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**Working Paper**

## The role of credit aggregates and asset prices in the transmission mechanism: a comparison between the euro area and the US

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**NO 816 / SEPTEMBER 2007**

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AGGREGATES AND ASSET  
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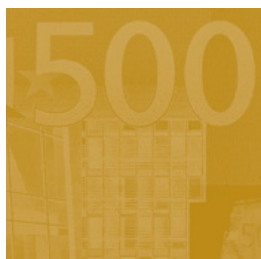
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# THE ROLE OF CREDIT AGGREGATES AND ASSET PRICES IN THE TRANSMISSION MECHANISM

## A COMPARISON BETWEEN THE EURO AREA AND THE US<sup>1</sup>

by Sylvia Kaufmann<sup>2</sup>  
and Maria Teresa Valderrama<sup>3</sup>

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## Abstract

We analyze the interaction between credit and asset prices in the transmission of shocks to the real economy. We estimate a Markov switching VAR for the euro area and the US, including additionally GDP, CPI and a short-term interest rate. We find evidence for two distinct states in both regions. For the euro area, we find a regime which is correlated to the business cycle and which captures periods of very low real credit growth at the end of recessions. However, during this regime credit markets and asset price markets do not impede economic recovery. In the other regime, we do find a procyclical effect of credit and asset price shocks on GDP. Shocks in both variables explain each about 20% of GDP's forecast error variance after four years. Credit shocks have a positive effect on inflation and explain about 35% of the forecast error variance, which confirms that credit aggregates contain information about the monetary stance. The effect of asset price shocks on inflation is insignificant and their share in explaining the forecast error variance negligible. For the US, regime 1 captures periods of stable GDP growth, and low and stable inflation, combined with accelerating asset prices. We find procyclical effects of credit and asset price shocks on GDP only in regime 2. Shocks in both variables explain about the same share (20%) of GDP forecast error variance, whereby the share explained by asset price shocks is about two and a half times larger than in regime 1. Shocks to credit and asset prices have no significant effect on CPI and explain each about 10% of its forecast error variance in both regimes. This is consistent with the view that monetary policy may achieve price stability without necessarily achieving financial stability.

JEL classification: C11, C32, E32, E44

Keywords: Asymmetry, asset prices, financial system, lending, transmission mechanism.

## Non-technical summary

The importance of credit aggregates as transmitters of monetary policy and other shocks to GDP and inflation is by now well established in the theoretical and empirical literature. In this paper, we analyze the role of the interaction between credit and asset prices in the transmission of shocks to the real economy. By comparing results for the euro area and the US we additionally obtain evidence for differences between two regions characterized by a bank-based and by a market-based financial system.

Three working hypotheses form the background of our analysis. In theoretical models it has been shown that *credit aggregates and asset prices reinforce each other*. This phenomenon arises when equity plays an important role as collateral for lending in an imperfect market environment subject to asymmetric information and when at the same time, lending stimulates investment, which fuels asset prices. Another strand in the literature stresses the role of credit aggregates in the build-up of financial imbalances. These studies show that in conjunction with strong economic prospects and a low and stable inflation environment, financial imbalances, which put the financial system under stress, may first materialize in strong credit growth and rapid asset price increases. Stylized facts also suggest that the relationship between credit aggregates and asset prices may differ between periods when financial stability is at risk and periods when this is not the case, which leads to the hypothesis of *asymmetric dynamics* underlying the relationship between credit and asset prices and their effects on output. Given that these asymmetric dynamics may depend on the relative importance of equity financing in the economy, we expect to observe *differences between bank-based and market-based financial systems*. In particular, the effects should be stronger in countries where firms obtain a large share of financing on the asset market, i.e. in countries with a market-based financial system, as opposed to countries with a developed bank-based financial system in which mainly banks provide firms with financing.

To model the asymmetric transmission of shocks through credit and asset markets we use a non-linear vector autoregression which allows for time-varying parameters that switch according to an unobservable state indicator. Given that the state is unobservable and estimated simultaneously with the parameters, we do not have to select a priori a set of variables which may determine the threshold and the timing of regime switches. Given the posterior estimate, however, we can relate the different regimes to time series properties of the variables investigated, which jointly characterize specific economic conditions prevailing during the regimes. Moreover, the comparison to results obtained from a linear vector autoregression model confirms that the non-linear framework uncovers additional region-specific characteristics.

We find regime-switching in both regions. For the euro area we identify two periods which are characterized by very low real credit growth. The generalized impulse responses reveal that lending during these periods may be characterized as supply-driven while the dynamics in the other regime display features of a demand-driven lending behaviour. The mutually reinforcing effects of lending and asset prices contributing to the build-up of financial imbalances during boom periods is not confirmed in our model. Moreover, the evidence suggests that tight credit market conditions do not amplify shocks and thus do not have an amplifying effect on the business cycle of the economy. During periods of demand-driven lending credit has a procyclical effect on output.

For the US, the regime prevailing from the fourth quarter of 1988 to the first quarter of 1989 and from mid 1991 to the first quarter of 1997 is characterized by low volatility in GDP growth, inflation and asset price growth together with rapid credit growth. These dates correspond to a period of stable economic growth which often has been attributed to better monetary and fiscal policy. Our results confirm that the reinforcing effects between asset prices and lending are stronger in the market-based financial system.

The generalized variance decomposition for both the euro area and the US confirms the important role of asset prices and lending in the transmission mechanism. The analysis also highlights the differences between the two systems. As expected, in the US asset prices contribute more to the forecast error variance in GDP than in the euro area. On the other hand, lending explains a large fraction of the inflation forecast error variance in the euro area during the demand-driven lending regime.



## 1. Introduction

The importance of credit aggregates as transmitters of monetary policy and other shocks to GDP and inflation is by now well established in the theoretical and empirical literature. In this paper, we analyze the role of the interaction between credit and asset prices in the transmission of shocks to the real economy. By comparing results for the euro area and the US we additionally obtain evidence for differences between two regions characterized by a bank-based and by a market-based financial system.

Bernanke and Blinder (1988) show that monetary policy actions affect the real economy not only through the money market but also through the credit market, when bonds and bank loans are not perfect substitutes. A policy induced change in the bond rate influences the lending rate indirectly by shifting loan demand and supply. Ultimately, changes in the lending rate and in the supply of loans will influence production and thus will have an additional effect on the real side of the economy (Bernanke and Blinder 1992). This mechanism, termed financial accelerator, originally developed in Bernanke and Gertler (1989) strengthened the credit view of monetary policy transmission as opposed to the ‘money’ or monetarist view. The authors show in a neoclassical framework, how business cycles might emerge or be amplified through borrowers’ balance sheet. During business upturns, borrowers’ net worth improves, agency costs decrease and investment increases, which amplifies the business cycle. The opposite happens during periods of economic slowdown, but the effect during the slowdown tends to be larger.

The existence of collateral turns out to be crucial. Kiyotaki and Moore (1997a, 1997b), Kocherlakota (2000), Boissay (2001) and Chen (2001) show that in the presence of asymmetric information and other capital market imperfections, equity plays an important role as collateral for loans, and at the same time growth in the supply of loans influences asset prices by improving investment prospects. This mechanism suggests a reinforcing effect between asset prices and credit, which may lead to the build-up of financial imbalances.

How strong these effects are, depends on how important equity is as collateral to solve asymmetric information problems. Given the role of liquidity smoothing and relationship lending in bank-based financial markets (Allen and Gale, 2000), we expect that the propagation of shocks should be smoother in bank-based systems and that therefore, the mutually reinforcing effects of credit and asset price developments should be less pronounced in the euro area.

To take into account the asymmetric transmission of shocks through credit and asset markets predicted by theory, we use a non-linear vector autoregression which allows for

time-varying parameters that switch according to an unobservable Markov process. The model allows capturing asymmetries in a general way. Given that the state is unobservable and estimated simultaneously with the parameters, we do not have to select a priori a set of variables which may determine the threshold and the timing of regime switches. Given the posterior estimate, however, we can relate the different regimes to time series properties of the variables investigated, which jointly characterize specific economic conditions prevailing during the regimes. Moreover, the comparison to results obtained from a linear vector autoregression model confirms that the non-linear framework uncovers additional region-specific characteristics.

We find regime-switching in both regions. For the euro area we identify two periods which are characterized by very low real credit growth. The generalized impulse responses reveal that lending during these periods may be characterized as supply-driven while the dynamics in the other regime display features of a demand-driven lending behaviour. The mutually reinforcing effects of lending and asset prices contributing to the build-up of financial imbalances during boom periods is not confirmed in our model. Moreover, the evidence suggests that tight credit market conditions do not amplify shocks and thus do not have an amplifying effect on the business cycle of the economy. During periods of demand-driven lending credit has a procyclical effect on output.

For the US, the regime prevailing from the fourth quarter of 1988 to the first quarter of 1989 and from mid 1991 to the first quarter of 1997 is characterized by low volatility in GDP growth, inflation and asset price growth together with rapid credit growth. These dates correspond to a period of stable economic growth which often has been attributed to better monetary and fiscal policy. Our results confirm that the reinforcing effects between asset prices and lending are stronger in the market-based financial system.

The generalized variance decomposition for both the euro area and the US confirms the important role of asset prices and lending in the transmission mechanism. The analysis also highlights the differences between the two systems. As expected, in the US asset prices contribute more to the forecast error variance in GDP than in the euro area. On the other hand, lending explains a large fraction of the inflation forecast error variance in the euro area during the demand-driven lending regime.

Our analysis is related to Balke (2000) and Calza and Sousa (2006) who find threshold effects of credit conditions in the US and the euro area, respectively. In both investigations, non-linear impulse responses yield evidence for larger output effects during tight credit conditions which prevail before recessionary periods in the US and which are characterized by low real loan growth in the euro area. Our analysis complements the previous evidence by jointly investigating credit aggregates and asset prices.

The paper is organized as follows. Section two describes the working hypotheses; section three describes the econometric model and the Bayesian estimation method. The fourth section presents results. The final section concludes with policy implications.

## **2. Hypotheses – Intuition and background literature**

### **2.1. Hypothesis 1: Credit and asset prices reinforce each other**

In theoretical models it has been shown that credit aggregates and asset prices reinforce each other. Among others, Kiyotaki and Moore (1997a), Kocherlakota (2000), Boissay (2001) and Chen (2001) have shown that in the presence of asymmetric information, equity plays an important role when it is used as collateral for lending. At the same time, lending stimulates investment, which fuels asset prices.

Another strand in the literature stresses the role of credit aggregates in the build-up of financial imbalances (Borio and Lowe, 2002 and Detken and Smets, 2004). Thus, their developments may also have important implications for economic stability (Bordo and Wheelock, 2004). These studies show that in conjunction with strong economic prospects and a low and stable inflation environment, financial imbalances, which put the financial system under stress, may first materialize in strong credit growth and rapid asset price increases. These stylized facts suggest that the joint analysis of credit aggregates and asset prices helps identifying economic conditions under which financial imbalances may build up over time. The facts also suggest that the relationship between credit aggregates and asset prices may differ between periods when financial stability is at risk and periods when this is not the case.

### **2.2. Hypothesis 2: Asymmetric dynamics**

Kiyotaki and Moore (1997b) develop a theoretical model that relates credit to business cycles and asset prices. In the model, credit markets propagate shocks to the economy in a non-linear way. The effect of shocks is stronger during recessions and depends on the level of indebtedness and the interaction with asset prices. This leads to credit cycles which are caused by increasing default rates during economic downturns, by changes in bank lending standards or by monetary policy tightening.

In the framework of Bernanke and Blinder (1988), shocks may have asymmetric effects on output if the interest rate elasticity of loan supply depends on the level of economic activity.<sup>4</sup> In this case, we may distinguish between periods during which lending is demand or supply-driven. We define periods of demand-driven lending by a situation in which the

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<sup>4</sup> Asymmetric effects of shocks at the aggregate demand level have been justified with similar arguments and investigated in Karras (1996).

interest rate elasticity of loan supply is larger than loan demand elasticity, i.e. when the loan supply curve is flat relative to the loan demand curve. In this case, shocks in the interest rate have small effects on loans while productivity or real shocks have a positive effect on loans. Lending is supply-driven, when the interest rate elasticity of loan supply is lower than the loan demand elasticity. If economic prospects deteriorate, loan supply may become inelastic (nearly vertical) relative to loan demand, reflecting increasing liquidity tightness in credit market conditions. Interest rate shocks then have a negative effect on loans while productivity or real shocks have nearly no effect on loans.

### **2.3. Hypothesis 3: Differences between bank-based and market-based financial systems**

The third hypothesis takes into account that both the reinforcing effect between asset prices and credit and the switching between demand-driven and supply-driven regimes depends on the relative importance of equity financing in the economy. In particular, the effects just described should be stronger in countries where firms obtain a large share of financing on the asset market, i.e. in countries with a market-based financial system, as opposed to countries with a developed bank-based financial system in which mainly banks provide firms with financing.

Although the level of indebtedness is usually higher in bank-based systems, debt default occurs less frequently owing to the existence of close lending relationships.<sup>5</sup> These close lending relationships develop owing to the house bank system typical of bank-based financial systems. As firms and households rely on a single bank to do most of their financial and financing transactions, lenders and borrowers can overcome asymmetric information by building long-standing relationships. Thanks to these lending relationships borrowers are less dependent on internal funds, since lenders provide creditworthy clients with funds even during an economic downturn. As a result, borrowers can smooth spending decisions over the cycle.

Therefore, we analyze the euro area and the US. Due to the house bank principle characterizing the bank-based financial system of euro area countries, asymmetric effects of shocks may be less severe than in the US.

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<sup>5</sup> See Ongena and Smith (1998) and Boot (2000) for a more detailed account of effects of lending relationships.

### 3. The econometric framework

#### 3.1. Model and estimation

To analyze the joint behaviour of credit aggregates and asset prices and their relationship to GDP, inflation and interest rates, we use a vector autoregression (VAR) model in which we allow the parameters to depend on an unobservable state indicator. The state indicator follows a Markov switching (MS) process and is assumed either to capture changing credit or economic regimes. Given that it is unobservable, we estimate it along with the model parameters. Therefore, we do not have to specify a priori a variable or a combination of variables which is driving the changing process of the dynamics in the data. Nevertheless, by estimating it using the information contained in the data, we will be able to characterize the periods in which asset prices and credit aggregates were mutually reinforcing each other or not or had a weaker or a stronger effect on the economy. In this setup, it may well be that not all periods of high credit growth lead to asset price bubbles or that not all periods of low credit growth define one regime, as would be the case in a threshold model.

Let  $y_t$  be the  $p \times 1$  vector containing the observable variables. The general specification of the MS-VAR model including  $q$  lags of the endogenous variables is written as:

$$y_t = v(s_t) + A_1(s_t)y_{t-1} + A_2(s_t)y_{t-2} + \dots + A_q(s_t)y_{t-q} + \varepsilon_t, \quad (1)$$
$$\varepsilon_t \sim i.i.d.N(0, \Sigma(s_t)),$$

where  $s_t$  represents the unobservable state variable which takes one out of 2 values,  $s_t = k, k = 1, 2$ , in each period. The Markov switching process relates the probability that regime  $j$  prevails in  $t$  to the prevailing regime  $i$  in  $t-1$ ,  $\Pr(s_t = j | s_{t-1} = i) = \eta_{ij}$ . In the following, the  $2 \times 2$  conditional transition probabilities are gathered in the transition matrix  $\eta$ :

$$\eta = \begin{bmatrix} \eta_{11} & \eta_{12} \\ \eta_{21} & \eta_{22} \end{bmatrix}. \quad (2)$$

We estimate the model by Bayesian simulation methods. As all conditional posterior distributions are known, we apply the Gibbs sampler. To obtain draws from the unconstrained posterior distribution, we use the random permutation sampler (Frühwirth-Schnatter, 2001), i.e. we first estimate the model without setting a state-identifying restriction on the parameters.<sup>6</sup> After the estimation, we explore the simulation output by means of

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<sup>6</sup> A common restriction which allows to discriminate between the states would be e.g.  $v_1(1) < v_1(2)$ , meaning that the first regime would relate to below-average growth periods in the first variable of the system, while the second regime would relate to above-average growth rate periods.



scatter plots and marginal distributions to find a state-identifying restriction (see also appendix C of Kaufmann and Valderrama, 2004).

Let the vector  $\theta$  contain all model parameters,  $\theta = (v(1), v(2), A_1(1), \dots, A_q(2), \Sigma(1), \Sigma(2), \eta)$  and the vector  $s^T$  represent the path of the state indicator,  $s^T = (s_T, \dots, s_0)$ . The posterior distribution  $\pi(\theta, s^T | y^T)$  is obtained by updating the prior  $\pi(\theta, s^T)$  with the information contained in the data:

$$\pi(\theta, s^T | y^T) = \frac{L(y^T | \theta, s^T) \pi(\theta, s^T)}{L(y^T)},$$

where the likelihood, conditional on  $s^T$ , may be factorized as:

$$L(y^T | \theta, s^T) = \prod_{t=1}^T f(y_t | y^{t-1}, \theta, s_t), \quad (3)$$

with the observation density  $f(y_t | y^{t-1}, \theta, s_t)$  being multivariate normal:

$$f(y_t | y^{t-1}, \theta, s_t) = |\Sigma(s_t)|^{-1/2} (2\pi)^{-p/2} \exp\left\{-\frac{1}{2}(y_t - \mu(s_t))' \Sigma(s_t)^{-1} (y_t - \mu(s_t))\right\}, \quad (4)$$

with  $\mu(s_t) = v(s_t) + A_1(s_t)y_{t-1} + A_2(s_t)y_{t-2} + \dots + A_q(s_t)y_{t-q}$  and  $y^{t-1} = (y_{t-1}, y_{t-2}, \dots, y_1)$ .

To obtain draws from the joint posterior distribution  $\pi(\theta, s^T | y^T)$ , we successively draw from the conditional posterior distributions  $\pi(v, A_1, \dots, A_q | y^T, s^T, \Sigma)$ ,  $\pi(\Sigma | y^T, s^T, \beta)$ ,  $\pi(\eta | s^T)$  and  $\pi(s^T | y^T, \theta)$ . The first three distributions are conjugate to the priors, i.e. are independent state-specific normal, Wishart and Dirichlet distributions, respectively. A path  $s^T$  from  $\pi(s^T | y^T, \theta)$  is obtained by multi-move sampling (Chib, 1996). The prior specification and the derivation of the posterior moments of these distributions are found in appendix B.

We draw 23,000 times from the posterior and discard the first 8,000 values to remove dependence on the starting values. We retain every 3<sup>rd</sup> draw to account for potential correlation between successive draws. After estimation, we use explorative tools like scatter plots and marginal posterior distributions to obtain a parsimonious representation of the system, in which parameters that are not switching are restricted to be equal across states or in which insignificant parameters are restricted to zero. The final model specifications are assessed by marginal likelihoods, with which we also test the switching specification against a linear model. We estimate the marginal likelihood using the optimal bridge sampler proposed in Frühwirth-Schnatter (2004).



Model inference is then obtained by averaging over the simulated parameter values to obtain the posterior mean estimate and by computing the standard deviation to estimate the standard deviation of the posterior distribution. To save space, we only tabulate the state-dependent posterior estimates of the intercepts  $\nu$  and the diagonal elements of the error covariance matrix  $\Sigma_{jj}$  in table 2. The remaining results are obtainable upon request. The inference on the state indicator is also obtained by averaging over the simulated paths for  $s^T$ . We define the turning points of the regimes by the rule  $P(s_{t+1} = s_t = j | y^T, s_{t-1} \neq j) > 0.5$ , which means that a regime prevails at least for half a year. Plotting  $s^T$  against the variables of the system and relating it to simple statistics of the data (e.g. the mean and the standard deviation) yields a characterization of the states.

### 3.2. Order-invariant impulse responses and variance decomposition

The parsimonious and identified models are used to compute state-dependent generalized impulse response functions (Pesaran and Shin, 1998). The advantage of the approach is that, conditional on the state, we obtain impulse responses which are independent of the ordering of the variables and also independent of views on how the variables interact at the short-term or long-term horizon.<sup>7</sup> Given the observed historical path of the variables and the historical distribution of the errors, we compute the state-specific response  $GI_{j,d}^h(s_t)$  of the variables  $y_t$  at horizon  $h$  to a one standard deviation shock in variable  $j$  as

$$GI_{j,d}^h(s_t) = \sigma_{jj,s_t}^{-1/2} C_h(s_t) \Sigma(s_t) e_j,$$

where  $\sigma_{jj,s_t}$  represents the  $j^{\text{th}}$  diagonal element of  $\Sigma(s_t)$  and  $e_j$  is a selection vector with 1 as  $j^{\text{th}}$  element. The matrix  $C_h(s_t)$  refers to the coefficient matrix at lag  $h$  of the inverted system (1). Cumulated responses are obtained with

$$GI_{j,c}^h(s_t) = \sigma_{jj,s_t}^{-1/2} B_h(s_t) \Sigma(s_t) e_j,$$

where  $B_h(s_t) = \sum_{l=0}^h C_l(s_t)$  is the cumulative effect of shocks and  $C_0(s_t) = B_0(s_t) = I_p$ .

Given the sample from the posterior distribution of the parameters, we compute for each parameter draw the state-dependent impulse responses. We average the impulse responses

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<sup>7</sup> Such views are usually parameterized as restrictions on the short-term and/or long-term interaction between variables and define a structural VAR model.

and evaluate at each horizon the 90 percentile interval. In this way, we can for example, confirm whether in one regime lending is demand-driven or supply-driven as predicted by the financial accelerator model or bank lending channel; or whether in one regime there are reinforcing effects of asset prices and credit aggregates as predicted by the credit cycle literature. In general, by looking at the asymmetric dynamics of the system in different regimes we gain some insights into the transmission mechanism.

The impulse responses describe the reaction of variables to shocks and the dynamic interactions between the variables. However, they do not give an indication on the importance of the shocks in explaining the variability in the variables. This answer is obtained from the variance decomposition, which we base on the state-dependent generalized impulse responses. Denote the state-dependent fraction of variable's  $i$  forecast error variance at the forecast horizon  $h$  explained by variable  $j$  by  $V_{ij}^h(s_t)$ . The state-dependent order-invariant forecast error variance decomposition is obtained with

$$V_{ij}^h(s_t) = \frac{\sigma_{jj,s_t}^{-1} \sum_{l=0}^h (e_i' B_l(s_t) \Sigma(s_t) e_j)^2}{\sum_{l=0}^h e_i' B_l(s_t) \Sigma(s_t) B_l'(s_t) e_i},$$

where  $i, j = 1, \dots, p$  and  $h = 0, 1, \dots$ . Due to non-zero covariance between shocks, the fractions may not sum up to one. Computing the variance decomposition for each set of simulated parameters, we obtain a sample from the whole posterior distribution of the variance decomposition. We summarize the results by reporting the posterior mean at selected time horizons.

#### 4. Empirical Evidence

The model estimated is a five-variable system which includes GDP, CPI, equity prices (DataStream Index for Euro area<sup>8</sup> and Standard & Poor's 500 for the US), lending to the private sector and the 3-month interest rate. We use seasonally adjusted quarterly data covering the period from the first quarter of 1980 up to the second quarter of 2004. All variables except the CPI and the short-term interest rate are expressed in real terms and in quarterly growth rates. The interest rate is differenced once. As there is evidence for a non-stationary euro area inflation rate (Kugler and Kaufmann, 2005), we difference twice the price level. Finally, the data is demeaned and standardized for computational purposes. Because of a change in the statistical definition of euro area loans, we include a dummy variable for euro area loans in the third quarter of 1990.

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<sup>8</sup> This is a weighted index constructed by DataStream from country data areas dating back to 1973 covering 75-80% of stock market capitalization.

For both the euro area and the US, we find evidence for two regimes. Table 1 reports the marginal likelihoods for various model specifications. The highest marginal likelihood is obtained for the restricted switching specification. Although significant differences between regimes are observed for other parameters as well, to save space we report in table 2 only the posterior mean of the intercepts  $\nu$  with standard errors in parentheses and the error variance of each equation. For the euro area, significant regime differences show up in the intercept for the loans equation. All error variances but the one for the loans equation are two to four times larger in regime 2 than in regime 1. For the US, a significant difference between regimes is estimated for the intercept in the asset price equation. In regime 2, the error variance is even six times larger than in regime 1. In all other equations, the variance is two to four times larger in regime 2.

In the following, we discuss the results for each region separately. We first characterize the regimes relating the posterior state probabilities to the variables in the system and then use generalized impulse responses to assess whether the relationships between the variables depend on different credit or economic regimes. In particular, we will pay attention to whether a certain regime can be characterized by lending being demand or supply-driven. To get an idea of the information gain we obtain by taking a non-linear approach, we compare the impulse responses to those obtained from a linear VAR model.

## 4.1. Euro Area

### 4.1.1. Posterior state probabilities

The posterior state probabilities obtained for the system of the euro area are robust to different model specifications. Regime 1 prevails from the beginning of the observation period to the end of 1981 and from the second quarter of 1993 to the first quarter of 1995 (see graph 1). The dates correspond to the end of recession periods defined by the CEPR, although regime 1 ends earlier in 1981 and begins later than the recession in the first half of the 1990s. Regime 1 captures periods of strong economic recovery (graph 1, top right panel) and very low real loan growth (graph 1, bottom left panel).

Tables 3 and 4 compare the regime-dependent average growth rates and the acceleration rates (i.e. the change in the growth rates) of the five variables with those obtained using the CEPR recession dates, and using the regimes identified by Calza and Sousa (2006, CS henceforth).<sup>9</sup> Regime 1 of the MS-VAR captures below-average GDP

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<sup>9</sup> Calza and Sousa (2006) estimate a threshold VAR model with below-average real loan growth as threshold, i.e. also the below-average growth periods in the mid 1980s and around 2002 are defining their regime. Besides the methodology the main differences are our inclusion of asset prices and the use of a short term interest rate while Calza and Sousa (2006) include a synthetic lending rate.

growth, 0.45% per quarter, which is nevertheless accelerating at 0.12 percentage points (pp) per quarter; very low, decelerating real credit growth, 0.07%, and -0.17pp, respectively, and decelerating asset price returns. The main difference to the regimes identified by CEPR and to those identified by CS shows up in the growth rate of real loans. During CEPR recession phases real loan growth is nearly five times larger (0.33%) and during regime 1 of CS it is six times larger (0.45%) than during regime 1 of the MS-VAR. GDP growth during regime 1 of the MS-VAR is seven times larger than CEPR recession growth rates of GDP (0.06%).

Table 5 contains the state-dependent standard deviations of the variables. In the MS-VAR, GDP and real loan growth are less volatile in regime 1, nearly half as volatile as in regime 2. While asset prices are also less volatile in regime 1, the volatility of inflation and the interest rate is higher in regime 1. Except for GDP volatility, the state-dependent volatilities are similar whether we use regime identification by MS-VAR or by CEPR dates. Differences in state-dependent volatilities are less pronounced in the model of CS. Lower volatility of real loan growth in regime 1 is the main difference.

To summarize, regime 1 identified by the MS-VAR captures periods of low real credit growth at the end of recession periods which, nevertheless, does not impede economic recovery.

#### **4.1.2. Generalized impulse responses**

Impulses responses are also robust to different model specifications. We depict the responses of regime 1 and regime 2 in graph 2a and 2b, respectively.

In regime 1, the response of loans to an interest rate shock is negative (marginally significant) and insignificant to an output shock, while in regime 2 the response of loans to an interest rate shock is insignificant and positive to an output shock. Therefore, regime 1, in which real credit growth is very low, may additionally be characterized as a supply-driven lending regime. In regime 2, lending is mainly demand-driven.

Besides the characterization of the regimes we are also interested in evidence for reinforcing effects between credit aggregates and asset prices. The response of asset prices to a loan shock is insignificant in both regimes. On the other hand asset price shocks have a significant positive effect on loans in regime 2. Thus, mutually reinforcing effects between asset prices and lending are not found in the data. Nevertheless, the response of loans to asset prices is consistent with the view that asset price increases reflect borrowers' net worth improvements and therefore obtain more easily bank loans when economic conditions are favourable.

We can further observe that in regime 2, the demand-driven lending regime, there is a positive response of output to shocks in asset prices and lending. Although both variables

have a procyclical effect on production, the risk of rising financial imbalances may still be contained. Inflation reacts significantly positively to shocks in production and lending, which means that rising tensions are reflected in price increases. In regime 1, there is no procyclical effect on production of asset price and loan shocks, and no significant response of loans to an asset price shock and vice versa. This result corroborates the view that although real loan growth is very low during regime 1, it does not impede economic recovery and does not impose financing constraints on firms.

#### **4.1.3. Generalized impulse responses of the linear model**

To assess the gains of modelling credit aggregates in a non-linear system we estimate an unrestricted linear VAR with two lags to compare the generalized impulse responses of both specifications.

Graph 3 depicts the mean generalized impulse responses obtained from the linear and from the Markov switching specification. The mean impulse responses and the 90 percentile interval of the linear specification are plotted in graph 4. In graph 3, we observe that most of the linear responses closely match those obtained for regime 2 (the demand-driven lending regime) in the non-linear model. The short period of supply-driven lending and the different dynamic interactions between the variables thus remain undetected under the linear specification. The picture obtained is one of a procyclical economy, in which shocks to loans and asset prices have a significant positive effect on GDP and in which also shocks to GDP affect positively lending and asset prices. The non-linear model refines the picture in the sense that at the end or right after recessions, although lending standards tighten (lending becomes supply-driven) they do not impede economic recoveries. Moreover, this change in lending behaviour may pre-emptively restrain the build-up of financial imbalances in early periods of recovery.

#### **4.1.4. Variance decomposition**

Graph 5 contains the state-dependent variance decomposition of GDP and the inflation rate. Our previous results are confirmed, given that the role of lending and asset prices turns out to be less important in regime 1. All shares reach their long-run level after 8 quarters. In regime 1, asset price, loan and interest rate shocks explain each between 10% and 15% of the GDP forecast error variance after 24 quarters. In regime 2, the shares of asset prices and loans both increase to around 20% at the 24 quarter horizon. On the other hand, in this regime the forecast error attributed to the short term interest rate is negligible. In both regimes, the forecast error variance of GDP attributed to asset prices and loans (together) is significantly higher than the contribution of the short term interest rate, which confirms the important role of both variables in the transmission mechanism.

Interestingly, the shares of asset price, loan and interest rate shocks in explaining the forecast error variance of the inflation rate reach about the same share as for the GDP in regime 1, namely 12%, 13% and 17%, respectively. In regime 2, the variance share of asset price shocks is nearly insignificant while the share of loan shocks rises to 24% at the 8 quarter and to 36% at the 24 quarter horizon, almost 3 times as large as in regime 1. The large variance share explained by loan shocks supports the view that developments in credit aggregates contain information about future inflation prospects, which is of interest for monetary policy following a price stability target.

## **4.2. United States**

### **4.2.1. Posterior state probabilities**

The posterior state probabilities obtained for the US are robust to different model specifications. The characterization of the regimes is not as straightforward as for the euro area, however. They are not obviously correlated with the business cycle (graph 6, top left panel). Regime 1 prevails twice during each recovery in the 1980s and in the 1990s, in particular during the first half year of 1985 and during 1988 till the first quarter of 1989; then, more persistently, from the second quarter of 1991 to the end of 1992 and again from the second quarter of 1994 to the first quarter of 1997. After the last recession in 2001, regime 1 prevailed for half a year during the last quarter of 2001 and the first quarter of 2002. The tables 6 and 8 report the mean growth rates and the volatility of the series, respectively. We compare the state-dependent numbers with those obtained using the NBER business cycle states. The characterization of the MS regime is best based on the volatility in the series rather than on the mean growth rates. Except for asset prices and interest rates, the differences in growth rates are not that large between regimes. Asset price increases in regime 1 are about one third higher than in regime 2 and credit growth is nearly 30% lower in regime 1. On the other hand, in regime 1 the volatility of GDP growth and of inflation are about half of that in regime 2.

A further distinguishing feature of regime 1 is that growth rates in all variables but the inflation rate and real loan growth are accelerating (see table 7). Thus, regime 1 corresponds to a situation in which financial imbalances may build up given good economic and low inflationary prospects. Whether developments in asset prices and loans reinforce each other and may get on an unsustainable growth path may be assessed with the generalized impulse responses.



### 4.2.2. Generalized impulse responses

The impulse responses conditional on regime 1 are found in graph 7a and the ones conditional on regime 2 in graph 7b. The response of loans to an output shock is insignificant in regime 1 and positive in regime 2, while the response to an interest rate shock is marginally positive in both regimes. Thus, we again can characterize lending as demand-driven in regime 2. The responses in regime 1 do not allow a conclusion.

Loans do not react to a shock in asset prices in regime 1, while there is a positive reaction in regime 2. In the short run, asset prices react marginally positively to a shock in loans. In the long-run, the reaction becomes insignificant. Thus, we find some evidence for reinforcing effects between lending and asset prices during regime 2. Significant positive effects of shocks to asset prices and loans on GDP are present in regime 2, while the response of GDP is insignificant in regime 1. On the other hand, shocks to asset prices and loans have no effect on prices and only a marginal positive effect on the interest rate in regime 2.

The impulse responses are consistent with the view that in an environment of low inflation and steadily increasing asset prices combined with favourable economic prospects (regime 1), inflationary pressures and the potential build-up of financial imbalances may not be primarily reflected in price increases. In regime 2 as well, during which asset price and loan shocks have a procyclical effect on GDP and lending is mainly demand-driven, pressures resulting from unsound developments in financial markets are not adequately reflected in price developments.

### 4.2.3. Generalized impulse responses for the linear model

The impulse responses of the linear model are compared to the impulse responses of the non-linear specification in graph 8. In graph 9, we plot the impulse responses with the 90 percentile interval. Most linear impulse responses represent either a weighted average of the non-linear impulse responses or closely follow the responses of regime 2 of the non-linear specification. We obtain a picture of an economy with procyclical behaviour of loans and asset prices. Shocks to GDP and to the interest rate have a positive effect on loans. We observe a positive effect of shocks to loans on asset prices and, on impact, a positive effect of shocks to asset prices on loans. Shocks in both variables have a positive effect on GDP, although the effect of shock to loans is marginally significant in the long run.

Shocks to GDP have an insignificant effect on prices and a positive effect on the interest rate. Shocks to asset prices and loans lead to an increase in the interest rate but to a decrease in prices.

For monetary policy the results both in the non-linear and the linear model convey that shocks affecting credit and asset markets do not materialize into higher prices. The evidence

obtained is consistent with the concerns that by achieving monetary stability, monetary policy may not necessarily achieve financial stability at the same time. Thus, the assessment whether financial imbalances are building up needs special attention.

#### **4.2.4. Variance decomposition**

Graph 10 depicts the variance decomposition for GDP and inflation. As for the euro area, the long-run level of the variance shares is reached nearly after eight quarters.

In both regimes, shocks to lending explain about the same share, around 20%, of the forecast error variance in GDP. While the share of asset price shocks remains below 10% in regime 1, it increases to 22% in regime 2. This pattern is consistent with the view that in a market-based economy firms find it easier to raise external finance other than bank loans when economic and financial conditions become favourable.

Turning to the variance decomposition of CPI we find that in regime 1 the variance shares attributable to asset price, loan and interest rate shocks are somewhat lower to those obtained for the euro area, around 10% for the first two and 14% for the interest rate shock. The main difference to the euro area is observable in regime 2, during which the variance share of shocks to loans and to asset prices are virtually the same as in regime 1 (12%), while for the euro area the variance share of loan shocks is 3 times higher in regime 2 while the share of asset price shocks remains negligible.

## **5. Summary and policy implications**

In the present paper, we analyze credit aggregates and asset prices jointly in a system which also includes GDP, prices and a short-term interest rate. It has been argued that in an environment of low and stable inflation rates and of favourable economic prospects, inflationary pressures may first show up in unsound developments in financial markets and materialize in prices only with a substantial delay. Given that borrowers' net worth usually serves as collateral for new bank loans, an improvement in net worth leads to an increase in bank loans which increase investment prospects. In turn, improved investment prospects lead to increases in asset prices. These mutual reinforcing effects lead to the build-up of financial imbalances. The predictions of the theoretical literature also suggest that asset prices and credit aggregates together with real and price variables should empirically be modelled in a non-linear framework. We estimate the model for two regions, the euro area and the US. By comparing the results we can assess whether there are differences in the role of asset prices and loans in the transmission mechanism between an economy characterized by a bank-based and an economy characterized by a market-based financial system, respectively.

For the euro area we are able to characterize the two regimes as one in which lending is demand-driven and one in which it is supply-driven. For the euro area, regime 1 prevails at the end of recessions from the beginning of the observation sample to the end of 1981 and from the first quarter of 1993 to the first quarter of 1995. Regime 1 relates to periods of supply-driven lending, during which, nevertheless, no amplifying effects of asset price and loan shocks on GDP are observable. We also cannot observe a mutually reinforcing behaviour between asset prices and loans during this regime. During the demand-driven lending regime (regime 2), shocks to asset prices and to lending have a procyclical effect on output. However, the unsound build-up of financial imbalances is contained, as shocks to asset prices and loans have a positive impact on inflation and the interest rate. Moreover, there is no evidence that asset prices and lending reinforce each other in regime 2, either.

In the US, regime 1 prevails twice during the recoveries of the 1980s and the 1990s. The distinguishing feature of the regimes for the US is the lower volatility of GDP growth and inflation in regime 1, which is about half of their volatility in regime 2. Moreover, all variables except CPI and real loans grow at an accelerating rate during regime 1. The generalized impulse responses show a transitory positive effect of asset price shocks on loans and vice versa in regime 2. In regime 2, shocks to asset prices and loans have a positive effect on GDP, too. In both regimes, shocks in these two variables do not materialize in higher prices and only marginally positively affect the interest rate. The impulse responses are consistent with the view that in an environment of low and stable inflation and steadily increasing asset prices, combined with favourable economic prospects, inflationary pressures and the potential build-up of financial imbalances may not be primarily reflected in price increases. Thus, monetary policy, by achieving monetary stability, may not necessarily achieve financial stability at the same time, which would call for a special assessment of developments in financial markets.

The variance decomposition analysis highlights the differing roles of both asset prices and lending in the transmission mechanism of the euro area and the US. In regime 2, the share of GDP forecast error variance attributable to loan shocks is 20% in both regions. Asset price shocks account for 19% of GDP forecast error variance in the euro area and 22% in the US, whereas in regime 1 the shares are 13% and 8%, respectively. This reflects the fact that in an economy with a market-based financial sector, firms have easier access to external finance other than bank loans when economic conditions are favourable. The importance of loans in the euro area is reflected in the result that lending shocks account for 36% of the inflation forecast error variance in regime 2, while the share of asset price shocks is negligible. The policy conclusion for the euro area is that credit growth contains

information about future inflation prospects and may serve as an indicator for future liquidity prospects.

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## APPENDIX A: Tables and Graphs

**Table 1. Log of the marginal likelihoods of various model specifications**

	Euro area	U. S.
Linear with 1 lag	-1208.6	-1178.5
Linear with 2 lags	-1180.1	-1152.1
Switching unrestricted with 1 lag	-1158.0	-1101.1
Switching unrestricted with 2 lags	-1121.8	-1045.1
Switching restricted	<b>-1118.9</b>	<b>-1039.8</b>

**Table 2: Mean parameter estimates: intercepts (standard deviation) and error variance.**

<b>(a) Euro area</b>					
	GDP	Inflation	Asset prices	Loans	Interest rate
regime 1 $\nu$	0.09	0.12	-0.17	-1.13	0.35
	(0.34)	(0.24)	(0.45)	(0.40)	(0.38)
$\Sigma_{ii}$	0.22	0.17	0.21	0.25	0.23
regime 2 $\nu$	0.00	0.01	0.02	0.04	-0.06
	(0.12)	(0.09)	(0.13)	(0.07)	(0.12)
$\Sigma_{ii}$	0.90	0.53	0.84	0.30	0.47
<b>(b) United States</b>					
	GDP	CPI	Asset prices	Loans	Interest rate
regime 1 $\nu$	-0.01	-0.03	0.14	-0.11	0.06
	(0.17)	(0.12)	(0.13)	(0.16)	(0.16)
$\Sigma_{ii}$	0.21	0.19	0.19	0.33	0.14
regime 2 $\nu$	0.07	-0.04	-0.13	0.13	-0.18
	(0.14)	(0.11)	(0.20)	(0.13)	(0.13)
$\Sigma_{ii}$	0.56	0.55	1.46	0.56	0.61

**Table 3. Euro area: State dependent average growth rates\* of the variables**

	MS VAR		CEPR		Calza and Sousa		whole sample
	regime 1	regime 2	recessions	otherwise	regime 1	regime 2	
<b>GDP</b>	0.45%	0.52%	0.06%	0.60%	0.43%	0.60%	0.51%
<b>Inflation**</b>	-0.20%	-0.09%	-0.26%	-0.07%	-0.31%	0.03%	-0.10%
<b>Asset prices</b>	1.19%	2.61%	1.33%	2.64%	2.63%	2.39%	2.43%
<b>Loans</b>	0.07%	0.94%	0.33%	0.93%	0.45%	1.15%	0.83%
<b>Interest rate**</b>	-8	-11	-10	-11	-15	-7	-11

\*Averages during periods in which the probability of being in regime 1 or 2 is more than 50%

\*\*Inflation: Change in percentage points, interest rate: Change in basis points



**Table 4. Euro area: State dependent average acceleration rates (in percentage points)  
\* of the variables**

	MS VAR		CEPR		Calza and Sousa		whole sample
	regime 1	regime 2	recessions	otherwise	regime 1	regime 2	
<b>GDP</b>	0.12%	-0.01%	-0.08%	0.02%	-0.02%	0.03%	0.00%
<b>Asset prices</b>	-1.52%	0.17%	0.34%	0.34%	-0.10%	-0.59%	-0.04%
<b>Loans</b>	-0.17%	0.02%	-0.08%	-0.08%	-0.02%	0.00%	-0.01%
<b>Interest rate**</b>	0	-1	-19	3	-9	11	0

\*Averages during periods in which the probability of being in regime 1 or 2 is more than 50%

\*\*Change in basis points

**Table 5. Euro Area: State dependent standard deviations of growth rates\***

	MS VAR		CEPR		Calza and Sousa		whole sample
	regime 1	regime 2	recessions	otherwise	regime 1	regime 2	
<b>GDP</b>	0.28%	0.54%	0.53%	0.47%	0.56%	0.49%	0.51%
<b>Inflation</b>	0.71%	0.36%	0.67%	0.35%	0.47%	0.33%	0.42%
<b>Asset prices</b>	4.72%	7.98%	5.27%	8.02%	6.68%	8.49%	7.64%
<b>Loans</b>	0.54%	0.63%	0.69%	0.64%	0.47%	0.70%	0.68%
<b>Interest rate**</b>	99	46	98	43	61	54	55

\*Averages during periods in which the probability of being in regime 1 or 2 is more than 50%

\*\*Inflation: Change in percentage points, interest rate: Change in basis points

**Table 6. US: State dependent average growth rates\* of the variables**

	MS VAR		NBER		whole sample
	regime 1	regime 2	recessions	otherwise	
<b>GDP</b>	0.78%	0.77%	-0.19%	0.93%	0.77%
<b>CPI</b>	0.77%	0.88%	1.13%	0.79%	0.84%
<b>Asset prices</b>	2.76%	2.02%	-0.18%	2.66	2.26%
<b>Loans</b>	0.78%	1.12%	0.41%	1.10%	1.01%
<b>Interest rate**</b>	-11	-14	-99	0	-13

\*Averages during periods in which the probability of being in regime 1 or 2 is more than 50%

\*\*Change in basis points

**Table 7. US: State dependent average acceleration rates (in percentage points)\* of the variables**

	MS VAR		NBER		whole sample
	regime 1	regime 2	recessions	otherwise	
<b>GDP</b>	0.08%	-0.06%	0.00%	-0.01%	-0.01%
<b>CPI</b>	-0.04%	0.00%	-0.22%	0.02%	-0.02%
<b>Asset prices</b>	<b>0.07%</b>	-0.02%	3.46%	-0.54%	0,01%
<b>Loans</b>	<b>-0.07%</b>	0.07%	-0.18%	0.05%	0.02%
<b>Interest rate**</b>	2	0	-32	4	-1

\*Averages during periods in which the probability of being in regime 1 or 2 is more than 50%

\*\*Change in basis points

**Table 8. US: State dependent standard deviation of growth rates\***

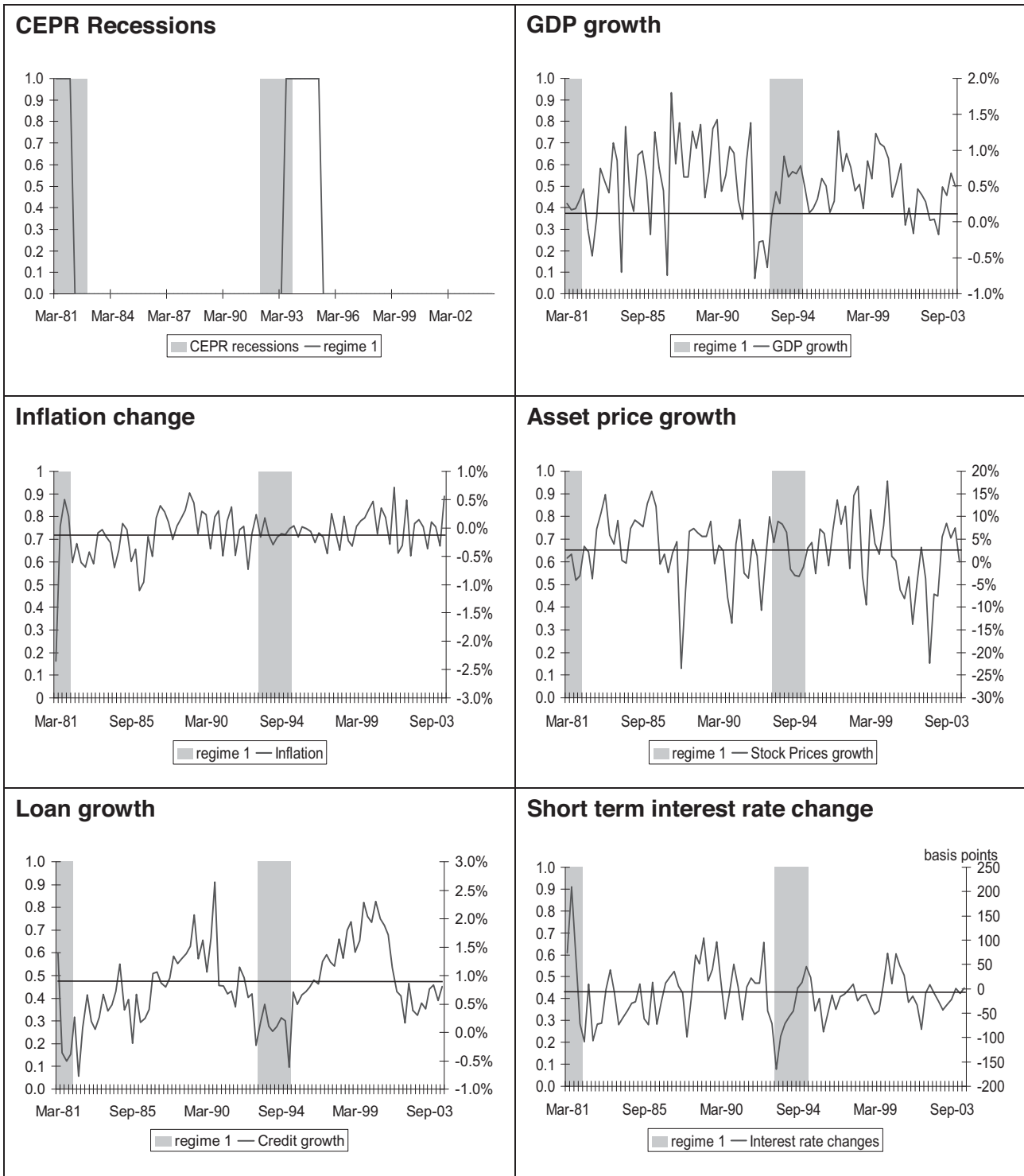
	MS VAR		NBER		whole sample
	regime 1	Regime 2	recessions	otherwise	
<b>GDP</b>	0.49%	0.77%	0.76%	0.53%	0.68%
<b>CPI</b>	0.28%	0.57%	0.78%	0.42%	0.50%
<b>Asset prices</b>	8.06%	8.25%	11.60%	7.48%	8.15%
<b>Loans</b>	<b>1.10%</b>	0.99%	0.75%	1.05%	1.03%
<b>Interest rate**</b>	59	72	119	42	68

\*Averages during periods in which the probability of being in regime 1 or 2 is more than 50%

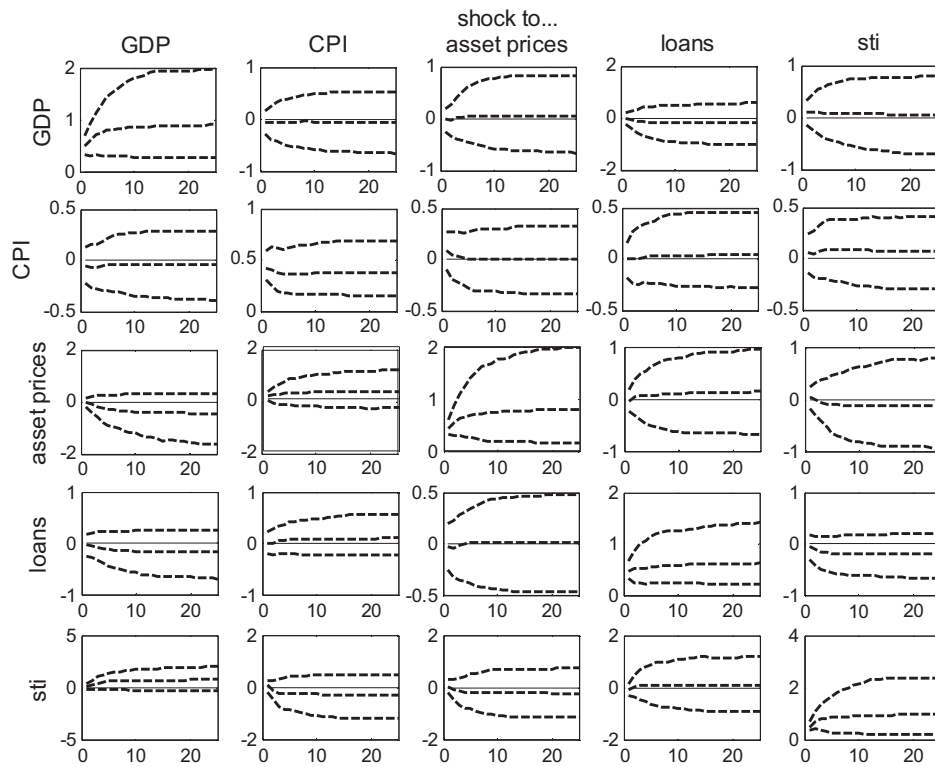
\*\*Change in basis points

### Graph 1. Euro area. Regimes based on the switching rule

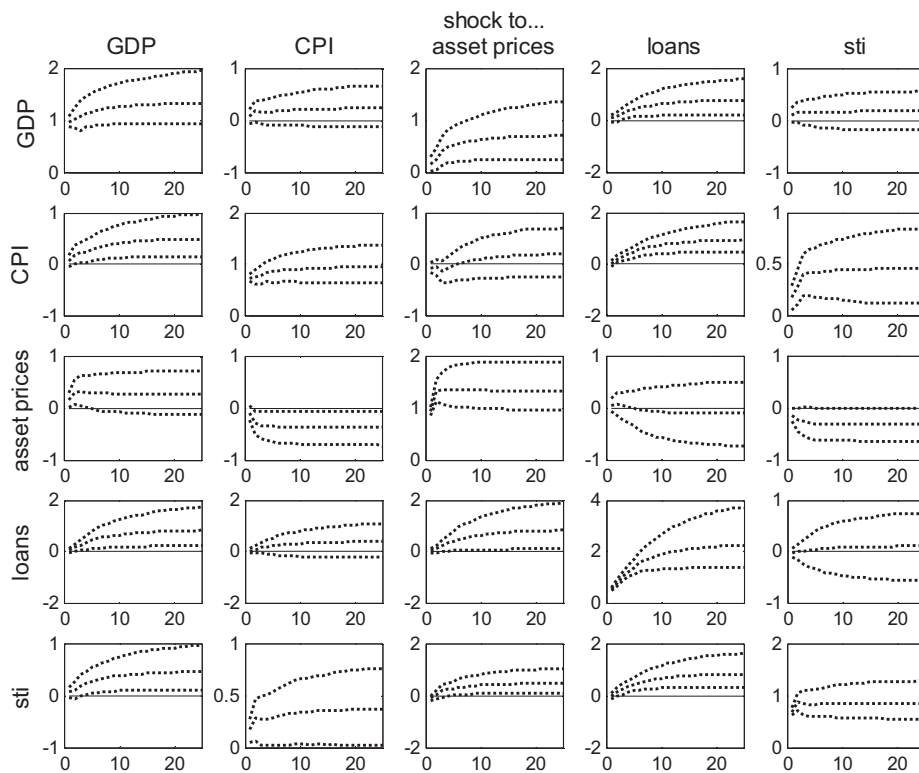
$$P(s_{t+1} = j | y^T, s_{t-1} \neq j) > 0.5, P(s_t = j | y^T, s_{t-1} \neq j) > 0.5.$$



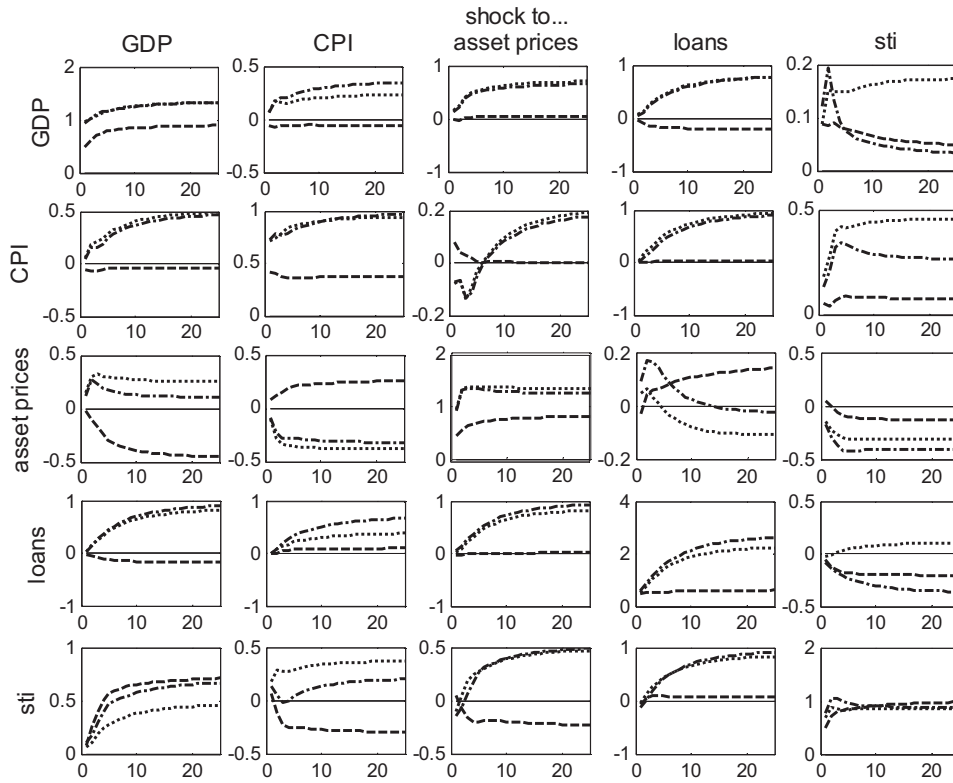
**Graph 2a. Euro area. Cumulated generalized impulse responses. Regime 1 with 90<sup>th</sup> percentile interval**



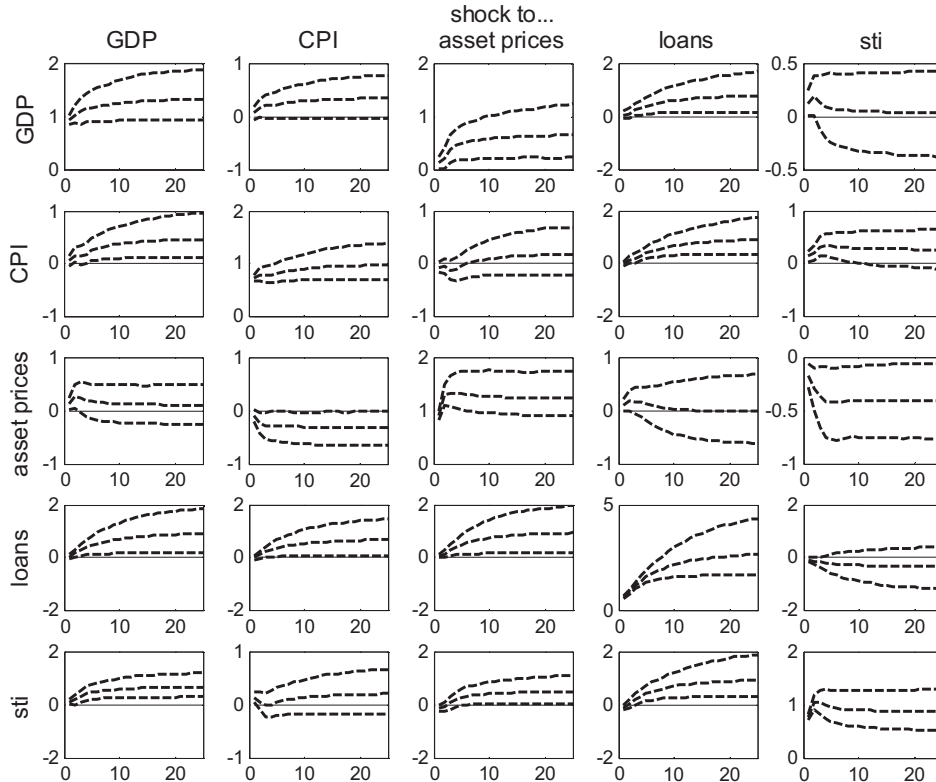
**Graph 2b. Euro area. Cumulated generalized impulse responses. Regime 2 with 90<sup>th</sup> percentile interval**



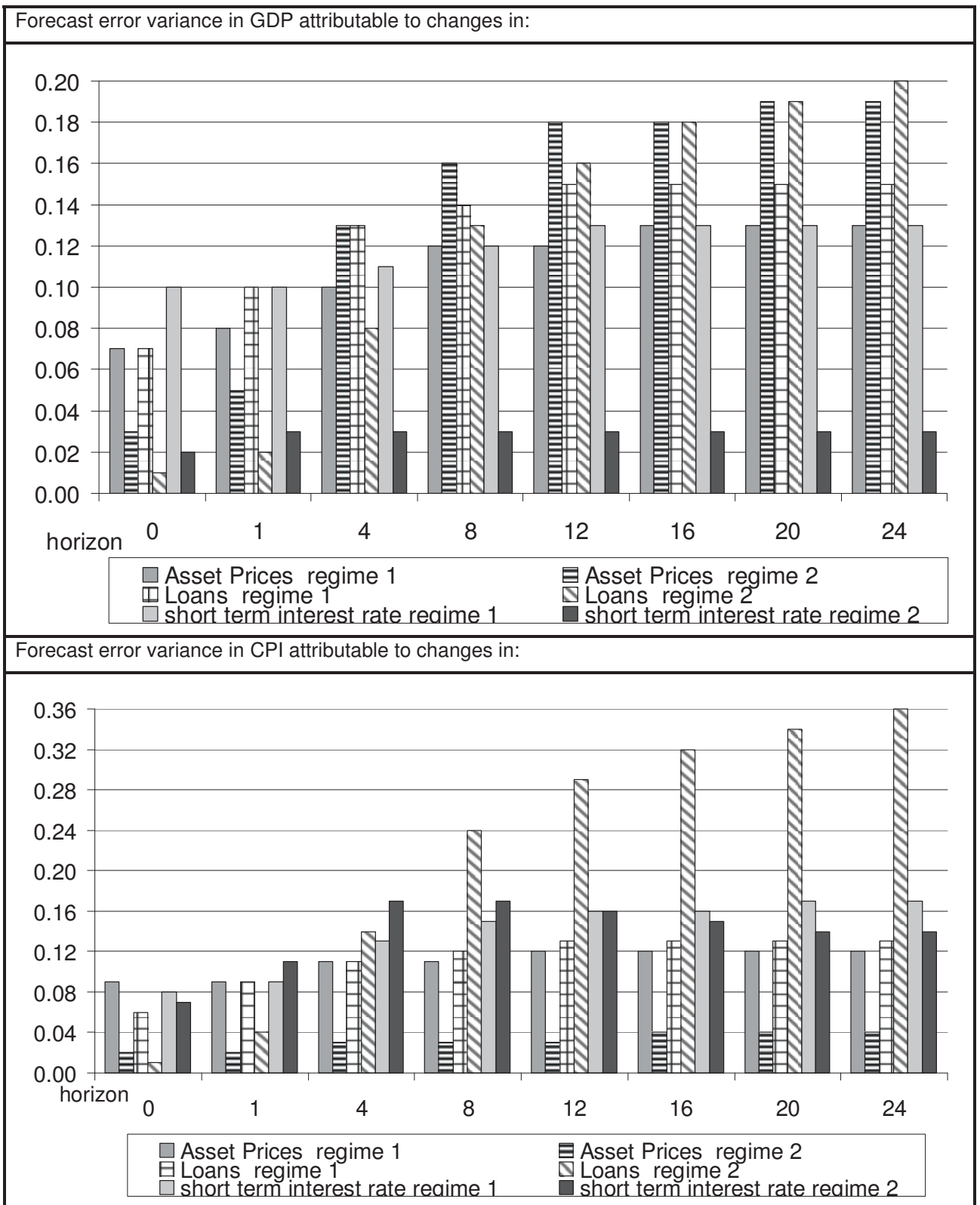
**Graph 3. Euro area. Mean generalized impulse responses. Regime 1 (dashed), regime 2 (dotted), linear response (dash-dotted)**



**Graph 4. Euro area. Cumulated generalized impulse responses. Linear responses with 90<sup>th</sup> percentile interval**



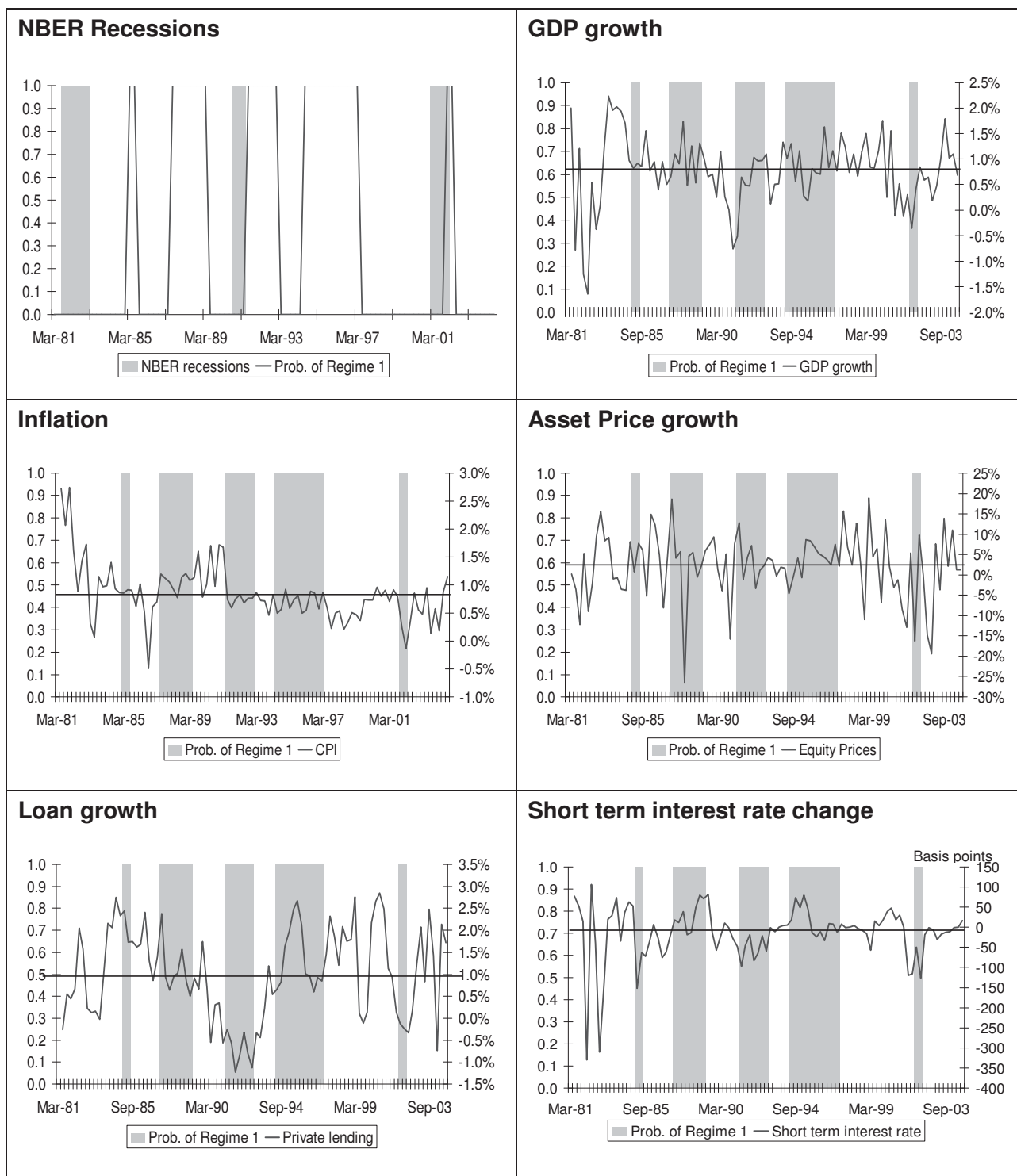
**Graph 5. Euro area: variance decomposition**



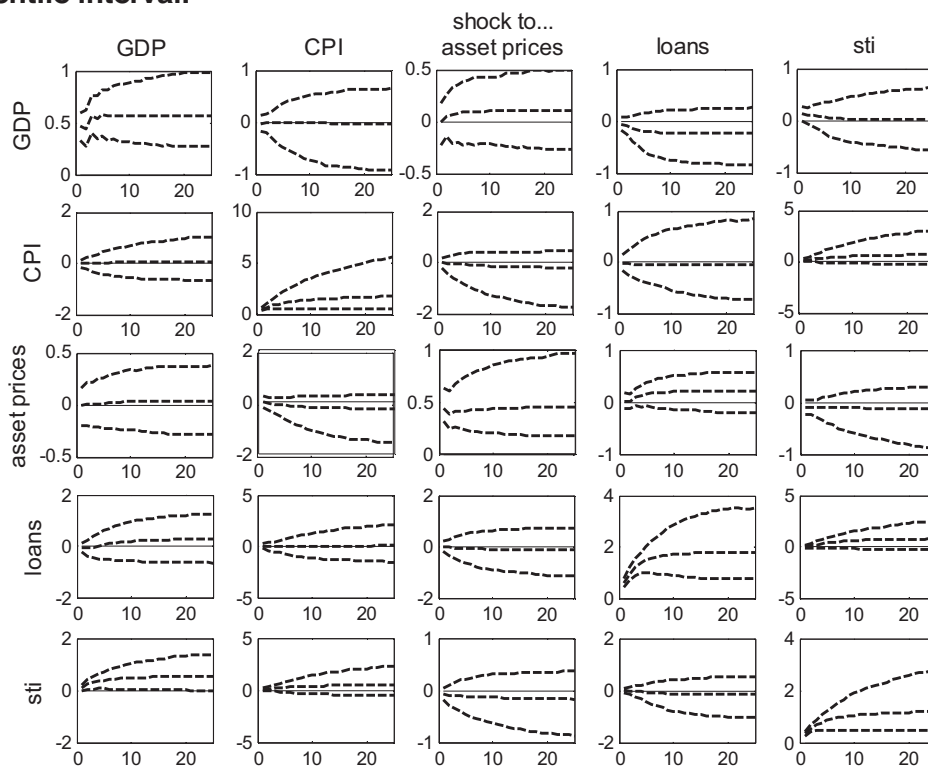


### Graph 6. US. Regimes based on the switching rule

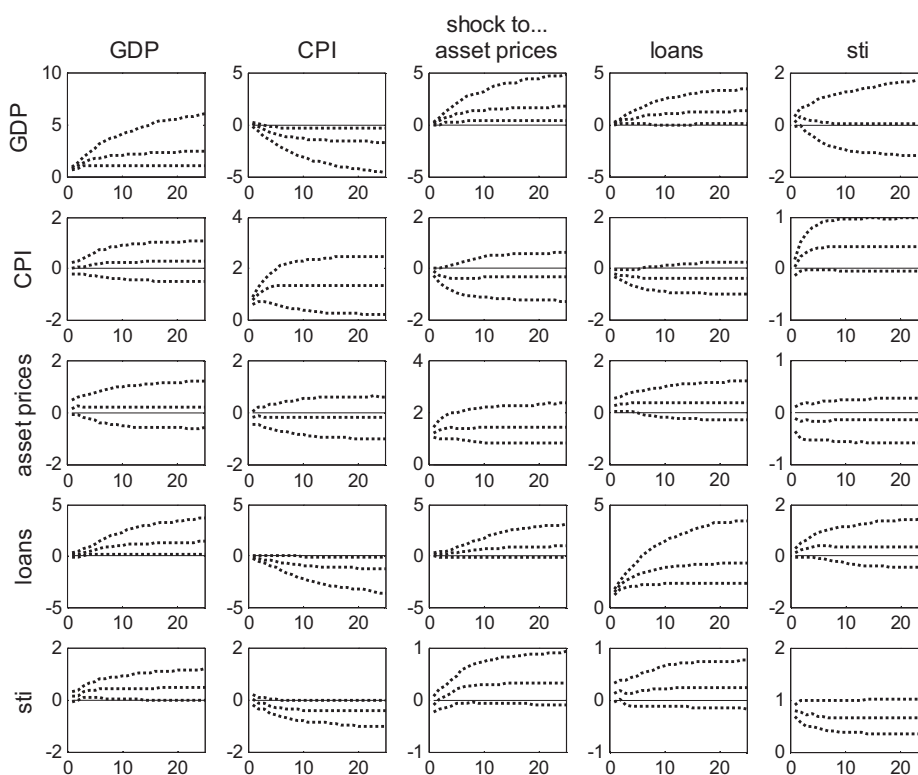
$$P(s_{t+1} = j | y^T, s_{t-1} \neq j) > 0.5, P(s_t = j | y^T, s_{t-1} \neq j) > 0.5.$$



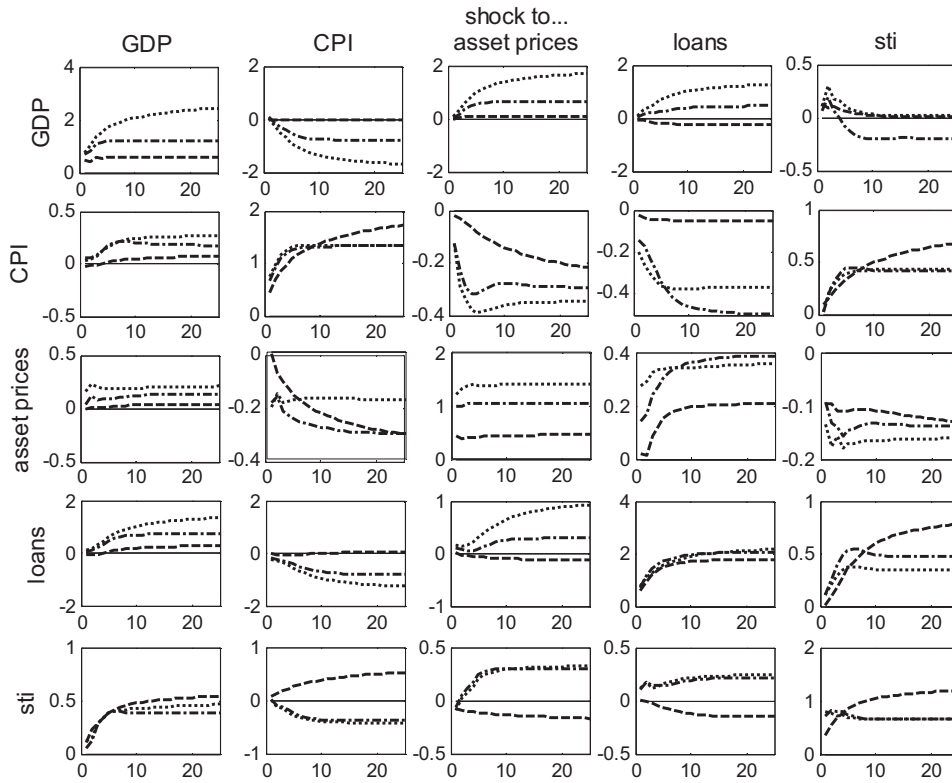
**Graph 7a. US. Cumulated generalized impulse responses. Regime 1 with 90<sup>th</sup> percentile interval.**



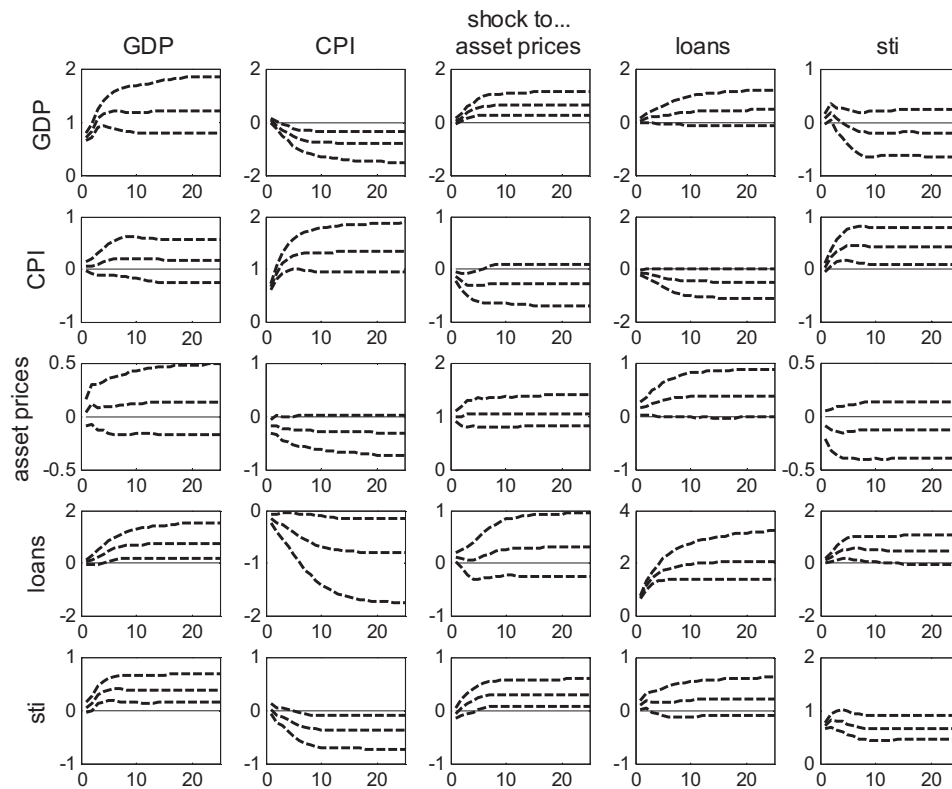
**Graph 7b. US. Cumulated generalized impulse responses. Regime 2 with 90<sup>th</sup> percentile interval.**



**Graph 8. US. Mean generalized impulse responses. Regime 1 (dashed), regime 2 (dotted), linear response (dash-dotted)**

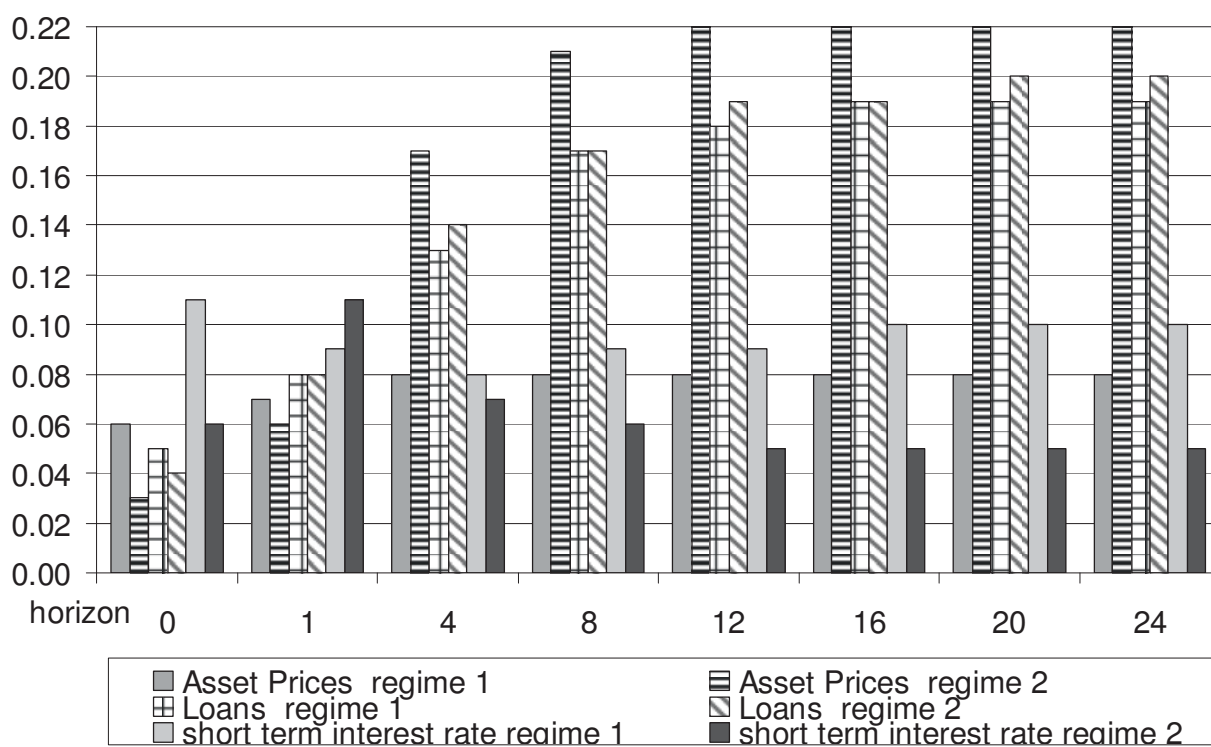


**Graph 9. US. Cumulated generalized impulse responses. Linear responses with 90<sup>th</sup> percentile interval**

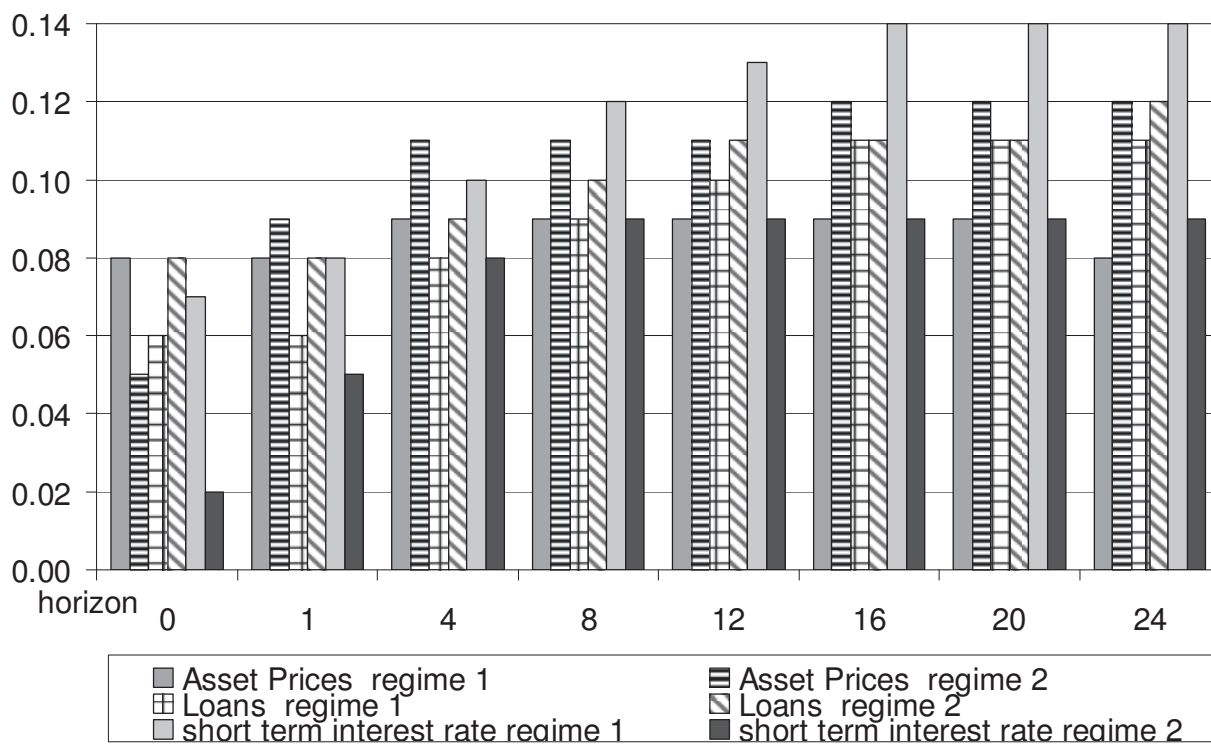


**Graph 10. US: variance decomposition**

Forecast error variance in GDP attributable to changes in:



Forecast error variance in CPI attributable to changes in:



## APPENDIX B: Prior specification and conditional posterior distributions

For expositional convenience we assume that  $q=1$  in the MS-VAR model (1). We can then write concisely:

$$y_t = y_{t-1}^* \beta(s_t) + \varepsilon_t, \quad \varepsilon_t \sim i.i.d.N(0, \Sigma(s_t)), \quad (1')$$

where  $y_{t-1}^* = (I_p \otimes [1 \ y'_{t-1}])$  and  $\beta(s_t) = \text{vec}([ \iota_p \ A(s_t) ]')$  with  $\iota_p$  being a  $p \times 1$  vector of ones.

We assume that the prior distribution of the VAR parameters  $\beta = \text{vec}(\beta(1), \beta(2))$ , the residual covariance matrices  $\Sigma = (\Sigma(1), \Sigma(2))$  and the transition probabilities  $\eta$  are independent,  $\pi(\theta) = \pi(\beta)\pi(\Sigma)\pi(\eta)$ . Specifically,

- $\beta$  is assumed to be state-invariant and multivariate normal  $N(b_0, B_0^{-1})$ , i.e.  $B_0^{-1}$  is block-diagonal across states and block-diagonal within states as we assume independence between the intercept term and the autoregressive parameters. For all parameters, we assume a prior mean of 0. The prior information for the intercept terms  $(v(1), v(2))$  is set to 1. The prior covariance matrix of the autoregressive parameters  $A(1), A(2)$  is designed in a way that takes into account the possible different scales of the system variables and that tightens the prior standard errors of higher order lags (see Litterman, 1986, and Hamilton, 1994, pp.360–362). The overall tightness parameter is set to 0.4 and the weight for off-diagonal elements to 0.5.
- $(\Sigma(1), \Sigma(2))$  are independent a priori and have an inverse Wishart distribution,  $\Sigma^{-1}(k) \sim W(\nu_0, S_0)$ , for  $k=1,2$ , where  $\nu_0 = p+2$  and  $S_0 = I_p$ .
- $\eta_1, \eta_2$  are independent a priori and are assumed to have a Dirichlet prior distribution,  $\eta_k \sim D(e_{k1}, \dots, e_{kk})$ ,  $k=1,2$ , where  $e_{kk} = 2$  and  $e_{kj} = 1$  for  $k \neq j$ .

The conditional posterior distributions can now be derived as:

- $\pi(\beta | y^T, s^T, \Sigma) = N(b, B^{-1})$ , with  $B = Y'WY + B_0$ ,  $b = B^{-1}(Y'Wy + B_0b_0)$  and  $y = \text{vec}(y_2, \dots, y_T)$ . The matrices  $Y$  and  $W$  are the predictor and the weighting matrices of model (1'), respectively:

$$Y = \begin{bmatrix} y_1^* D_2^1 & y_1^* D_2^2 \\ \vdots & \vdots \\ y_{T-1}^* D_T^1 & y_{T-1}^* D_T^2 \end{bmatrix}, \quad W = \text{diag}(\Sigma(s_2)^{-1}, \dots, \Sigma(s_T)^{-1}),$$

where  $D_t^k = 1$  if  $s_t = k$  and 0 otherwise. The draw is accepted, if the simulated

parameter values define a stationary system; if this is not the case, we reject the draw and retain the current values to continue with the next sampling step.

- $\pi(\Sigma^{-1} | y^T, s^T, \beta) = \prod_{k=1}^2 W(v_k, S_k)$ , where  $v_k = v_0 + N_k$  and  $S_k = S_0 + \sum_{s_t=k} \varepsilon_t' \varepsilon_t$

with  $N_k = \#\{s_t = k\}$  being the number of periods in which state  $k$  was prevailing.

- $\pi(\eta | s^T) = \prod_{k=1}^2 D(e_{k1} + N_{k1}, e_{k2} + N_{k2})$ , where  $N_{kj} = \#\{s_t = j | s_{t-1} = k\}$ .

Finally, we draw  $s^T$  from  $\pi(s^T | y^T, \theta)$  by applying the multi-move sampler described in Chib (1996). As we start the sampler by simulating the VAR parameters, we need a starting value for  $s^T$ . We define it to be  $s_t = 1$ , if  $y_t$  is below average, and  $s_t = 2$ , if  $y_t$  is above average.

When iterating over the sampling steps, we first do not restrict the parameters to fulfil a state-identification restriction. Rather, we first explore the unconstrained posterior distribution using the random permutation sampler (Frühwirth-Schnatter, 2001) and define a state-identifying restriction by post-processing the simulation output, e.g. by looking at scatter plots of the VAR parameters against the persistence probabilities or by estimating marginal parameter distributions. On the basis of such graphical devices, it is usually straightforward to define a state-identifying restriction (see appendix C of Kaufmann and Valderrama, 2004).

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