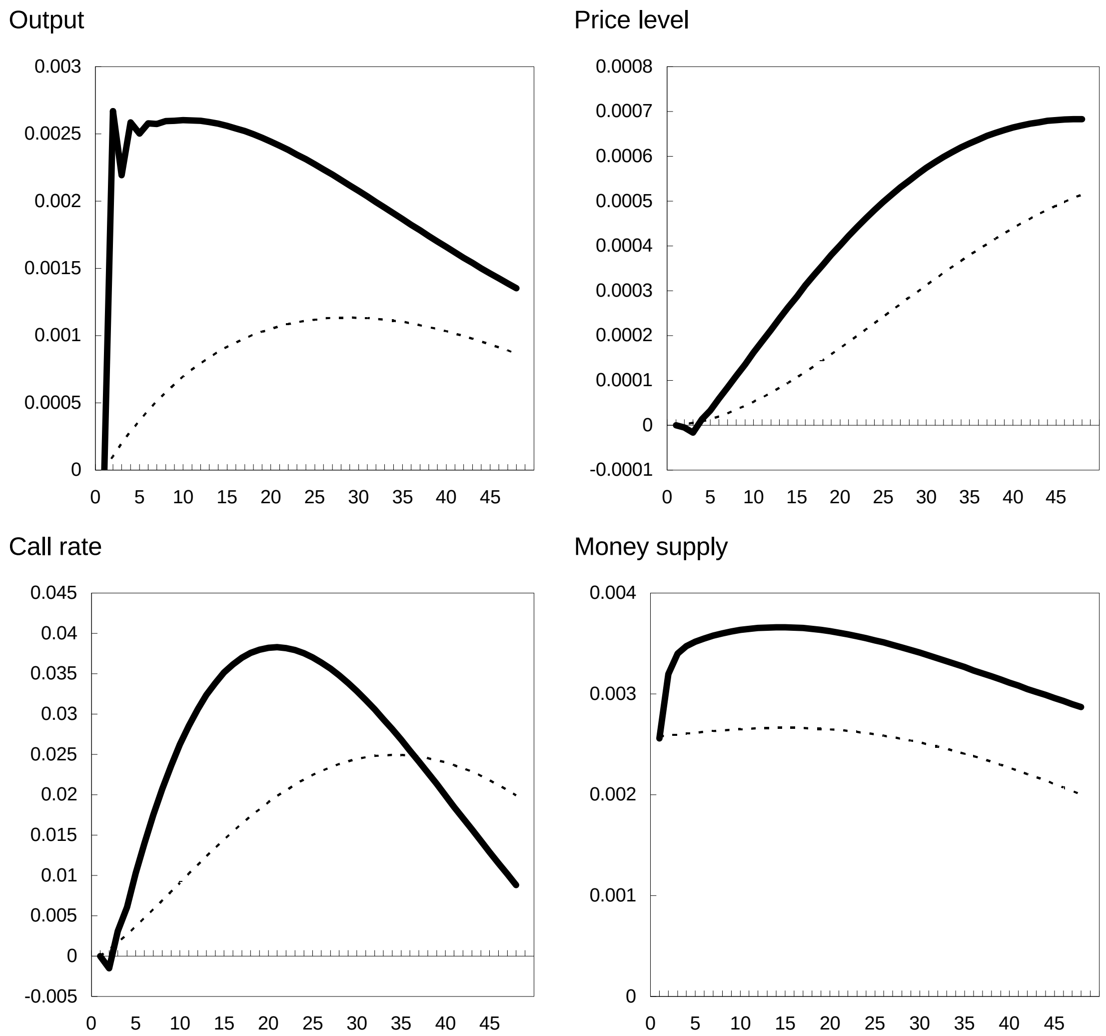


Chart 4

Impulse responses to monetary shocks: Linear VAR(5) models

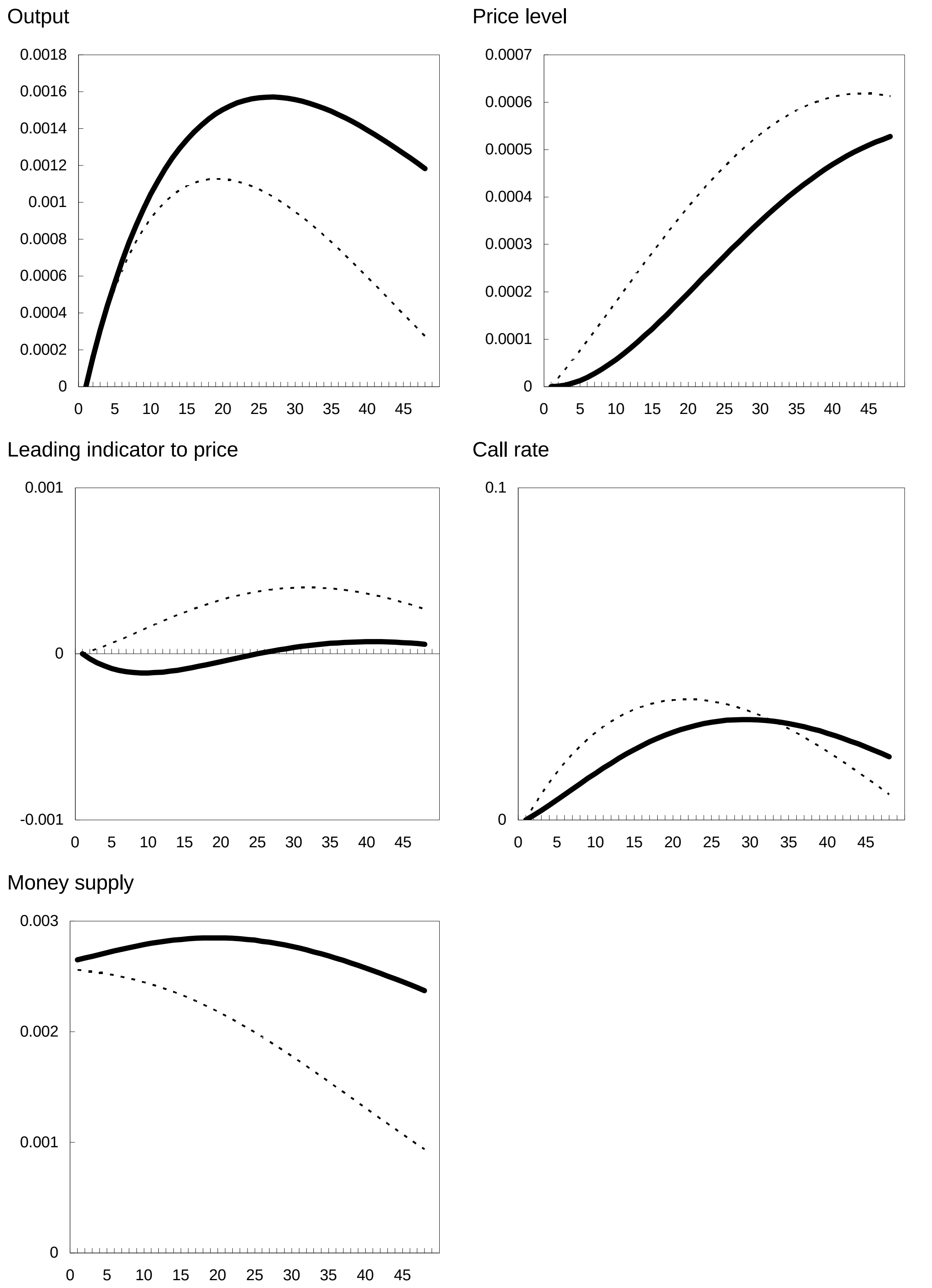


Chart 5

Regime probabilities

VAR(4): 1980-

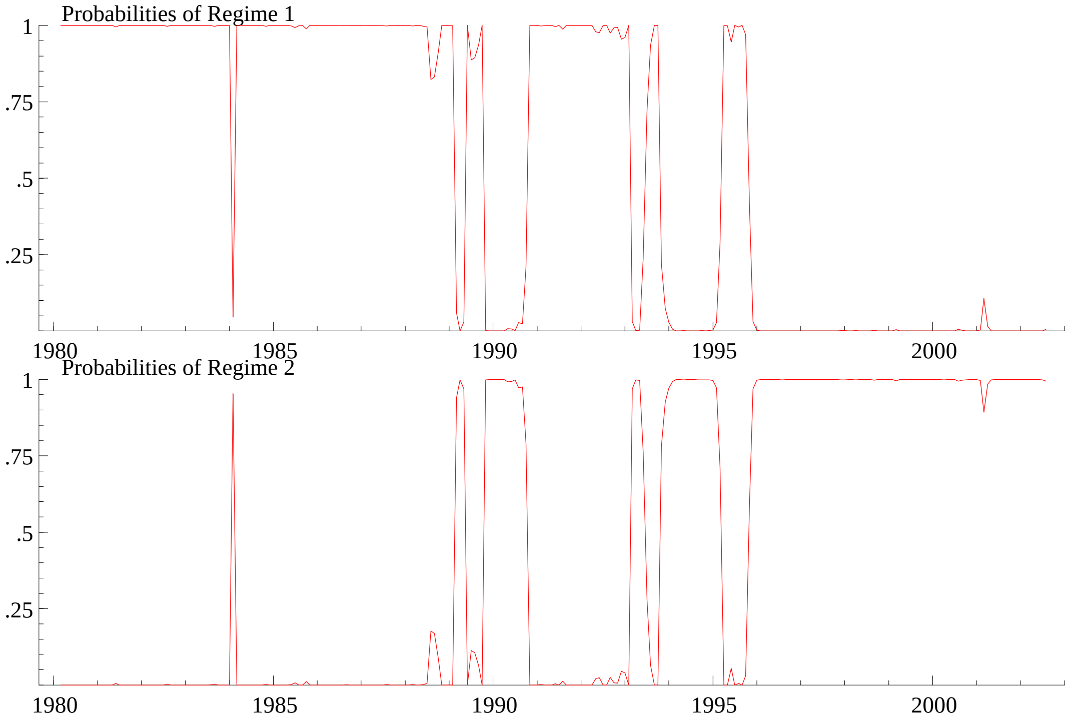


Chart 6

Impulse Responses to the nominal interest rate shock

VAR(4): 1980-

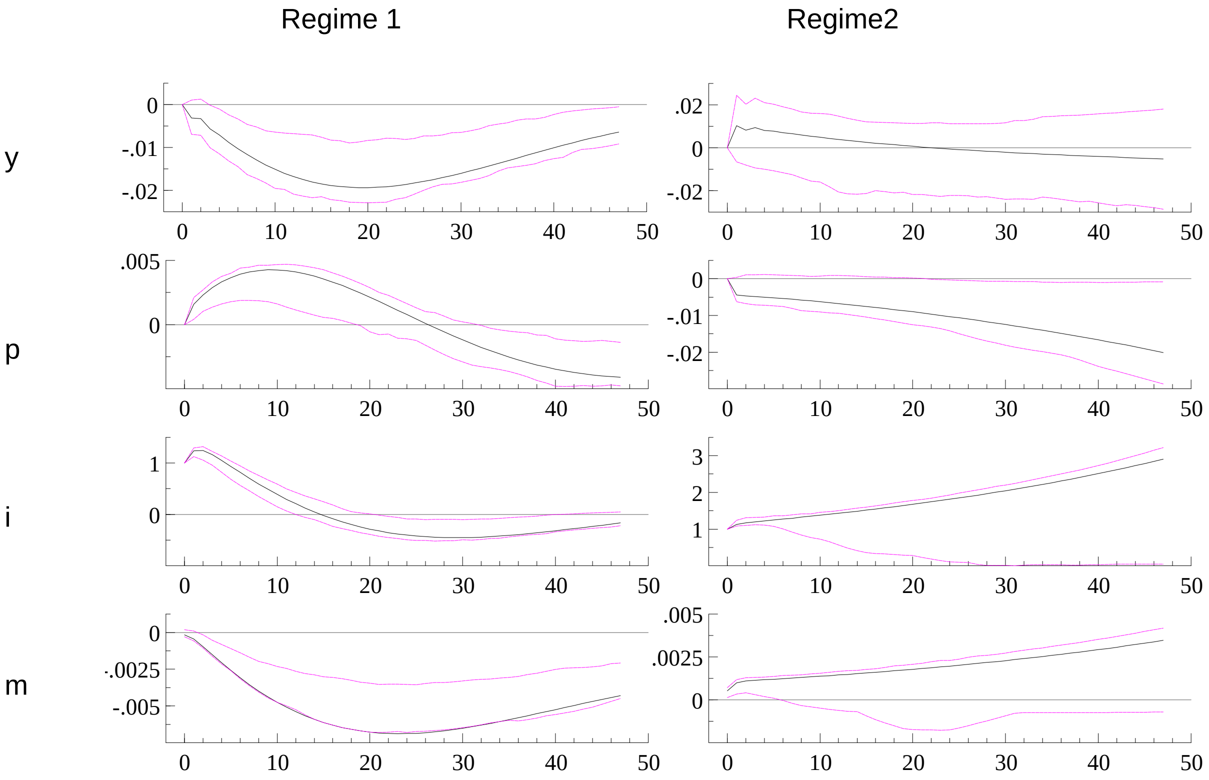


Chart 7

Impulse Responses to the monetary shock

VAR(4): 1980-

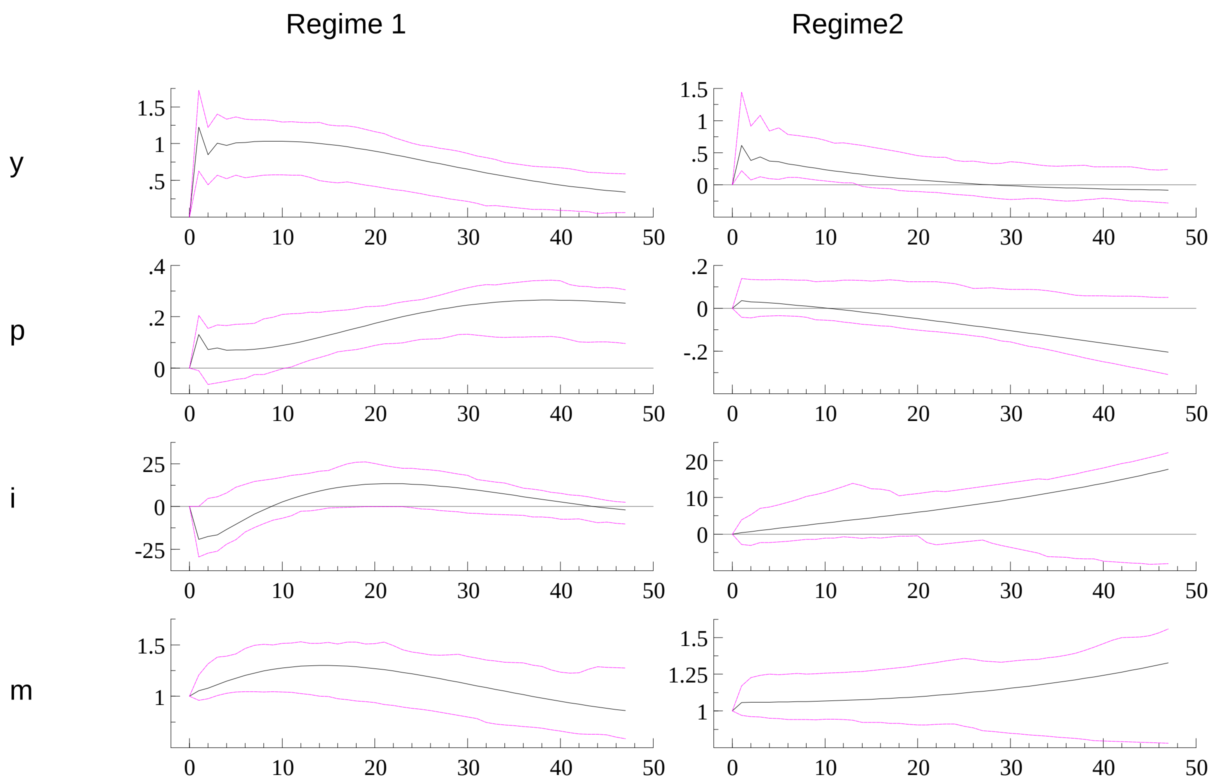


Chart 8

Regime probabilities

VAR(5): 1980-

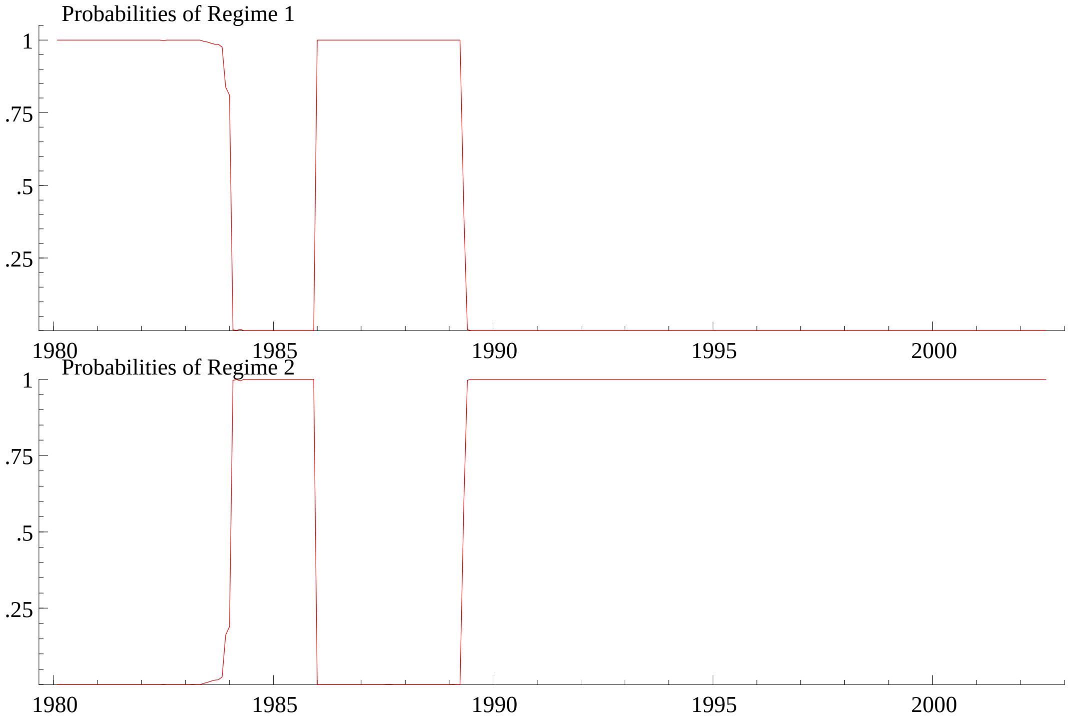


Chart 9

Impulse Responses to the nominal interest rate shock

VAR(5): 1980-

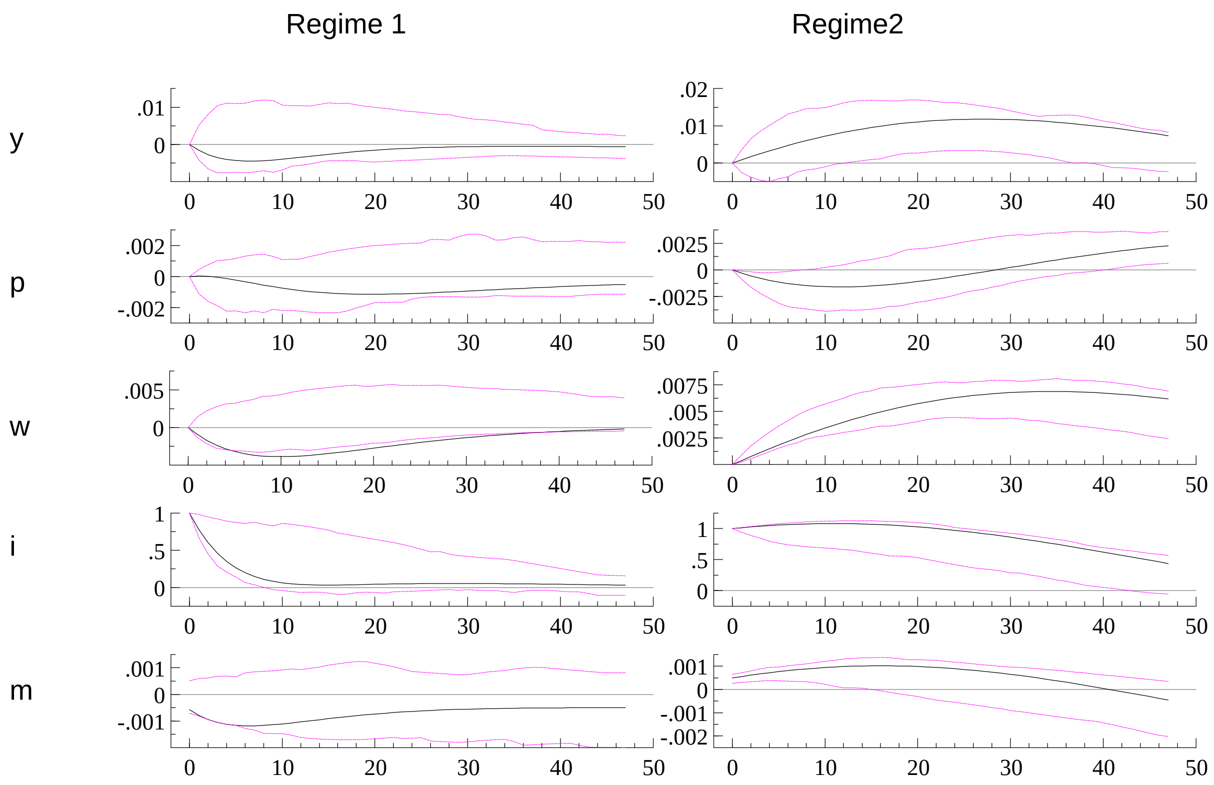
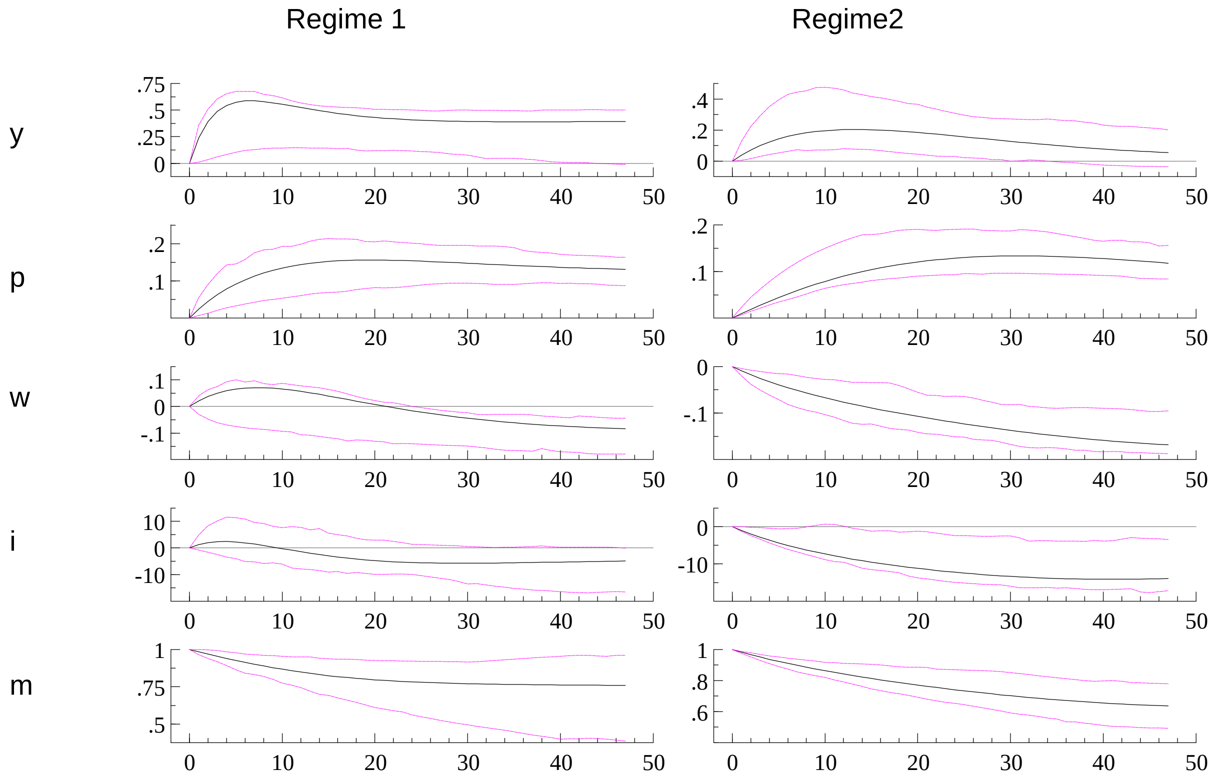


Chart 10

Impulse Responses to the monetary shock

VAR(5): 1980-



Regime probabilities

VAR(4): 1985-

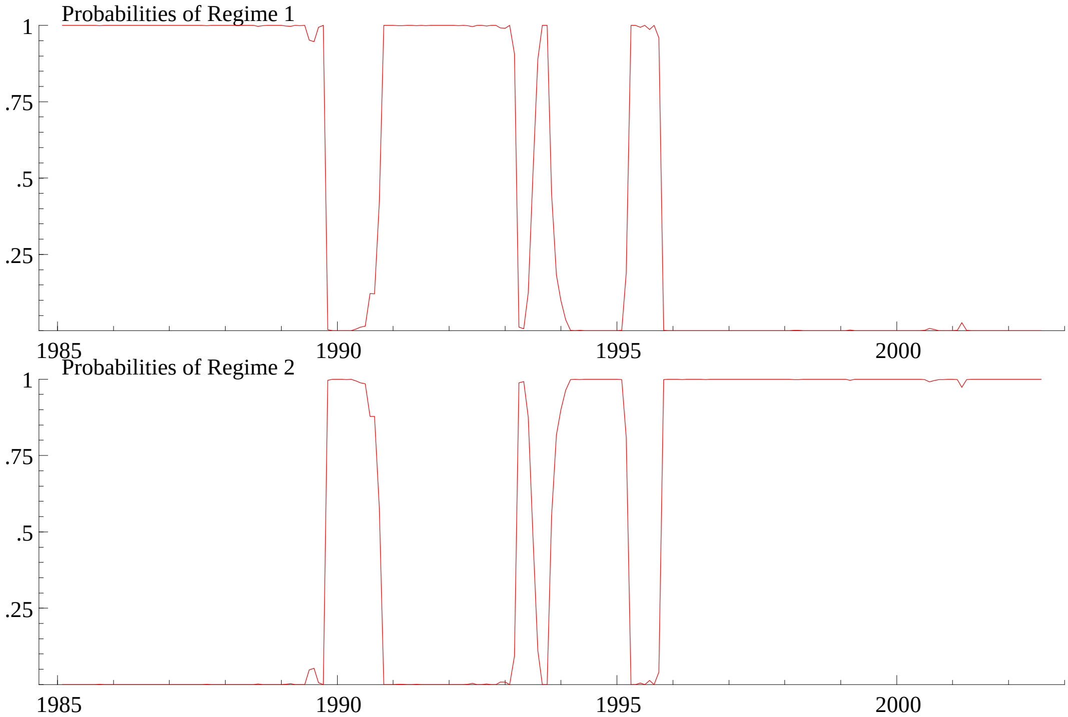


Chart 12

Impulse Responses to the nominal interest rate shock

VAR(4): 1985-

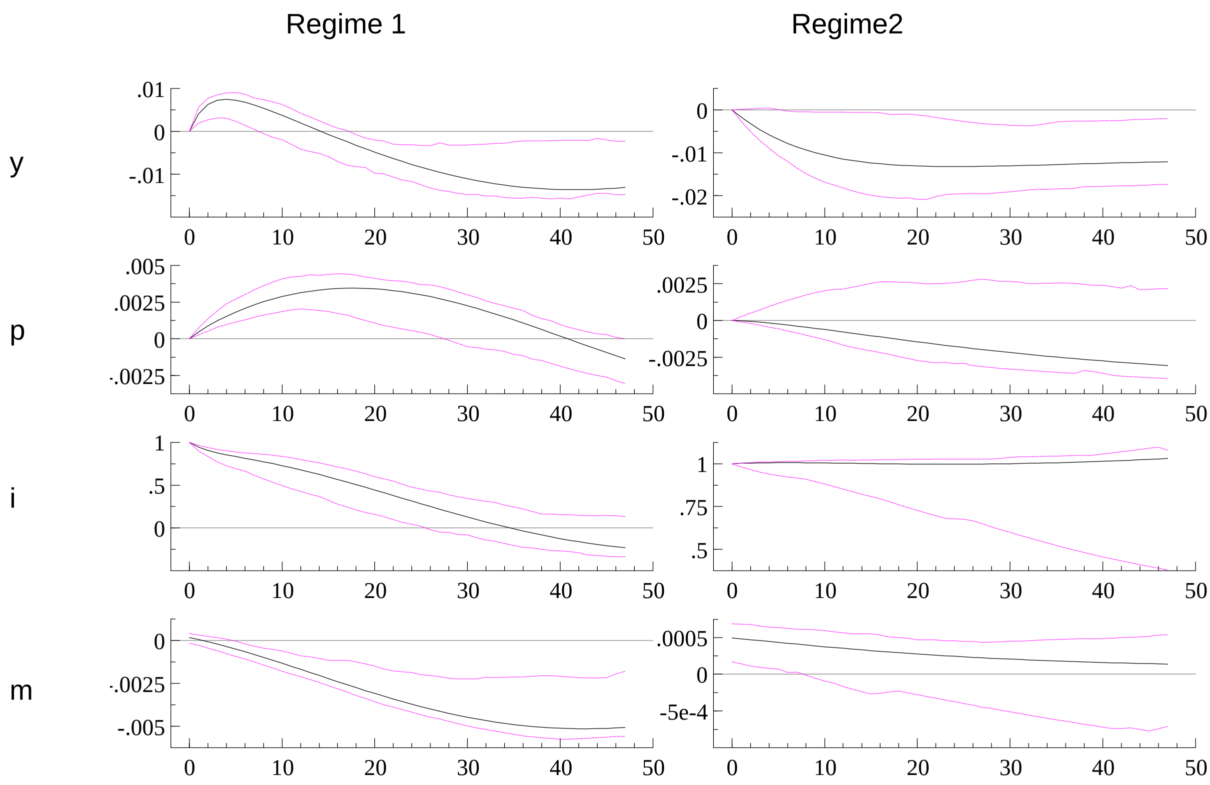


Chart 13

Impulse Responses to the monetary shock

VAR(4): 1985-

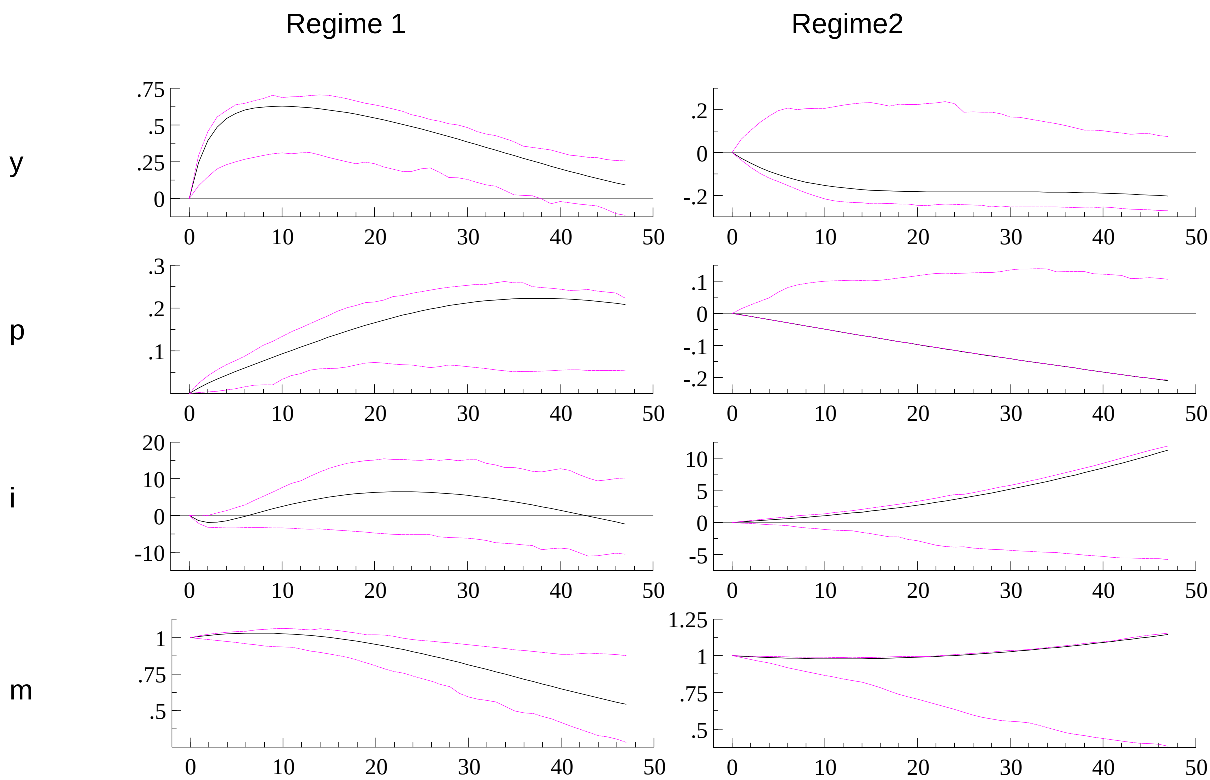


Chart 14

Regime probabilities

VAR(5): 1985-

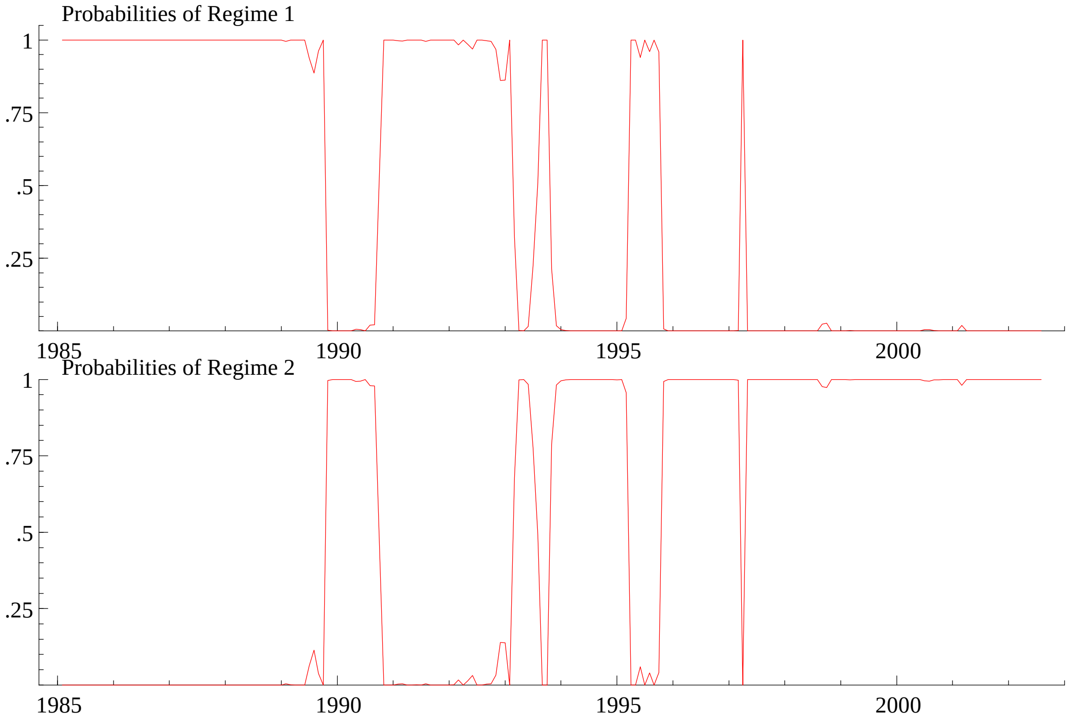


Chart 15

Impulse Responses to the nominal interest rate shock

VAR(5): 1985-

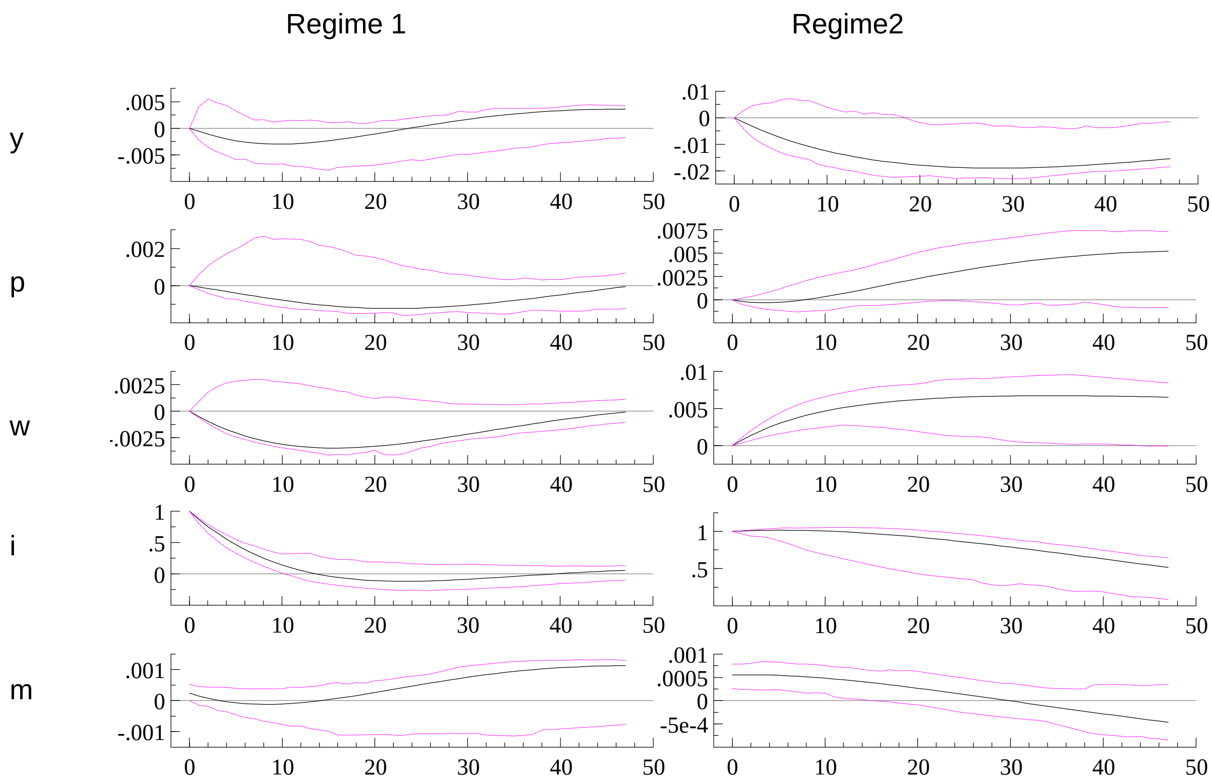


Chart 16

Impulse Responses to the monetary shock

VAR(5): 1985-

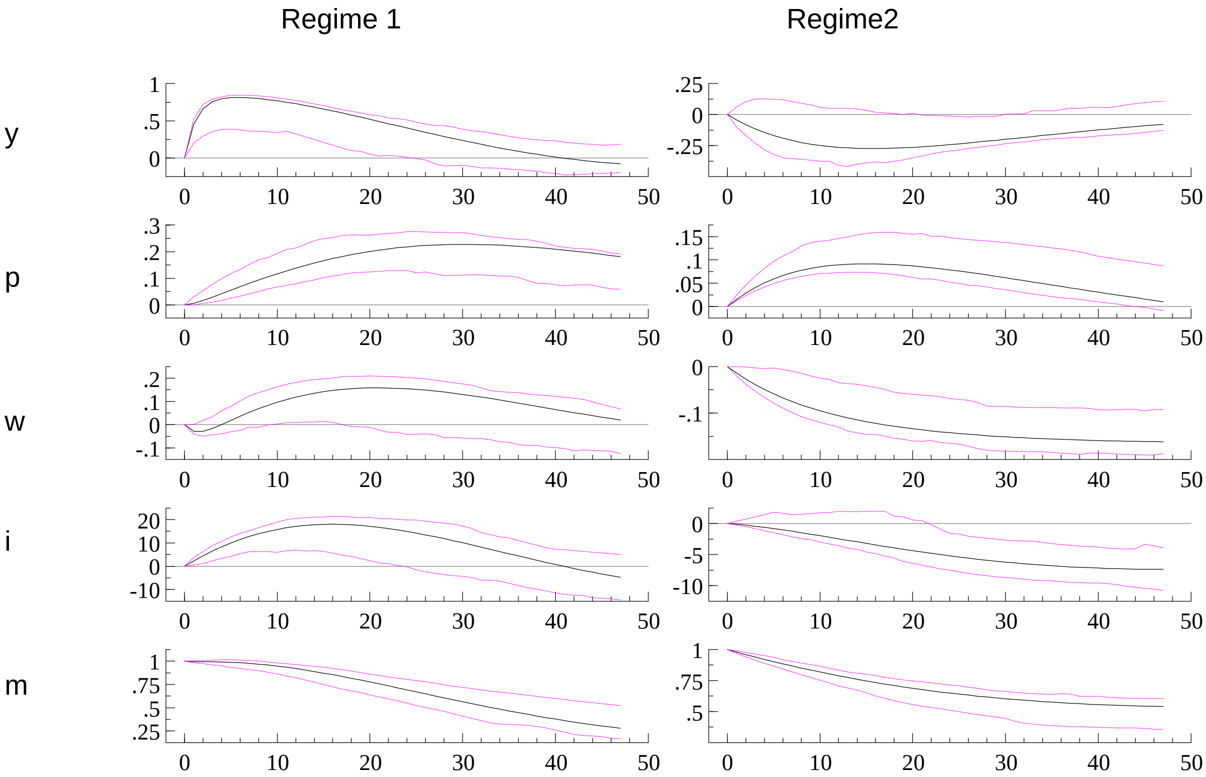


Chart 17

Regime probabilities

VAR(3): 1985-

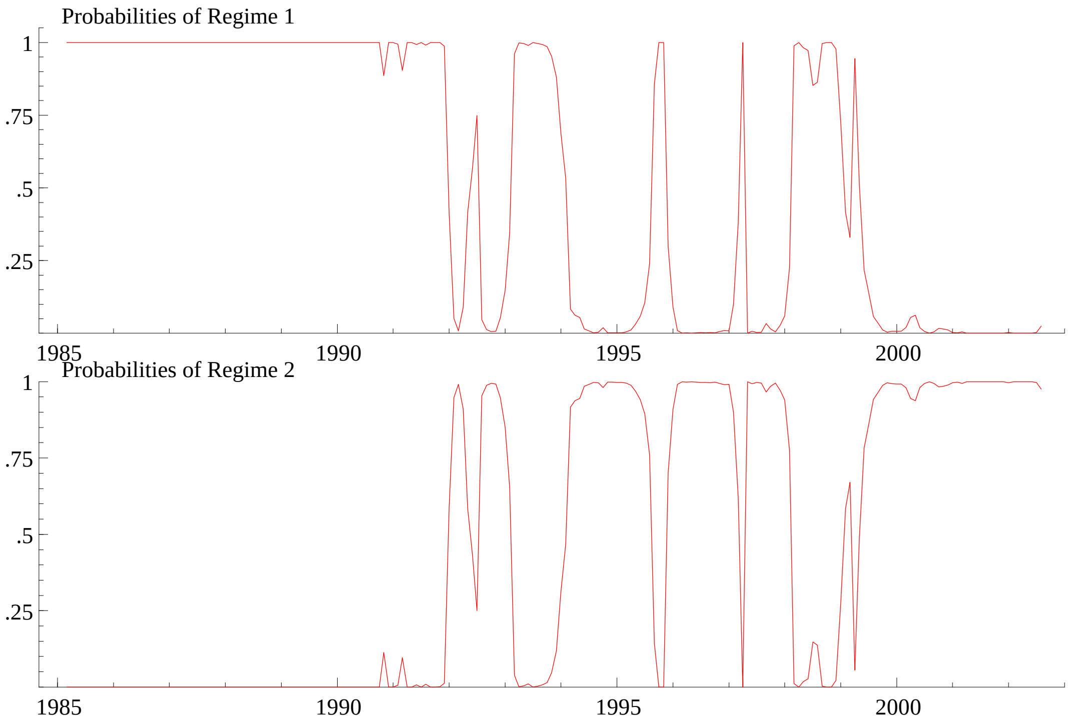


Chart 18

Impulse Responses to the monetary shock

VAR(3): 1985-