Monetary policy shocks, systematic monetary policy, and inflation regimes. Results from threshold vector autoregressions

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Abstract

This paper studies regime dependence in the effects of systematic and unsystematic monetary policy in the U.S. Results from a threshold vector autoregressive model show the effects of exogenous monetary policy shocks to differ strongly across two regimes. In a high inflation regime the standard results from the literature obtain. In a low inflation regime output shows no significant response to monetary policy shocks while inflation responds significantly negative. Both regimes are found to be relatively persistent with transitions between them being most strongly affected by inflation shocks. Simulating both regimes selected structural equations interchanged shows a change in inflation dynamics to be the most important source of the transition of the U.S. economy from the high into the low inflation state while the change in the monetary policy reaction functions has only very little effect. Our results indicate that favorable changes in the economic structure and less frequent and smaller shocks are more important explanations for the observed decline in U.S. macroeconomic volatility since the mid 1980s than a significant improvement in systematic monetary policy.

Keywords: monetary policy shocks, threshold vector autoregression, Great Moderation

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1 Introduction

Since the mid 1990s a very successful research program has studied the effects of monetary policy on macroeconomic variables. These effects have been identified by estimating the dynamic responses of output, inflation and other variables to "monetary policy shocks" in vector autoregressive (VAR) models of the economy. By focusing on monetary policy shocks which are identified as exogenous shifts in the monetary policy instrument, i.e. as residuals from the estimated monetary policy reaction function in the VAR, the causality problem caused by the monetary policy instrument responding endogenously to the other economic variables can be avoided.
The most prominent of these studies focus on the U.S.. The standard results which are robust with respect to different identification strategies are summarized in Christiano et al. (1999): A contractionary monetary policy impulse leads to a hump-shaped decline in output and inflation with output responding quicker than inflation. These results have played an important role as stylized facts that theoretical models of the monetary transmission mechanism need to match (e.g. Christiano et al. (2005)).

This paper investigates the stability of these results by studying threshold effects in the standard "monetary policy" VAR model. Our results show strong evidence for regime dependent reactions of macroeconomic variables to monetary policy shocks with the standard results being related to a regime of high inflation. In the low inflation regime output shows no significant response to monetary policy shocks while the inflation response is significantly negative. Our results also show that the monetary policy reaction function differs across regimes. The monetary policy instrument reacts weaker to shocks to output and inflation in the low inflation regime than if the inflation rate is high.

Studying threshold effects within a multi-equation context allows us to link our analysis to the recent discussion about the causes of the decline in macroeconomic volatility in the U.S. after the mid 1980s (e.g. Gordon (2005), Stock and Watson (2003)). One explanation focuses on beneficial changes in the structure of the U.S. economy making it less vulnerable to shocks. Another explanation is that size and frequency of shocks affecting the U.S. economy declined in this period. These first two explanations are often labelled as "good luck" while the next ones represent "good policy". These argue that the decline in macroeconomic volatility is the effect of improvements in the Fed's monetary policy, represented by an improved monetary policy reaction function and by a reduction in size and frequency of monetary policy shocks which are the deviations from the monetary policy rule, i.e. the policy residuals. In the first case, the improvement is attributed to the systematic component of monetary policy, in the second case to the unsystematic component.

This paper shows that the time period of this "Great Moderation" coincides with the dominance of one of the two regimes in the threshold model. Since the multivariate threshold model allows not only for nonlinearities and regime change in the monetary policy reaction function but also in the other economic relationships it enables us to investigate the causes of the observed improvements in macroeconomic stability by studying differences in the monetary policy reaction functions, in the dynamics of the other macroeconomic variables, and in the economic shocks across regimes. Our results indicate that favorable changes in the economic structure and less frequent and smaller shocks are more important explanations than a significant improvement in systematic monetary policy.

The starting point of our analysis is related to recent literature casting some doubt on the robustness of the conventional VAR evidence about monetary policy shocks. For example, estimating the canonical VAR model on a sample of post-1985 observations leads to results that differ from the standard evidence in important respects (Mojon (2008)). In particular, the responses of output and inflation to a monetary policy shock are not significantly different from zero. Mojon (2008) argues that these differences are the result of shifts in the mean of inflation. He shows that there is strong statistical evidence for a break in the intercept in the inflation equation and that accounting for these shifts strongly affects the estimated effects of monetary policy shocks on inflation. Instead of allowing for the change of only one specific parameter our empirical model allows for more general changes in the structural relationships in the economy.

In addition to changes in inflation dynamics, another possible source of changes in the estimated effects of monetary policy shocks on the economy is a change in monetary policy. There exists an extensive literature on shifts in the Federal Reserve's reaction function mostly modelled by estimating interest rate rules like the Taylor rule (Taylor (1993)) on split samples (e.g. Clarida et al. (2000)) or by using time-varying parameter models (e.g. Boivin (2006), Boivin and Giannoni (2006) and Mandler (2007,2008)). Changes to the Fed's monetary policy reaction function have also been studied in a VAR context, for example in Stock and Watson (2002) and Cogley and Sargent (2005).

The approaches discussed so far model both changes, those to structural economic relationships and to the monetary policy reaction function as exogenous shifts. Instead of being exogenous these changes might actually be triggered by the state of the economy. In this paper I focus on the level of inflation as the variable to trigger switches between regimes. For example, the relationship between output and inflation (the Philips curve) and the persistence of inflation depend on expected inflation and on the credibility of monetary policy. If high inflation erodes this credibility, inflation dynamics can be affected by changes to the level of inflation. Changes in the monetary policy reaction function can also depend on the level of inflation as the central bank might react differently to shocks depending on the size and direction of the deviation of inflation from its target.

Assuming a linear state-independent monetary policy reaction function as it is standard in the literature implies that the incremental reaction of monetary policy, i.e. the change in the interest rate set by the central bank, to the variables in the reaction function, is constant independent of the actual deviation of the economy from the central bank's target values. Linear reaction functions like these can be derived theoretically by assuming that the central bank minimizes a quadratic loss function in a subset of

economic state variables subject to a linear dynamic model that describes the evolution of these state variables through time (e.g. Clarida et al. (1999)). Modifications to either of these elements can result in the reaction function becoming nonlinear. For example, Orphanides and Wilcox (2003) and Aksoy et al. (2006) present a model which results in a target zone for inflation. The central bank only responds to shocks which drive the inflation rate outside the target zone. As long as the inflation rate remains within the target band monetary policy remains passive. This leads to the monetary policy reaction function being different depending on whether the inflation rate is within or outside of the target band.
Nonlinear reactions of monetary policy can also be the result of credibility concerns. For example, while small deviations of the inflation rate from its target might not cause a loss in public confidence in the central bank's commitment to the inflation target, large deviations might cause the central bank to lose credibility with the public. To avoid this credibility loss, the central bank might respond more aggressively to sizable inflationary excesses than to small ones (e.g. Cukierman (1992) and Cukierman and Meltzer (1986)). Uncertainty about the monetary transmission mechanism might also result in non-linearities in the central bank's reaction function (e.g. Meyer et al. (2001) and Swanson (2006)).

A straightforward way to model nonlinearities like these empirically is the estimation of a threshold model. Threshold models allow for different regimes, i.e. different sets of model parameters. Which regime applies to a given point in time depends on whether a specific variable, the threshold variable, exceeds a given threshold value. By introducing more than one threshold values the model can accommodate more than two regimes. Univariate threshold autoregressive models have been introduced by Tong (1978) and Tong and Lim (1980).[1] Bunzel and Enders (2010) estimate a nonlinear Taylor rule with an inflation threshold. These models have been extended to a multivariate context by Tsay (1998) and Balke (2000) who tests for regime dependence in macroeconomic

[1]See Tong (1990) for an extensive survey.

dynamics based on a threshold VAR with tight and loose credit growth as threshold variables In this paper, we adopt his VAR approach to the study of threshold effects in the analysis of monetary policy in the U.S.

The paper is structured as follows. Section 2 presents a brief discussion of the threshold VAR model and its estimation. Section 3 contains the estimation results and compares various elements of the threshold model across the regimes. Section 4 concludes with a discussion of the results.

2 Econometric Methodology

A threshold vector autoregressive (TVAR) model with two regimes can be written as (Balke (2000))

$$Y_t = \mu^1 + A^1 Y_t + B^1(L) Y_{t-1} + (\mu^2 + A^2 Y_t + B^2(L) Y_{t-1}) I(c_{t-d} > \gamma) + u_t. \qquad (1)$$

Y_t is a vector of endogenous variables. I is an indicator variable that equals 1 when the threshold variable c_{t-d} exceeds a threshold value γ and 0 otherwise. The dynamics of Y_t follow two different regimes dependent on the indicator variable. If $I = 0$ the dynamics of the VAR are given by the vector of constants μ^1, the matrix of contemporaneous interaction coefficients A^1 and the coefficients in the matrix of lag polynomials $B^1(L)$. If $I = 1$ the relevant coefficients are $\mu^1 + \mu^2$, $A^1 + A^2$ and $B^1(L) + B^2(L)$. u_t is a vector of serially and mutually uncorrelated structural innovations. The (diagonal) variance-covariance matrix of these innovations can also be regime dependent Σ_u^i, $i = 1, 2$. By specifying the threshold variable c_t as a function of the variables in Y_t the transition between the two regimes is endogenously determined by the model.

Testing for threshold effects in (1) is complicated by the fact that the threshold parameter γ is not identified under the null hypothesis of no threshold effects. To test for threshold effects the model is estimated by OLS on a grid of possible threshold values chosen to provide for each regime at a number of observations equal to the number of coefficients in each equation plus 15% of the overall number of observations. For each threshold value a Wald statistic is computed and three test statistics for the null hypothesis of no threshold effects are constructed: (sup-Wald) the maximum of the Wald statistic over all possible threshold values, (avg-Wald) the average of the individual Wald statistics, and (exp-Wald) the sum of exponential Wald statistics. The latter two statistics are suggested by Andrews and Ploberger (1994). In order to obtain p-values the empirical distributions of the sup-Wald, avg-Wald and exp-Wald statistics are then constructed under the null hypothesis by simulation using the method of Hansen (1996). The estimate of the threshold value is the one minimizing the log determinant of the variance-covariance matrix of the VAR residuals.

3 Results

3.1 Threshold Effects and Threshold Estimates

We use a standard data set commonly applied to VAR studies of monetary policy in the U.S. It contains quarterly observations on real GDP, the GDP deflator and the monetary aggregate M1. The indicator for monetary policy is the end-of-quarter Federal Funds Rate.[2] Standard VAR studies also include an indicator of commodity prices (e.g. Christiano et al. (1999)).[3] We constructed this indicator as the average

[2]Data was obtained from the FRED II database at the Federal Reserve Bank of St.Louis. http://www.stlouisfed.org/fred2

[3]This variable is included to alleviate the "price puzzle" - an increase in the price level following an exogenous restrictive monetary policy impulse. On explanation for this surprising result is that the central bank reacts to leading information signalling a future increase in inflation. Including a leading indicator of future inflation such as commodity price inflation accounts for monetary policy responding endogenously to a forecast of higher inflation and thus eliminates or reduces the price

annualized inflation rates in the prices indices for oil (West Texas Intermediate), for agricultural commodities and for metals.[4]

In order to identify the coefficients of the contemporaneous relationships in the A-matrices we impose a standard recursive causal ordering of the variables of output, prices, commodity prices, the Federal Funds Rate, and the monetary aggregate (e.g. Christiano et al. (1999)).

Including non-stationary data in the VAR might lead to spurios non-linearities (Calza and Sousa (2005)) and might also violate the regularity conditions required to obtain simulated p-values using the Hansen (1996) technique. Hence we set up the VAR in log differences of all variables except for the Federal Funds Rate and include annualized rates of quarter-to-quarter output growth, inflation, commodity price inflation and money growth. The overall estimation period runs from the starting date in Christiano et al. (1999) which is 1965Q3 to 2007Q2.

As a starting point Figure 1 replicates the standard results for the effects of a contractionary monetary policy shock, i.e. of an exogenous increase in the Federal Funds Rate using VAR estimates for the period 1965Q3 to 1995Q2 - the estimation period in Christiano et al. (1999).[5] 90% confidence bands were constructed by Monte Carlo simulation. An exogenous interest rate shock of one standard deviation has been imposed.

Figure 1 shows that a monetary policy shock causes a significant decline in output growth with a lag of about two quarters. Inflation declines after two quarters but the fall in inflation becomes marginally significant only after a considerable lag. The positive response of inflation in the first quarter after the shock indicates the presence of a price puzzle. The Federal Funds Rate shock leads to a significant increase in the Federal Funds rate itself which persists for some quarters.

puzzle (Eichenbaum (1992)). For an in depth discussion, see Hanson (2004)).

[4]This data is from the IMF's International Financial Statistics database.

[5]The results from the 1965Q3 to 2007Q2 sample are very similar to the ones shown here.

« Insert Figure 1 »

Estimation of the threshold VAR (1) requires to choose a threshold variable c_t and its lag order d. In the light of the discussion in the introduction we selected the lagged inflation rate. Our emphasis on regime dependence in the monetary policy reaction function suggests choosing a goal variable of monetary policy as threshold variable. Inflation is as many may argue the most important goal variable of the central bank. Furthermore, inflation is an observable variable. Using output growth as the target variable would require looking at the output gap, i.e. the deviation of output from full employment, which is unobservable. Since optimized monetary policy reaction functions generally attach a much lower weight to output than to inflation (e.g. Woodfod (2003), p 401) the inflation rate is more likely to trigger switches from one monetary policy regime to another. Finally, the period of the "Great Moderation" is associated with a significant decline in the level of inflation but less with a significant change in output growth. Since we want to allow the threshold VAR to associate one regime with this interesting time period inflation is a more promising threshold variable.[6]

Table 1 presents tests for the null hypothesis of no threshold effects in the VAR ($A^2 = B^2(L) = 0, \mu^2 = 0$) based on the complete sample from 1965Q3 to 2007Q2. The threshold variables under consideration are the inflation rate lagged once, and the average inflation rates in the preceding two or three quarters. Primiceri (2005) and Sims and Zha (2006) conduct formal tests of stability of coefficients in similarly structured VARs. They are unable to reject the hypothesis of stable coefficients after accounting for time variation in the shocks. To account for this, Panels A and B differ in the way the contemporaneous interaction coefficients in A^1 and A^2 and the variance-covariance matrix of the structural VAR residuals are treated. Panel A assumes $A^2 = 0$ and $\Sigma_u^1 = \Sigma_u^2$ by estimating the variance-covariance matrix of the reduced form VAR as

[6] Bunzel and Enders (2010) also use the lagged inflation rate as the threshold variable in their estimation of a Taylor rule.

Table 1: Tests for threshold VAR
Variables: GDP growth, inflation, com. inflation, Fed Funds Rate, M1 growth

A: No threshold effect in contemporaneous relationships				
threshold variable	Estimated Threshold value	sup-Wald	avg-Wald	exp-Wald
INFLATION	$\gamma = 4.85$	7152.61	1805.84	700.22
Lag=1	LD=10.16	(0.00)	(0.00)	(0.00)
B: Threshold effect in contemporaneous relationships				
threshold variable	Estimated Threshold value	sup-Wald	avg-Wald	exp-Wald
INFLATION	$\gamma = 4.85$	1249.53	299.35	619.47
Lag=1	LD=10.062	(0.00)	(0.00)	(0.00)

NOTES: Sample period is 1965Q3-2007Q2. P-Values in parentheses.

Based on Hansen (1996) with 1000 replications.

being identical in both regimes. Panel B allows for $A^2 \neq 0$ and $\Sigma_u^1 \neq \Sigma_u^2$ by estimating regime-dependent variance-covariance matrices for the reduced form VAR. The results in both panels show strong evidence for the presence of threshold effects and arrive at identical estimates of γ. These estimates are considerably higher than those for the single equation model in Bunzel and Enders (2010). The smallest value for the log determinant of the variance-covariance matrix of the residuals results for the lagged inflation rate in Panel B. Figure 2 shows a plot of the lagged inflation rate and the estimated threshold value.

« Insert Figure 2 »

3.2 Regime-dependent impulse responses and variance decompositions

The next figures show regime-dependent impulse response functions based on the specification in Panel B and a threshold value of 5.85 percent Each figure presents the impulse responses in both regimes to a given structural shock of size of one standard deviation in the high inflation regime. In both regimes the size of the structural shocks have been scaled to the size in the high inflation regime. In fact, the shocks are significantly larger in the high inflation regime.[7] The median Federal Funds Rate shock in the high inflation regime is almost three times as large as in the low inflation regime, the inflation shock about 50 percent larger and the output shock is about 25 percent larger. 90% confidence bands were constructed by Monte Carlo simulations. The wider confidence bands in the high inflation regime are to a large extent the result of the lower number of observations compared to the low inflation regime and to a thus less precise estimation of the VAR coefficients.

Figure 3 shows the effects of a monetary policy shock for each regime. A significant decline in output growth is caused only in the high inflation regime. Inflation responds significantly negative only in the low inflation regime and after a lag of one year. The price puzzle is only present when inflation is high. The Federal Funds Rate increase is much more persistent in the low inflation regime. Note that the standard results on the effects of monetary policy shocks in Figure 1 pertain to the high inflation regime.

« Insert Figure 3 »

Figure 4 traces the effects of an exogenous increase in the inflation rate on the other variables. The Federal Funds rate increases weakly and in returns quickly to its steady state in about one year. The median response of the Federal Funds Rate is somewhat stronger in the high inflation regime. Output growth reacts similarly in both regimes. The inflation rate reverts somewhat more quickly to its steady state in the low inflation

[7] For similar results, see e.g. Canova and Gambetti (2009), Stock and Watson (2003).

regime although it remains significantly above its starting level for a long time in both regimes.

« Insert Figure 4 »

The impulse responses for GDP growth, inflation and the Federal Funds Rate to a shock to GDP growth are broadly similar in both regimes (Figure 5). However, the immediate reaction of the Federal Funds Rate is significant only in the low inflation regime where it follows an inverted u-shaped pattern.

« Insert Figure 5 »

Table 2 presents the results of regime-dependent variance decompositions. Each panel shows the contributions of shocks to output growth, inflation and to the Federal Funds Rate to the forecast variance of the variable in the header for different forecast horizons. In the low inflation regime Federal Funds Rate shocks have a stronger effect on the forecast variance of output growth than in the high inflation regime but a lower long-run impact on the forecast variance of inflation at a longer horizon. Output shocks become less important for unexpected changes in the Federal Funds Rate in the low inflation regime but the explanatory power of inflation shocks increases.

3.3 Generalized impulse responses

The impulse responses in Figures 3 - 5 assume that the economy remains within the same regime for all periods following the shock. These results might be misleading if there is a non-negligible probability of the economy switching between regimes in the dynamic adjustment to the shock. To analyze this issue we use non-linear impulse response functions that do not restrict the model to remain within a given regime (Koop et al. (1996)). The construction of these generalized impulse response functions is more complicated than in the conventional linear case since the dynamic behavior of the model depends on both of the history of the time series (initial conditions) and

Table 2: Variance decompositions

A: Percentage contribution to GDPGR			
	1 quarter	4 quarters	16 quarters
FF	0.05	19.90	17.70
	(0.05)	(1.98)	(5.25)

B: Percentage contribution to INFL			
	1 quarter	4 quarters	16 quarters
FF	1.97	1.55	5.54
	(0.38)	(1.30)	(12.13)

C: Percentage contribution to FF			
	1 quarter	4 quarters	16 quarters
RGDPGR	4.87	9.34	9.79
	(8.03)	(36.49)	(51.44)
INFL	2.79	27.36	19.78
	(8.70)	(14.92)	(10.92)
FF	87.50	57.75	21.40
	(75.07)	(38.20)	(24.09)

NOTES: Sample period is 1965Q3-2007Q2. Numbers in brackets apply to regime $INFL_{t-1} \geq 4.86$

on the size of the shock.

The generalized impulse response of variable y in period k following a shock is defined following Koop et al. (1996) as the difference in the conditional expectations of the variable in question

$$GI_k = E[Y_{t+k}|\Omega_{t-1}, u_t] - E[Y_{t+k}|\Omega_{t-1}] \tag{2}$$

Ω_{t-1} is the information set at time $t-1$ and u_t is an exogenous shock which is typically constructed from a single identified structural shock.

We construct the non-linear impulse responses using the bootstrap procedure suggested by Balke (2000). For each initial set of observations Ω_{t-1} we draw a random vector of shocks $u_{t+j}, j = 0, \ldots k$ from the regression residuals and simulate the model in order to obtain $E[Y_{t+k}|\Omega_{t-1}]$. Based on the value of the threshold variable in this simulation, the VAR coefficients are allowed to change according to the two regimes. To retrieve $E[Y_{t+k}|\Omega_{t-1}, u_t]$ we repeat the procedure using the same random shocks plus an additional perturbation in period t which is constructed from a structural shock to a selected variable using the recursive identification assumption. The difference of these simulated expectations is the generalized impulse response function. This procedure is repeated seperately for each set of initial observations from each regime using 500 draws of random shock series. Figures 6 - 8 show these impulse responses averaged over all initial observations for each of the two regimes. The procedure used to derive these result differs from the approach in Balke (2000) by its construction of the structural shocks and of their contemporaneous impact from the regime-dependent variance-covariance matrix of the VAR residuals.

« Insert Figure 6 »

« Insert Figure 7 »

« Insert Figure 8 »

The impulse responses in Figures 6 - 8 are derived from four different shock sizes for each variable and regime: a positive two-standard-deviations shock, a positive one-standard deviation shock, a negative one-standard deviation shock, and a negative two-standard-deviations shock. Asymmetries in the responses to the negative and positive shocks result from differences in the the model switching between the regimes in the adjustment after the different shocks.

Figure 6 shows that the responses to the Federal Funds Rate shock are symmetric for the different shocks for starting in both regimes indicating that only negligible differences in regime switching are caused by the differently sized shocks. Due to the smaller size of the monetary policy shocks in the low inflation regime the difference in the responses of output growth is even more pronounced than in Figure 3. After six to seven quarters inflation responds strongly and in the right direction in the high inflation regime but the response is quicker in the low inflation regime. Similarly little evidence of differences in regime switching after shocks is provided by Figure 8 for the adjustment of the U.S. economy to the shock to GDP growth. While the initial response of monetary policy to the output shock is smaller in the low inflation regime but builds up to a size similar to the high inflation regime. In contrast, Figure 7 shows strong evidence for differences in regime switching following an inflation shock. Asymmetries are most pronouned for the response of output growth to the inflation shock.

Figure 9 shows the importance of the different structural shocks in causing switches between the two regimes. Each figure in the left column displays the probability of the economy being in the high inflation regime after having started in the high inflation regime and being subject to an exogenous shock. The right column shows the probabilities for the high inflation regime when the economy starts in the low inflation regime. The probabilities are constructed from the simulations underlying the generalized impulse response functions. For each initial set of observations from either regime the VAR is simulated 500 times using randomly drawn residuals and allowing

the VAR coefficients to change depending on the lagged inflation rate being above or below the threshold. Figure 11 displays the average frequency of the economy being in the high inflation regime k periods after being subject to a structural shock to one of the variables. The solid lines show these frequencies which result from simulating the nonlinear system with just the bootstrapped residuals. The other two lines represent the frequencies derived from combining the bootstrapped residuals with a structural shock of plus or minus two standard deviations to one of the variables in $k = 0$.[8]
The likelihood of the economy being initially in the low inflation regime and switching into the high inflation regime is small but non-neglibile even in the absence of structural shocks and rises to about 25%. The strongest effects on these probabilities can be observed for the inflation shock with a large positive shock substantially increasing the likelihood for the high inflation regime. The other shocks have only small effects on the regime probabilities if the economy starts in the low inflation regime.
The probabilities in the left column show the high inflation regime to be highly persistent as well. The probability of the economy being in the high inflation regime declines only slowly to about 50%. As in the case of the low inflation regime these probabilities are noticably affected by inflation shocks but shocks to commodity price inflation and to the Federal Funds Rate have sizable effects on the regime probabilities as well.

« Insert Figure 9 »

3.4 Counterfactual simulations

An interesting issue is the importance of regime-dependent changes in the Feds monetary policy reaction function for our results. Sims and Zha (2006) show that in their multivariate regime-switching model changes in the other equations are of little importance beside regime switches in the Feds monetary policy rule. We investigate this issue by running a counterfactual simulation by interchanging the estimated monetary

[8]The shocks again are scaled to the size of the shocks in the high inflation regime.

policy reaction functions between the two regimes. Counterfactual policy simulations like this are subject to the Lucas (1976) critique since the VAR coefficients might be affected by changes to the monetary policy rule. However, even if the Lucas critique holds in theory, its empirical relevance depends on the size and on the economic significance of the changes in the reduced form parameters. Even though many empirical studies show clear evidence of in the Fed's monetary policy reaction function empirical VAR and backward-looking non-VAR models appear to be stable, see, for example Rudebusch and Svensson (1999) and Bernanke and Mihov (1998). Rudebusch (2005) and Estrella and Fuhrer (2003) study the effects of plausible policy changes on reduced form representations of the economy and are mostly unable to reject the hypothesis of invariance in the coefficients.

**** Figures 10 to 12 display the generalized impulse response functions that result from this exercise. Comparing Figures 7 and 6 shows that switching the monetary policy reaction function leads to the interchange of the impulse response function of the Federal Funds Rate to its own shock as well. The dynamic response of inflation to an interest rate shock is little affected but the price puzzle which is present in the high inflation state only is reduced. The hump-shaped pattern of the response GDP growth to a monetary policy shock is still present if the economy is initially in the high inflation state but is much less pronounced than in Figure 9. The largest reduction in the growth rate of output is 0.6% in contrast to 2% before.

Comparing the dynamic response of the inflation rate to an inflation shock (Figure 14 and 10) shows the change in the monetary policy reaction function top have little effect. However, inserting the monetary policy reaction function from the low inflation regime into the high inflation regime leads to negligible response of the Federal Funds Rate to positive inflation shocks in the high inflation regime. The Federal Funds Rate does not rise before the fourth quarter after a positive inflation shock but increases strongly and persistently afterwards.

The impulse responses of real GDP growth to its own shock again is largely unaffected by the substitution of the monetary policy rule (Figure 15). The response of inflation starting in the high inflation regime is almost unchanged as well but inflation reverts to the baseline more quickly if the economy is initially in the low inflation regime. Comparing the responses of the Federal Funds Rate to the shock to output growth shows that the initial response in the high inflation regime again becomes weaker by interchanging the reaction function.

« Insert Figure 10 »

« Insert Figure 11 »

« Insert Figure 12 »

Figure 13 shows that interchanging the monetary policy reaction function does affect the probabilities of the economy being in the high inflation regime very little. The Figure combines the results from Figure 10 with a no-shock scenario and the interchanged Federal Funds Rate equation (solid line). The probability of the economy remaining in the high inflation regime does not decline in the left column indicating that the monetary policy reaction function from the low inflation regime does not affect the likelihood of the economy exiting the high inflation state. Since the probability of the inflation regime in the right column increases only slightly the Fed's reaction function from the high inflation regime is not a major source of pushing the economy from the low into the high inflation state.

Figure 14 shows the corresponding results for switching the output growth equation between the two regimes. The results are similar to those in Figure 13 with the change in the output equation causing a slighly higher rise in the probabilities by about 10% for the high inflation regime in the left column and slightly lower probabilities in the right column. Finally, Figure 15 shows that changes in inflation dynamics between the two regimes are very important for the regime probabilities. The probabilities of the economy remaining in the high inflation regime (left column) decline substantially by about 25%. These results show that changes in output and inflation dynamics have been much more imporant than changes in the monetary policy reaction function in forcing the U.S. economy from the high into the low inflation regime.

« Insert Figure 13 »

« Insert Figure 14 »

« Insert Figure 15 »

4 Discussion

The results presented in this paper show strong evidence for important non-linearities and regime-dependence in standard VAR models commonly used in the analysis of monetary policy shocks in the U.S. Using a threshold vector autoregression we show that the standard effects of a monetary policy shock - identified as an exogenous increase in the Federal Funds Rate - apply to a regime of inflation rates above about 4.85 percent. We find strong evidence a second "low inflation" regime being important mainly from the mid 1980s on. Output growth in the high inflation regime shows the expected negative hump-shaped response to an increase in the Federal Funds Rate and inflation reacts only very sluggish and exhibits a prize puzzle. In contrast, output growth in the low inflation regime is not significantly affected by monetary policy shocks but inflation falls significantly. These results demonstrate a stronger reaction of output to monetary policy shocks and a weaker reaction of inflation if inflation is already relatively high.[9] The results for the high inflation regime are similar as those presented in Mojon (2008) with a price puzzle, a relatively weak negative response of inflation after three to four quarters and a humped shaped negative response of output growth. By treating the

[9] These results are in contrast to Francis and Owyang (2003) who - using a markov-switching vector error correction model - find one regime in which exogenous Federal Funds Rate shocks cause a decline both in output and in the price level and another regime in which both output and the price level increase.

VAR dynamics as constant through time his empirical model is unable to pick up how these results change in the low inflation regime. Our results indicate only relatively small differences in the responses of monetary policy to shocks to output growth and to the inflation rate.

The results in Section 3 are also relevant to the discussion of the causes for the observed decline in macroeconomic volatility in the U.S. since the mid-1980s. It has been argued whether the decline in output and inflation volatility was caused by a reduction in shocks to the U.S. economy ("good luck"), changes in the structure of the U.S. economy or by improvements in the Fed's monetary policy ("good policy") (e.g. Gordon (2005), Stock and Watson (2003)).

In this paper, we found the core of the period of the so called "Great Moderation" to be largely identical to the period in which the low inflation regime persisted. Hence, the comparison of the sources of macroeconomic volatility between the regimes can shed some light on this important debate. Supporting the "good luck" argument is our finding that the structural shocks to output and inflation were much larger in the high inflation regime than in the low inflation regime. The size of the policy shock in the low inflation regime is only about a third of its size in the other regime. This indicates that in the low inflation regime the Fed followed a more systematic monetary policy and deviated less from its policy reaction function, i.e. monetary policy in the U.S. became more predictable (see also e.g. Canova and Gambetti (2009)).

The impulse responses result from the interaction of the Fed's monetary policy reaction function with the dynamic equations of the other variables in the VAR. This makes it difficult to disentangle the effects of changes across regimes in the structural equations for the non-policy variables and in the monetary policy reaction function. The results in Figures 4 and 5 do not indicate large differences in the reaction of monetary policy to shocks to output and inflation, neither do the generalized impulse responses in Figures 7 and 8. In contrast, the evidence from the counterfactual simulations in Section 3.3. indicates that changes to the structural relationships in the U.S. economy have been important in bringing about the transition from a high to a low inflation regime as argued, for example, by Giannone et al. (2008).

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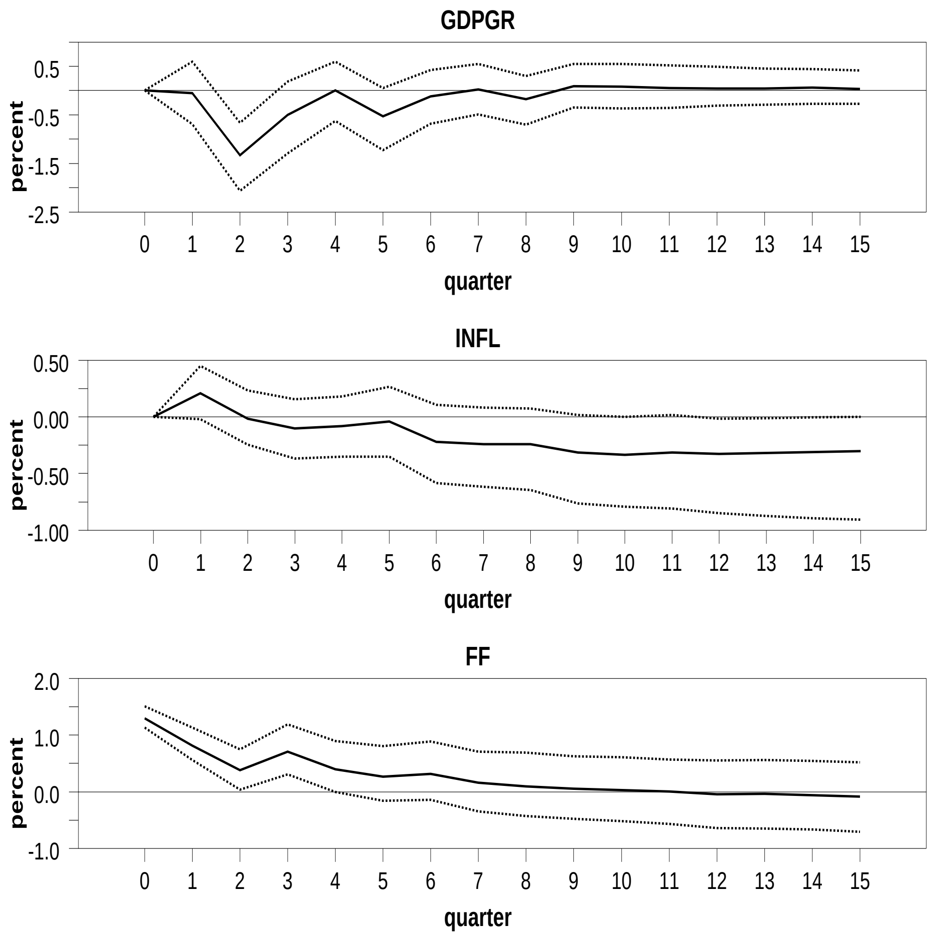

Responses to Federal Funds Rate

Figure 1: Impulse responses to monetary policy shock (1965Q3 - 1995Q2)

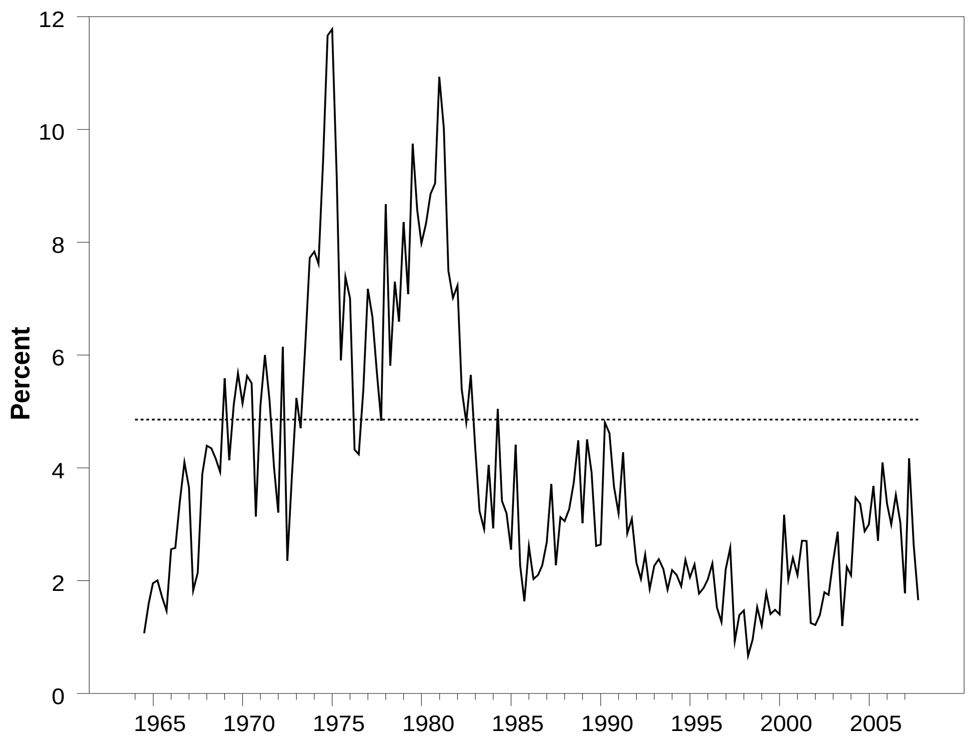

Figure 2: Lagged inflation and estimated threshold values

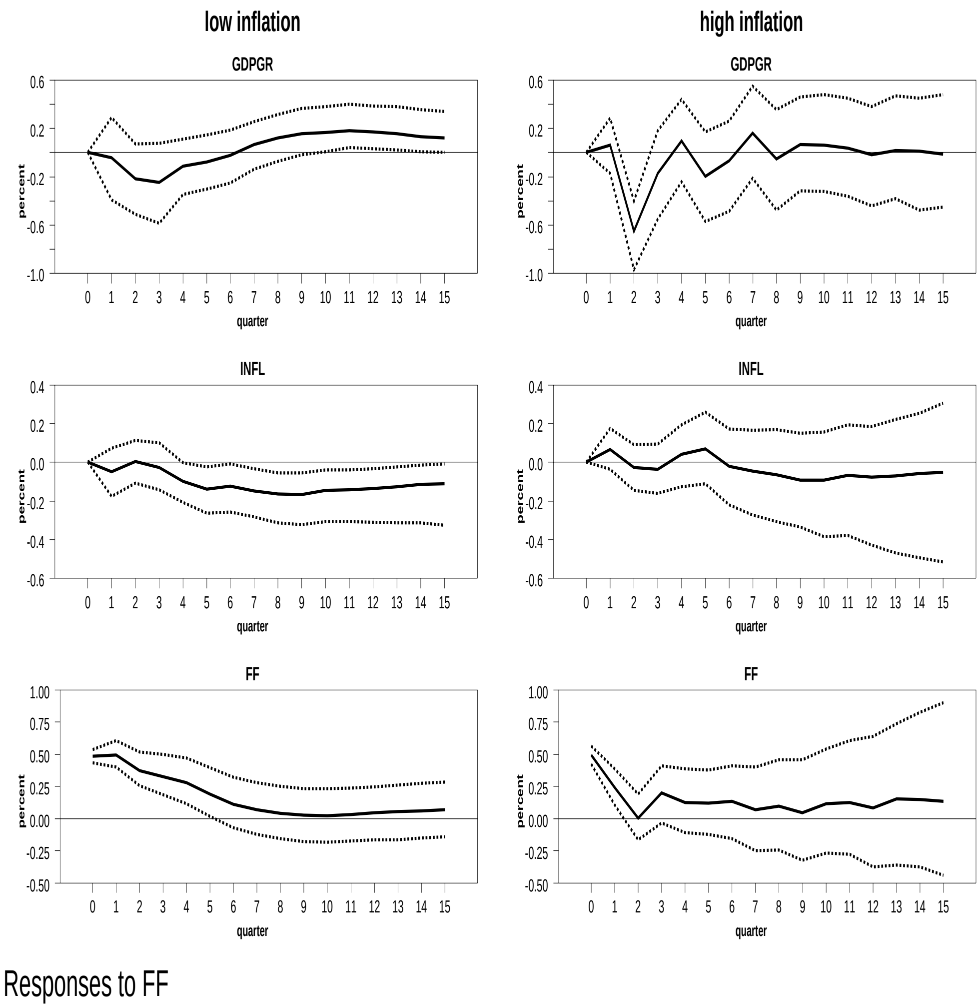

Figure 3: Impulse responses to monetary policy shock across regimes (shocks scaled to high inflation regime)

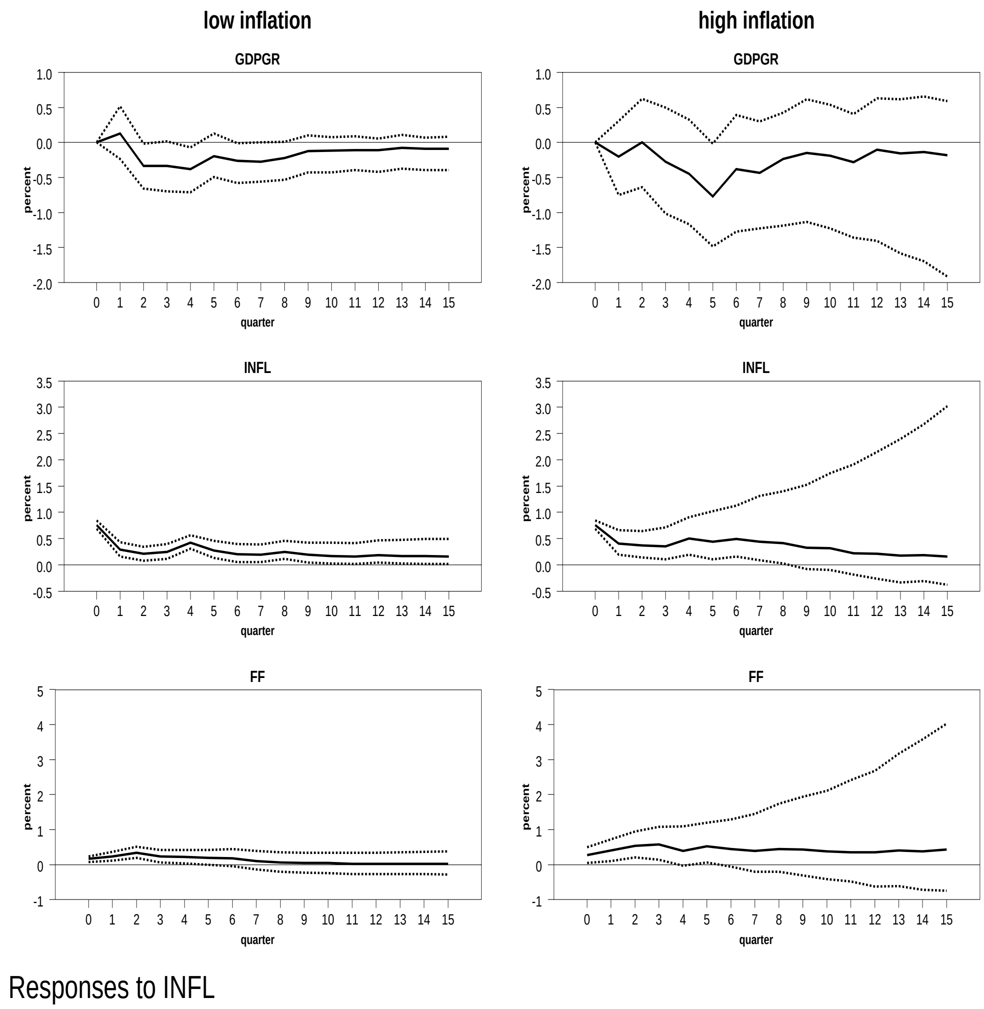

Figure 4: Impulse responses to inflation shock across regimes (shocks scaled to high inflation regime)

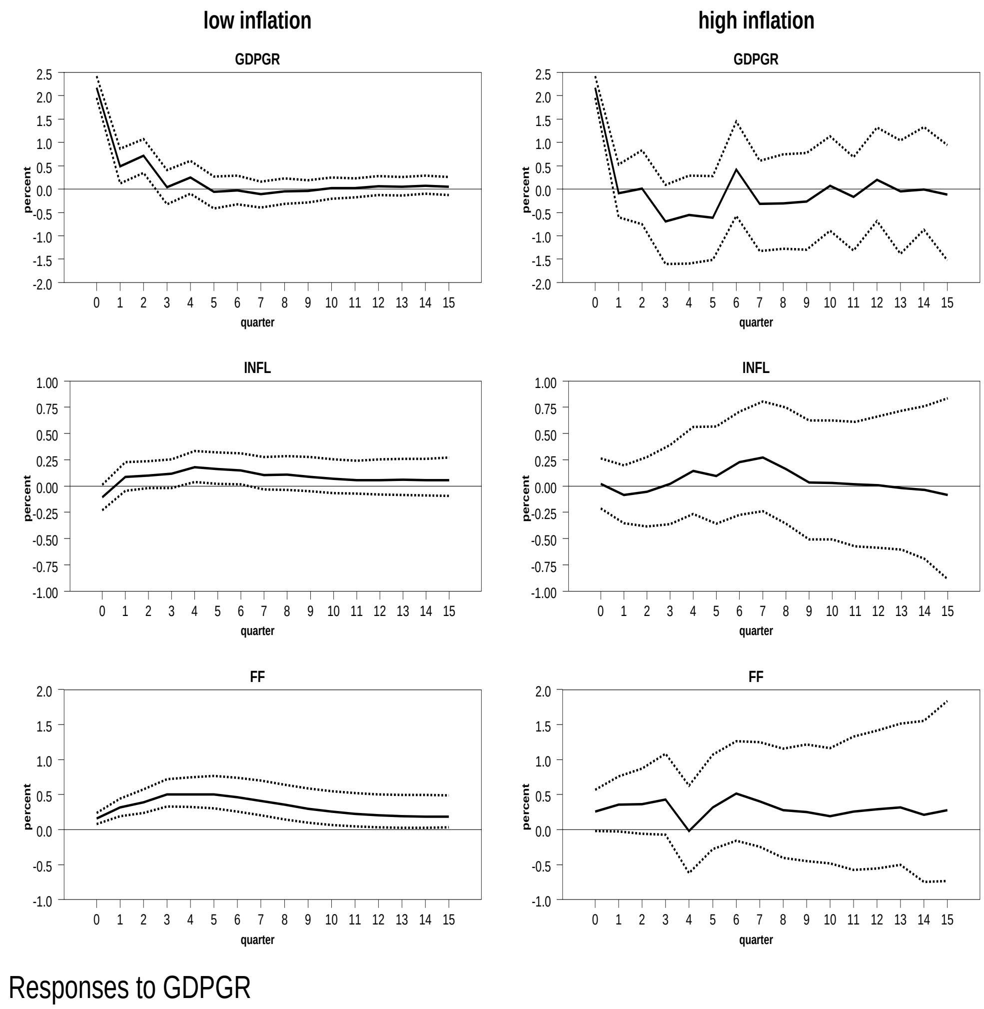

Figure 5: Impulse responses to output growth across regimes (shocks scaled to high inflation regime)

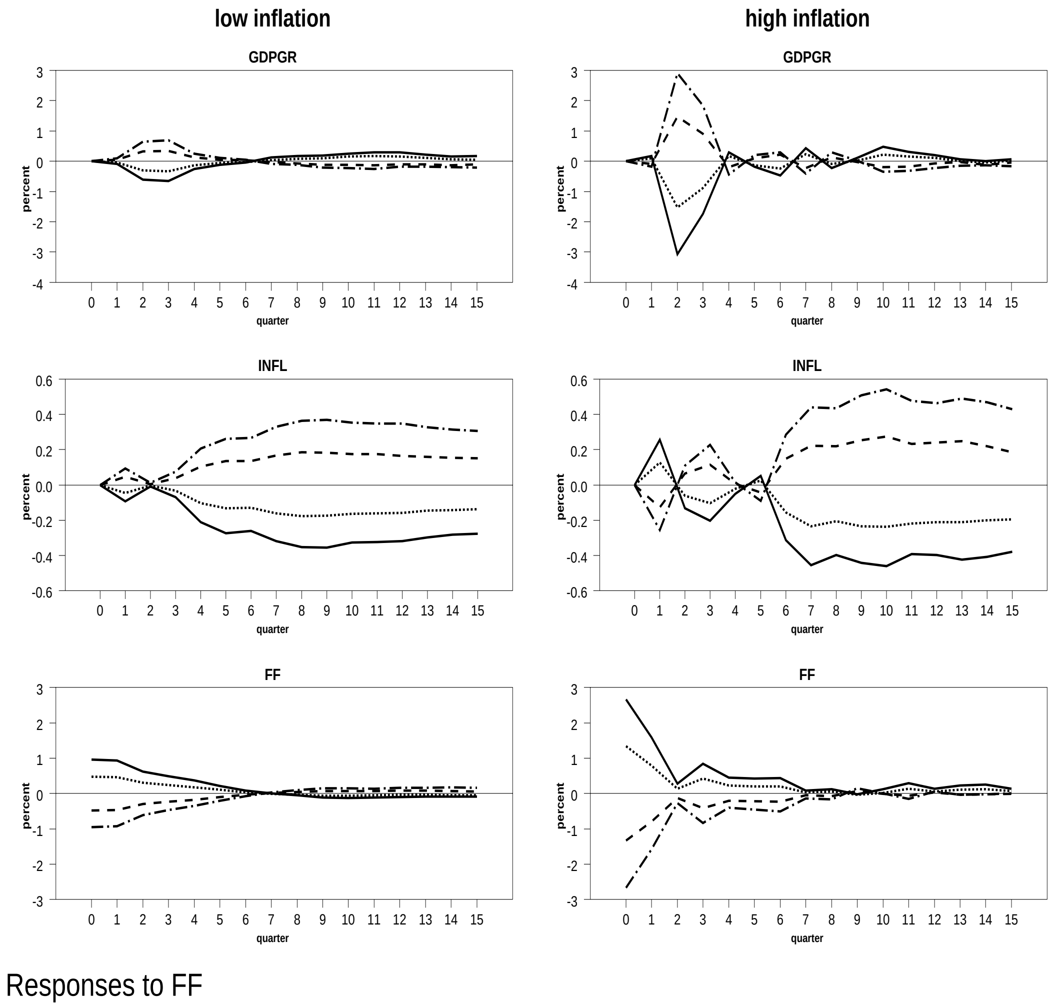

Figure 6: Generalized impulse responses to monetary policy conditional on initial regime. (Shocks: +2SD (solid), +1SD (dotted), -1SD (dashed), -2SD(dash-dotted))

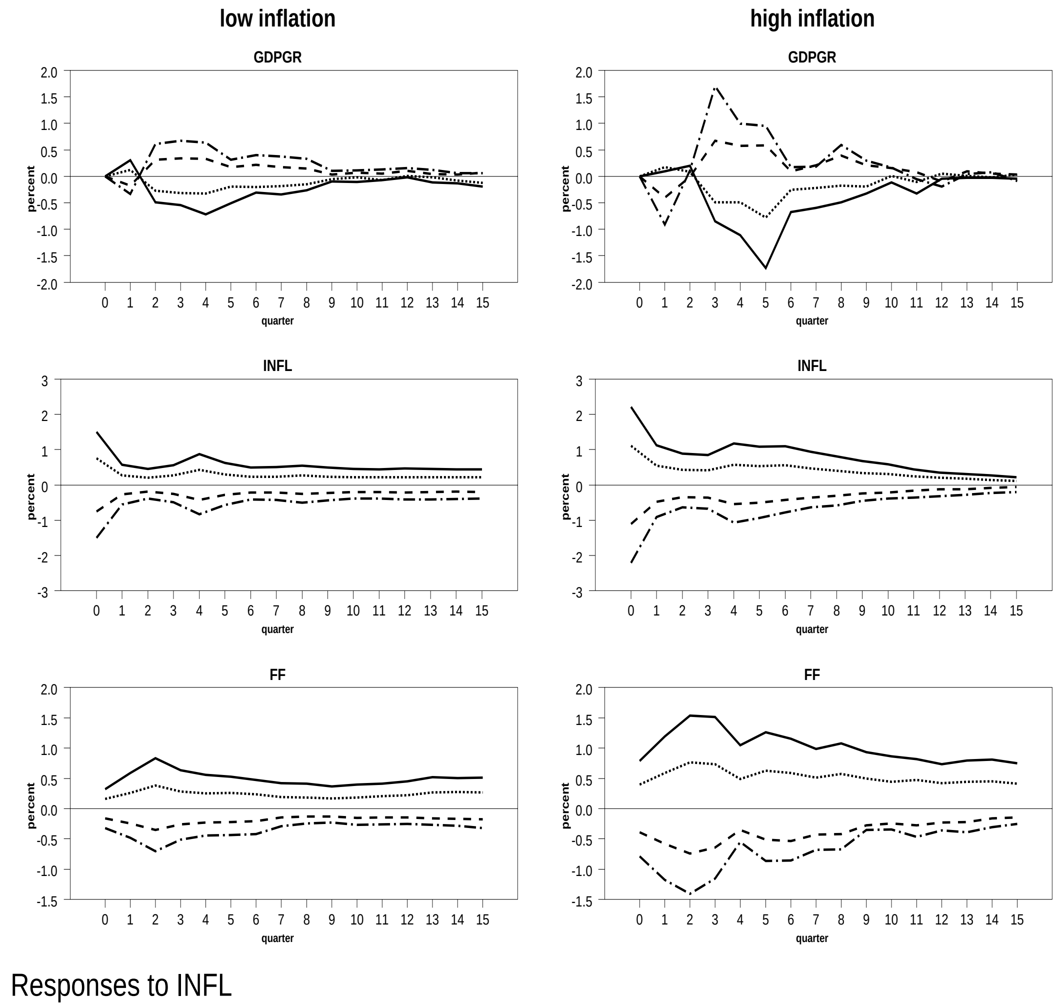

Figure 7: Generalized impulse responses to inflation conditional on initial regime. (Shocks: +2SD (solid), +1SD (dotted), -1SD (dashed), -2SD(dash-dotted))

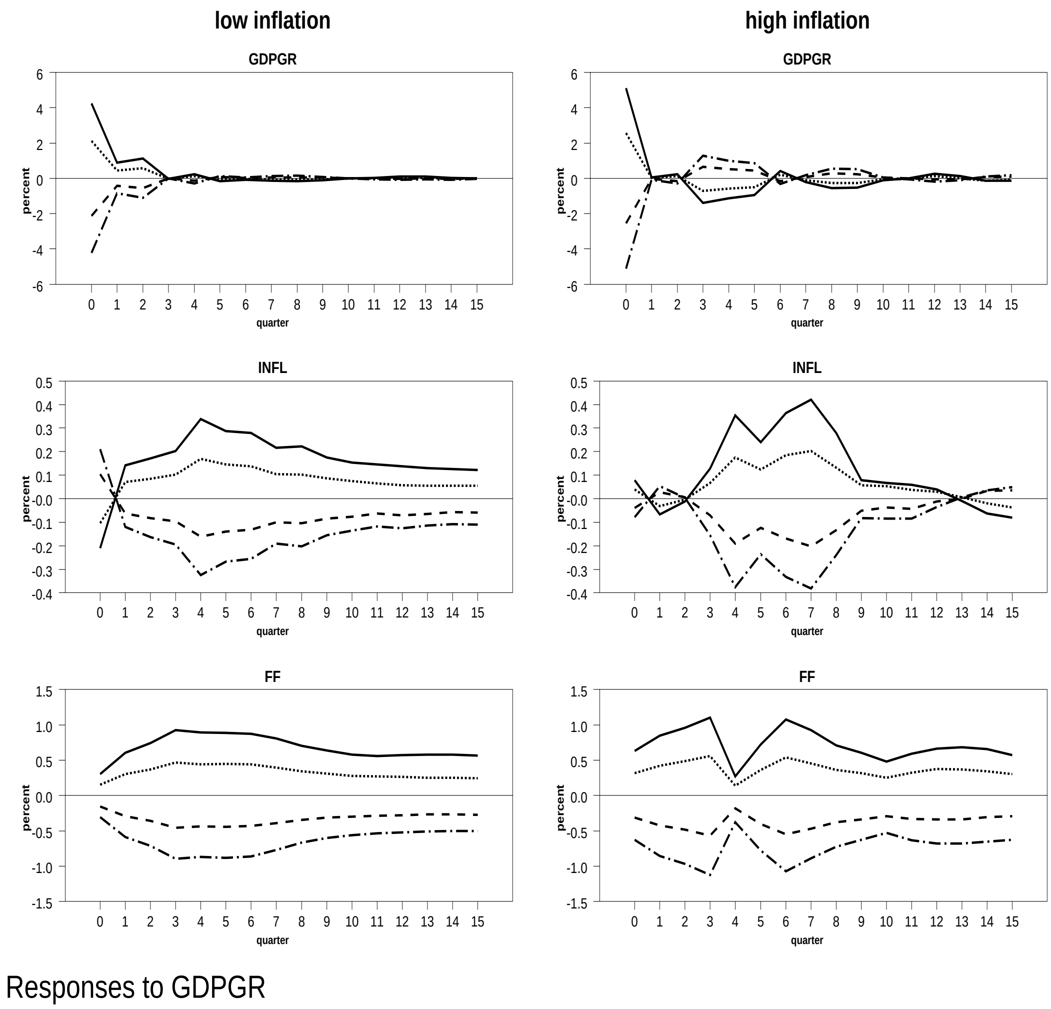

Figure 8: Generalized impulse responses to output growth conditional on initial regime. (Shocks: +2SD (solid), +1SD (dotted), -1SD (dashed), -2SD(dash-dotted))

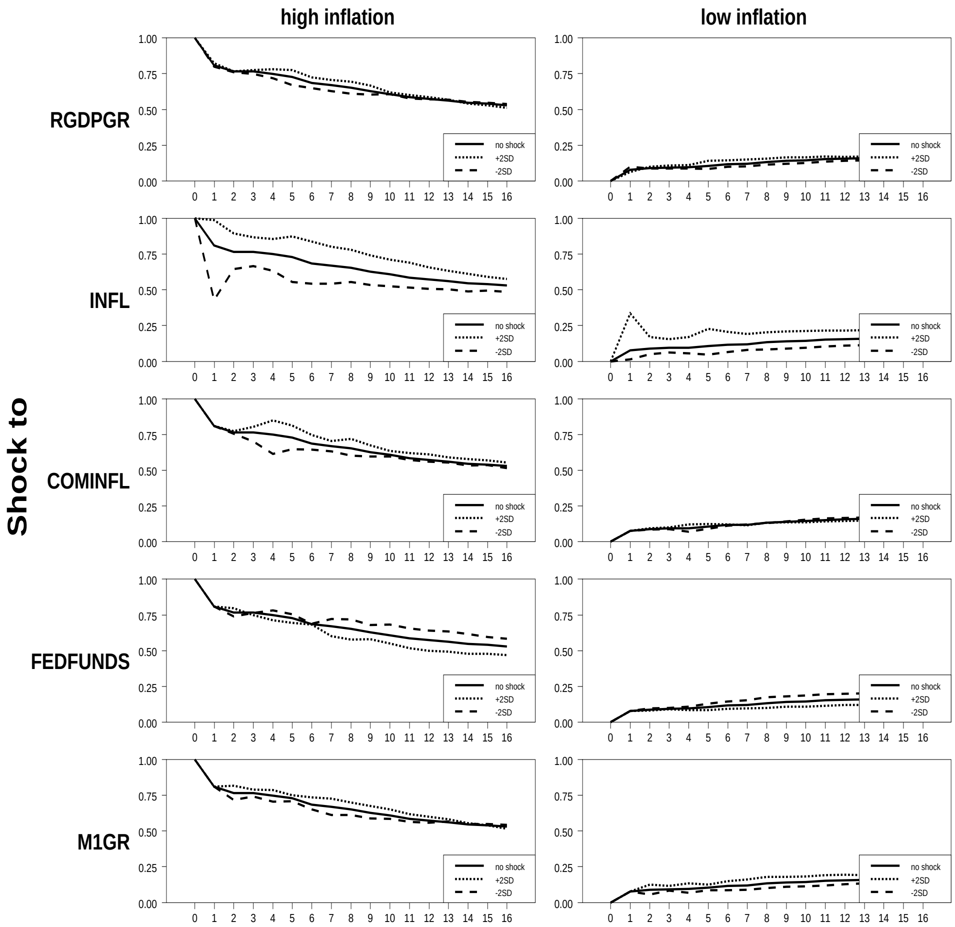

Figure 9: Probability of high inflation regime conditional on starting regime.

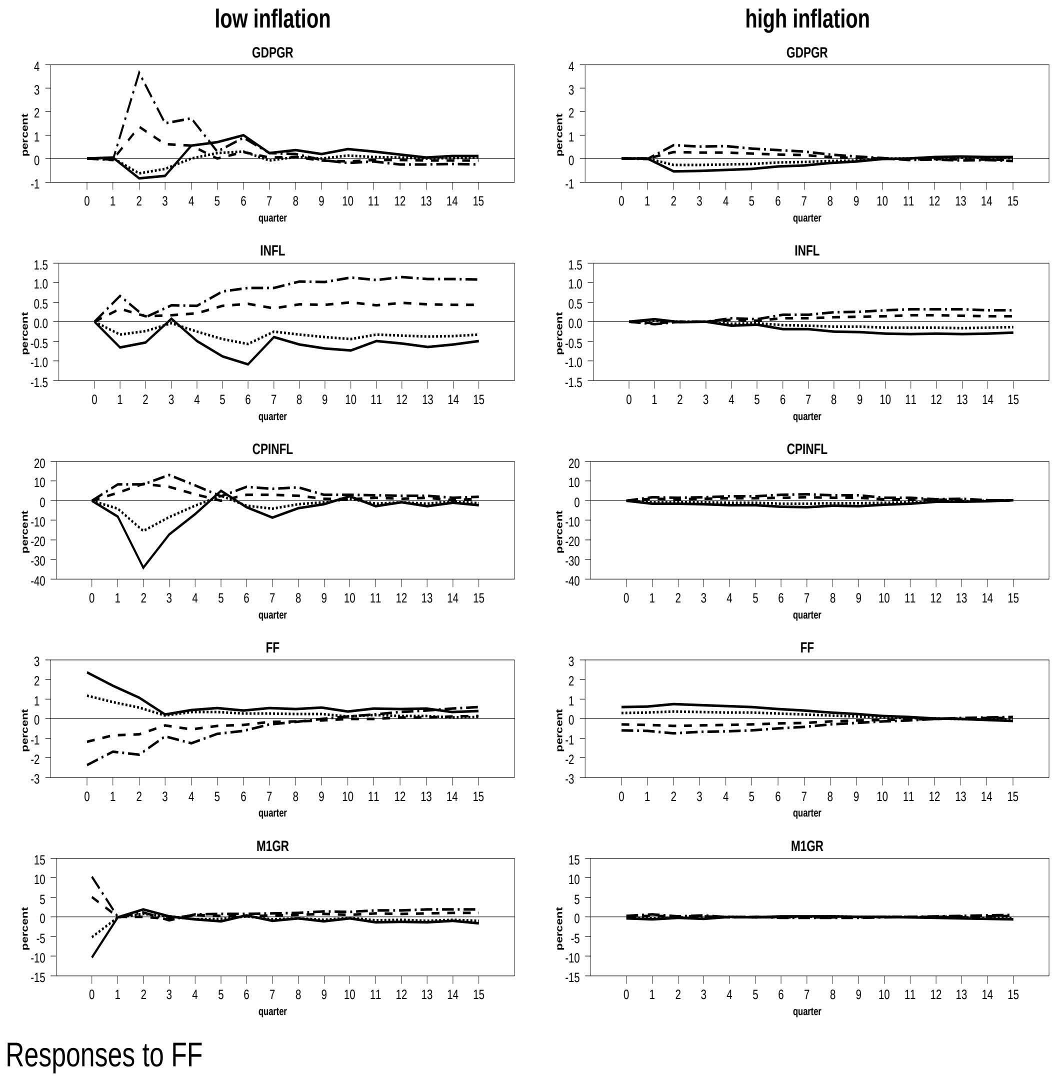

Figure 10: Generalized impulse responses to monetary policy conditional on initial regime. Monetary policy reaction function interchanged. Scaled Shocks. (Shocks: +2SD (solid), +1SD (dotted), -1SD (dashed), -2SD(dash-dotted))

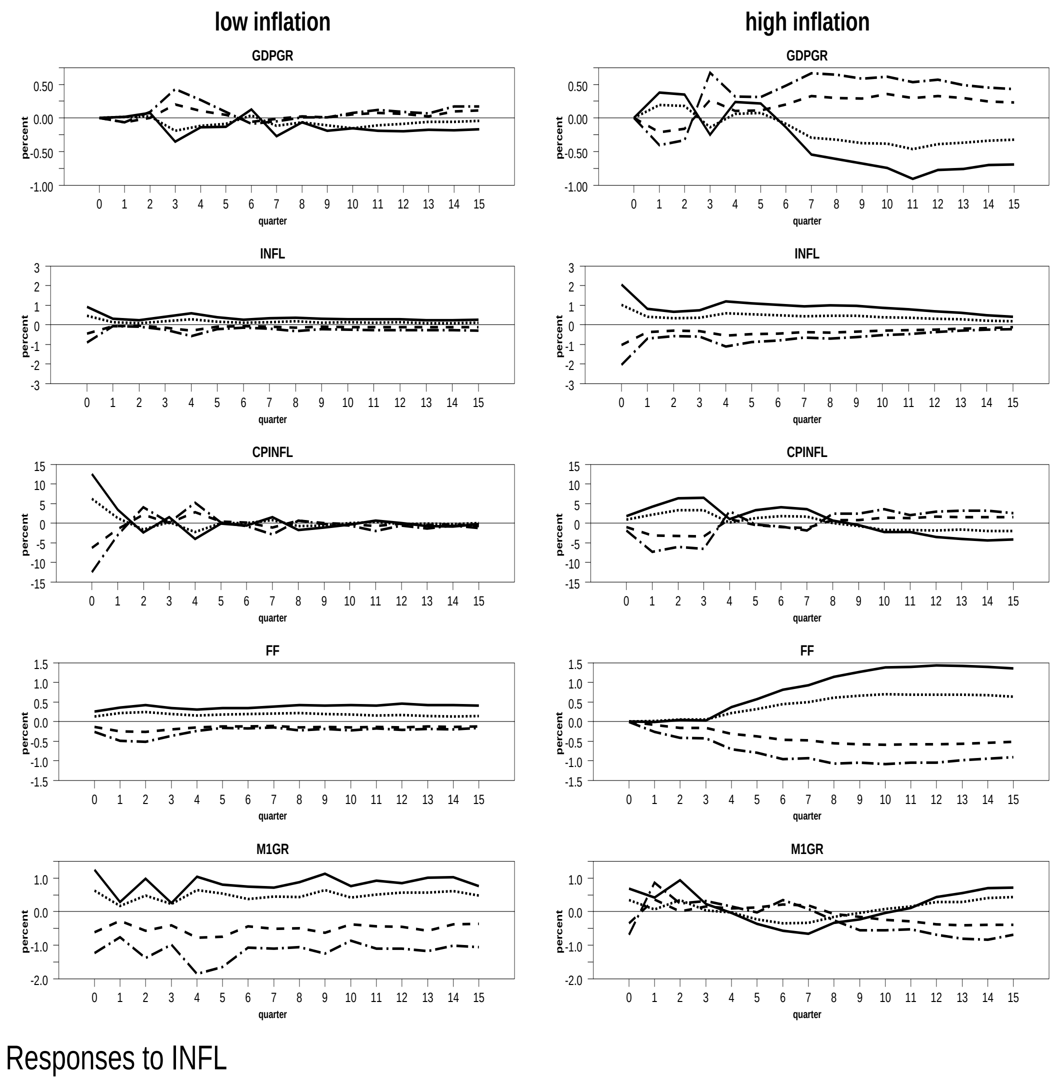

Figure 11: Generalized impulse responses to inflation conditional on initial regime. Monetary policy reaction function interchanged. Scaled Shocks. (Shocks: +2SD (solid), +1SD (dotted), -1SD (dashed), -2SD(dash-dotted))

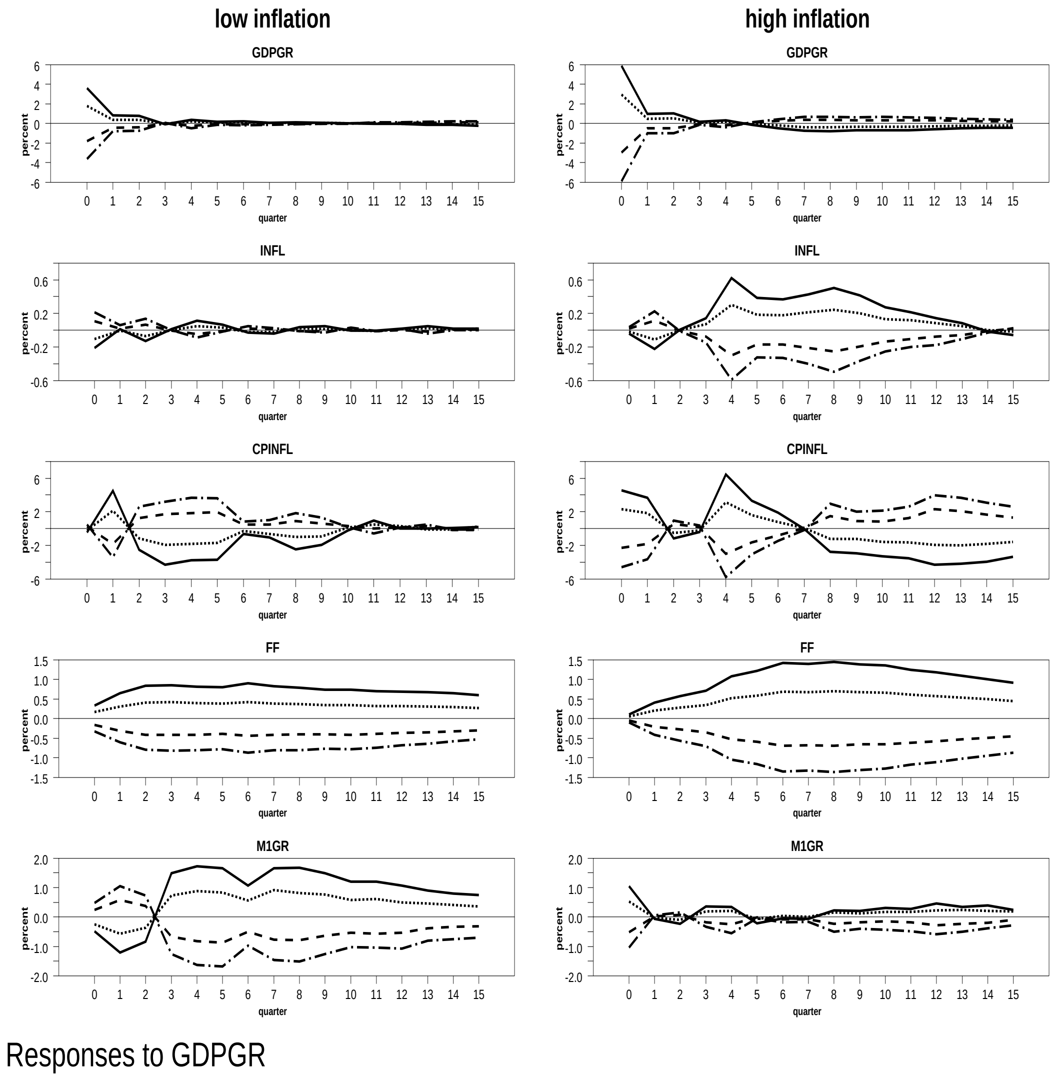

Figure 12: Generalized impulse responses to output growth conditional on initial regime. Monetary policy reaction function interchanged. Scaled Shocks. (Shocks: +2SD (solid), +1SD (dotted), -1SD (dashed), -2SD(dash-dotted))

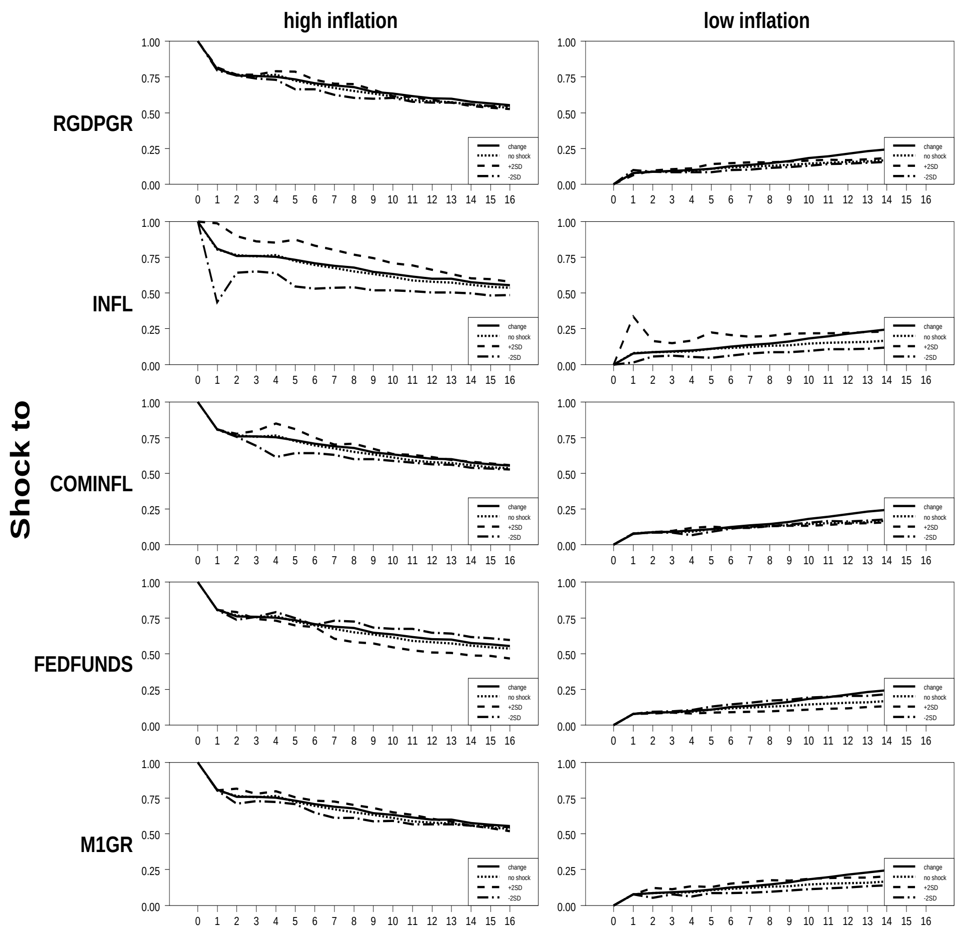

Figure 13: Probability of high inflation regime conditional on starting regime. Monetary policy reaction function interchanged (solid line).

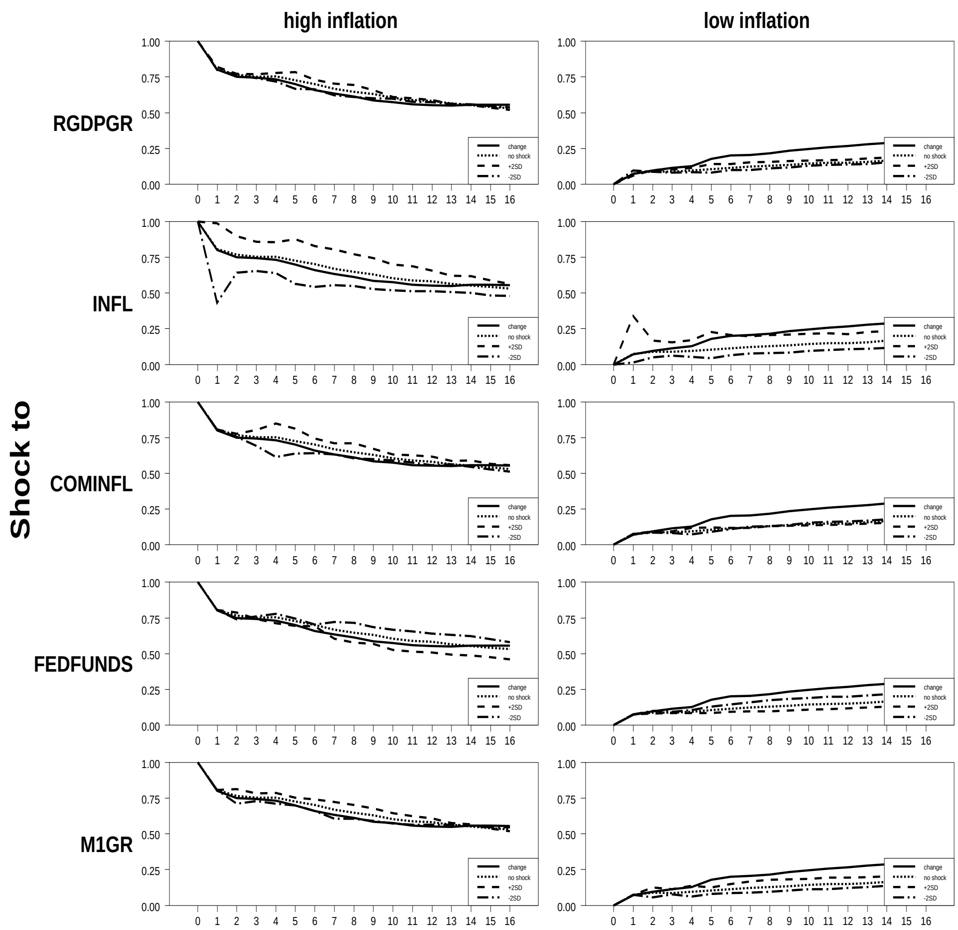

Figure 14: Probability of high inflation regime conditional on starting regime. Output equation interchanged (solid line).

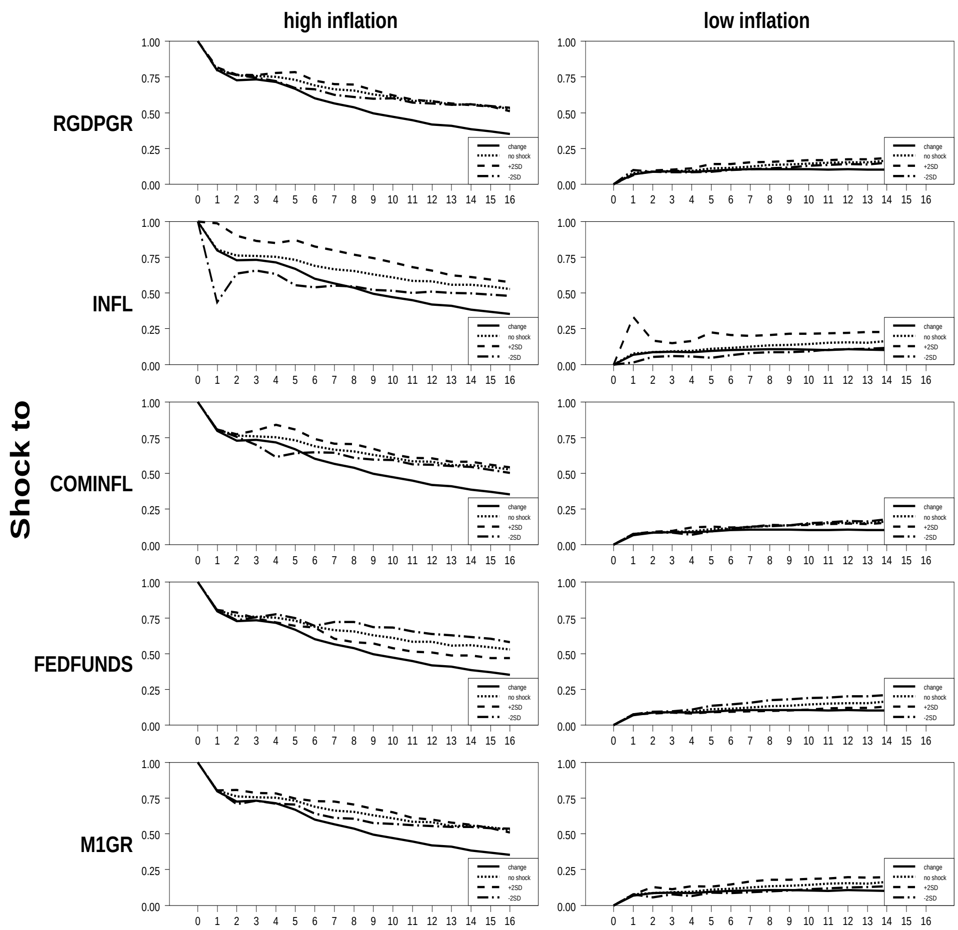

Figure 15: Probability of high inflation regime conditional on starting regime. Inflation equation interchanged (solid line).