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Abstract

Central banks have won in credibility as from the mid-eighties by keeping inflation under control. However, confidence in low inflation might have encouraged agents to excessive risk-taking, leading asset prices to rise. Moreover, the belief in a Federal Reserve guarantee against a sharp market decline spread across US markets as from the nineties. This belief, commonly referred to as the *Greenspan put*, raised again the question about the role of asset prices in monetary policy decisions.

The problem is addressed by modeling the reaction of the Fed to stock-market deviations from fundamentals over the period stretching from August 1987 to October 2008, which corresponds to the periods where Greenspan until January 2006 and Bernanke from thereon were chairmen. A Taylor rule describing the Fed's nominal feedback rule to inflation and economic activity on a monthly basis is extended to take account of asset prices. The indicators considered are deflation and volatility in stock prices. Furthermore, a Markov switching process allows to capture contemporaneous as well as forward-looking monetary policy responses to asset prices over the period.

We find out that taking asset price deflation improves the Taylor rule fit by some 8%. In periods when the Fed was actively pursuing an expansive or restrictive monetary policy, its reaction to volatility or deflation of financial markets was significant. We also see that the reaction of the Fed to asset prices was greater during financial crises, especially when modeling a forward-looking decision process. Agents' confidence in a stronger response of the US central bank to significant market declines urging to an easing of monetary conditions in their favour was therefore not unfounded.

JEL: C11, C22, E44, E52, E58.

Keywords: monetary policy, nominal feedback rule, asset prices, United States.

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1 Introduction

The subprime credit crisis which hit the world economy in 2007 illustrated once more the workings of integrated financial markets and raised a few major questions about the responsibilities of central banks. The expression *Greenspan put* had already established itself in the US markets at the end of the nineties as the belief that the Fed would intervene to guarantee a minimum level of asset prices. The consensus view amongst central bank practitioners is that inflation should be targeted. Excessive inflation in the prices of goods and services is harmful for economies. But just as conventional inflation can distort the allocation of resources, asset price inflation distorts economic behaviour by reducing savings and investments because of an inflated value of underlying assets. Other important effects of asset prices on the real economy operate through the balance sheet channel for firms or households using asset values when borrowing. Booms and busts in asset prices can therefore be as much a threat to economic stability as conventional inflation.

Many argue that asset prices, however, are not to be targeted, because bubbles are difficult to recognise ex ante; and even if it were possible, the macroeconomic consequences of bubbles and crashes are limited as long as central banks keep inflation under control (Bernanke, Gertler, 2002). Inflation targeting would make it unnecessary for central banks to try to influence asset prices. In the late nineties, the Federal Reserve Bank (Fed) used this framework to explain its decision path not to prick the stock market bubble, but instead waited for it to burst and then cut rates accordingly to cushion the economic consequences. As from 2003, the economic outlook in the US was again in a similar setting. Moreover, a question remains open: if at time of soaring asset prices monetary policy were to be tighter, would this stop a bubble building up? A rise in interest rates would hardly stop agents borrowing to buy an asset expected to appreciate, but would push inflation below target.

Other central banks, such as the Bank of England, the European Central Bank (ECB) and the Reserve Banks of Australia and New Zealand, have supported the view that monetary policy should sometimes act to restrain a rapid increase in credit and asset prices. This was for example one of the main justifications for raising interest rates in Britain in 2004, while the ECB pointed to the second pillar of its monetary policy strategy, which monitors growth in money supply and credit. The Bank of Japan declares its decision process to follow two directions: the first perspective is the outlook for economic activity and prices, while the second considers the risks relevant to the conduct of monetary policy. In its annual report published less than one year after the beginning of the credit crunch, the Bank for International Settlements (BIS, 2008) recalls the financial instability hypothesis[1] by Minsky. The institution insists on the procyclicality of the financial system and excessive growth rate and thus on the importance of the whole system operation. It believes that the expansion of money and credit has played a key role which is ignored in new Keyne-

[1] In the eighties, Hyman Minsky recognised that capital economies after a long period of prosperity end up in a circle of financial speculation. In brief, the financial instability hypothesis states that over a period of good times, the financial structures of a dynamic capitalist economy endogenously evolve from being robust to being fragile. The Minsky moment is the point when the Ponzi game collapses.

sian economic theory where financial markets have no economic consequences in the long run. For this reason, it suggests that monetary policy framework take explicit account of asset price developments and stresses on the need to tighten monetary policy when credit growth soars and asset prices explode, even if this temporarily could reduce inflation to lower levels than targeted. Substitution effects could also take place such that earnings on interest-bearing bonds increase.

Additionally to these divergences in views and behaviours, central banks also suffer from a credibility paradox. Their success in controlling inflation as from the mid-eighties have won them credibility; at the same time, confidence in a low inflation might have encouraged agents to excessive risk-taking which led prices in assets such as housing and securities to rise. Financial markets have gained in openness and integration in such a way that crises can spread across markets and continents with unexpected speed. The credit crisis might have unveiled the drawbacks of a hands-off view. If the banking system were insulated from the asset markets, the view that monetary policies should not be influenced by what happens in asset markets would make sense. Asset bubbles and crashes would affect only the non-banking sector; however, the movements in the asset markets did affect the banking sector. Banks were heavily implicated both in the development of the bubble in the housing markets and its subsequent crash. The central banks were also heavily involved owing to the fact that they provide liquidity to the banks during the crisis. In recent years, a significant part of liquidity and credit creation has also occurred outside the banking system. Hedge funds and special conduits have been borrowing short and lending long, and as a result have created credit and liquidity on a massive scale. As long as this liquidity creation was not affecting banks, it was not a source of concern for the central bank. However, banks were implicated and thus, the central bank was implicitly extending its liquidity insurance to institutions outside the regulatory framework.

Monetary policy changes have implications for financial markets. In this paper, we will not try to disentangle causality between monetary policy and asset prices, but will constrain the analysis to the reaction of monetary policy to asset markets in the United States over the past two decades. Has the attitude of the Fed towards asset prices undergone changes during specific phases? Have asset prices at some point influenced the choice of the central bank's instrument and thus been leading monetary policy decisions? Is there any evidence that the Fed behaved differently at historic moments, e.g. during the emerging market financial crises of 1997 and 1998, during the bubble in technology stocks that burst in 2000 or during the credit crunch that started in 2007? Extending a Taylor rule to asset prices as well as taking state-dependent reactions into account could provide some answers to these questions.

2 Asset prices and monetary policy in the US

In the wake of financial liberalisation, asset prices have gained importance in driving economic fluctuations, allocating resources across sectors and time. Moreover, asset prices take on several related roles within the monetary policy and financial frameworks: acting as information on market expectations and risk behaviour, as leading indicators of output, inflation and financial distress and as indicators of the shocks that hit the economy. In recent years, policymakers have been confronted with sometimes unusual developments in asset prices, including strong booms and busts, exceptional strength and breadth in the upswing of residential property prices, historically low long-term interest rates, low volatility and very narrow credit spreads. As a result, it has become more important to understand what determines asset price movements, to interpret the message they contain about the future and to reassess the place they take in policy decisions (Hördahl and Packer, 2006).

A leading indicator is an economic indicator that changes before the economy has changed. The Fed watches many of these indicators as it decides what to do about interest rates. Share prices are one of them, since they signal changes in real activity. Furthermore, there is empirical evidence for a negative relation between real share prices and expected inflation which can be explained by inflation proxying for real activity (Sellin, 1997). In countries that experienced broad swings in asset prices, asset price inflation has tended to be correlated with stable or declining consumer price inflation (Filardo, 2002). The author adds that consumer price inflation often rises after asset prices collapse.

During the Greenspan era, monetary policy appeared to have followed the Taylor rule to a surprising extent. Taylor (1999) argues that the higher responsiveness of monetary policy to both inflation and output growth during the period 1987 – 1997 was crucial for the lower level and greater stability of inflation. In a retrospective on asset price inflation and central bank policy, Voth (2000) notices that a failure to account for a positive output gap increases the danger of a bubble in asset markets developing. He suggests that the late nineties, a period of strong growth, low inflation and soaring asset prices, have been accompanied by a loose monetary policy due to a weakening reaction of the Fed to output gap: in fact, trying to give growth a chance would imply asymmetric policy responses to positive and negative output gaps.

Monetary policy decisions are influenced by a worsening condition of financial institutions. In the late nineties, the expression *Greenspan put* appeared in the press and meanwhile, it is an established expression in the financial vocabulary. It was used to describe a Fed guarantee against a sharp market decline, as in 1998 the investment firm Long-Term Capital Management collapsed. To ensure liquidity in capital markets, the Fed lowered its interest rate. From thereon, investors could assume that the Fed would be likely to lower its interest rates if there was a disruption in the capital markets which would serve to bail out investors who had engaged in behaviour they would not have had, had this guarantee not been in effect.

The fear that higher interest rates could prove disastrous for weakened banks can refrain central banks from raising them. Empirical studies show that monetary easing leads to higher equity prices (Sellin, 1997). Monetary policy also seems to exert an influence on stock prices independently of the business cycles. Generally, asset prices reflect perceptions of future income streams that assets will earn. But when asset price movements are out of line with underlying economic fundamentals, the question whether monetary policy contributed to this exuberance often arises. Schwartz

(2002) even asks whether the Fed has had any responsibility for share prices either during the upswing in the second half of the nineties or the downswing as from 2001. Literature suggests that monetary policy might have been too accommodative up to 1998 facilitating an upswing, but as from 1999 the easing was withdrawn.

Another point of interest is the lagged interest rate which Clarida, Galì and Gertler (2000) introduced to complete the Taylor rule: this lagged dependent variable allows for a gradual adjustment of interest rates to inflation and output gap. Rudebusch (2002) suggests that interest-rate smoothing could arise if an autocorrelated variable is incorrectly excluded from the estimated reaction function. Gerlach-Kristen (2004) reports interestingly that the excluded variable could reflect financial market conditions, or variables correlated with risk spreads in financial markets and thus capturing market stress.

In the first part of the analysis, we introduce the nominal feedback rule to the contemporaneous variables, inflation and output gap. The rule is then extended to two variables related to asset prices, and state-dependent reactions to the explanatory variables are explored. In the second part, we proceed with the same analysis, but this time with a forward-looking nominal feedback rule. To estimate the Taylor rule, we use the OLS methodology, and in the presence of endogenous explanatory variables GMM. For the MLE Markov-switching regression, we introduce the Hamilton filter in the absence and presence of endogenous explanatory variables, following Kim (2003).

Our main finding is that the Federal Reserve responded either to deflation or to volatility in asset prices significantly, thus reacting to asset prices over the whole period. Furthermore, the reaction of the Fed to future asset price development was greater during financial crises. These results suggest that if financial markets take the historical Taylor rule as given, then they could be confident that excessive asset price deflation would have a greater impact in the interest-rate setting and therefore that the Fed would be acting in their favour with an easing of monetary conditions.

3 Contemporaneous analysis with changes in regime

3.1 Data

We use monthly data to analyse the interest-rate setting in the United States. The interest rate i_t is a monthly average of the Federal Funds rate. Following Clarida, Galì and Gertler (1998), we use the consumer price index to measure inflation and an index of industrial production to measure output. The inflation π_t is the year-on-year change of the consumer price index. The output gap is computed as the percentage deviation of the industrial production index from its HP-filtered trend[2]. Capacity utilisation series display a similar pattern to the computed output gap.

[2]The parameter λ controlling the smoothness of the series filtered with the Hodrick-Prescott method is set to $129'600$. It corresponds to a power value of 4 recommended by the frequency power rule of Ravn and Uhlig (2002): the number of periods per year divided by 4, raised to a power, and multiplied by 1600.

We consider stock prices in order to have some monthly data of asset prices. Monetary policy has implications for stock markets. In order to avoid the endogeneity problems and biased OLS estimates caused by these interactions, we introduce lagged values for financial markets. The variable α_{t-1} is defined as the gap in inflation between asset prices and their fundamental values. Asset price inflation is the year-on-year change of a monthly average of the share price index (daily index, Standard & Poor's 500), while inflation in asset fundamental values is defined as the year-on-year change of a monthly average of dividend yields[3]. To prove the presence of a put protection on sharp market declines, we introduce the variable α_{t-1}^{-} as the negative gap in asset price inflation:

$$\alpha_{t-1}^{-} = \begin{cases} |\alpha_{t-1}| & \text{if } \alpha_{t-1} < 0 \\ 0 & \text{otherwise} \end{cases}$$

We will refer to this variable as asset price deflation, that is when asset prices grow less than their fundamental values. More generally, testing the Fed's response to α_{t-1} reveals high significance. Furthermore, there is an asymmetric reaction of the Fed to positive and negative gaps in inflation between asset prices and their fundamental values: regressions including both, positive gaps α_{t-1}^{+} as well as negative gaps α_{t-1}^{-}, display only significance of the former variable leaving the latter out. These results go beyond the scope of the paper which focuses only on negative developments in asset markets and therefore are not reported here.

The second moment of asset prices will be expressed by the volatility calculated as the standard deviation of stock returns within a month[4]. The volatility[5] reflects the nature of asset prices driven primarily by revisions in expectations of future returns, and thus expectations of future activity, inflation and monetary policy. In order to reduce the impact of very high values in volatility[6], we take the natural logarithm. Here again, by assuming an arbitrary minimal volatility of 1 which logarithm is deducted from the logarithm of volatility, we introduce the gap in volatility $\psi_{\alpha,t-1}$. Note also that we introduced above the absolute value of the negative gap in asset price inflation in order to describe the reaction of the Fed to either deflation or to volatility in asset prices as negative.

HERE Figure 1

[3]Dividends are a primary measure of fundamentals. The dividend yield of the S&P 500 is being used as an indicator of the overall value of the market. At market peaks, the average dividend yield sinks below 2%, whereas during extreme lows it can take on double figures. Negative growth in dividend yields give lead to an overpricing of shares, while positive growth in dividend yields can be considered as evidence that stocks are underpriced. (Campbell and Shiller, 2001)

[4]Stock returns are calculated as the growth in the share price index. The intra-month standard deviation is normalised with the number of labour days in a year, i.e. $\sqrt{260}$.

[5]We could also have considered the implicit volatility index (VIX), which shows the market's expectation of 30-day volatility. It is constructed using the implied volatilities of a wide range of S&P 500 index options. This volatility is meant to be forward looking and is calculated from both calls and puts. The VIX is a widely used measure of market risk and is often referred to as the investor fear gauge; the index tracking the S&P 500 and therefore allowing for a more accurate view of investors' expectations on future market volatility, is only available as from 2003. We therefore had to content ourselves with this calculation of volatility.

[6]In October 1987, volatility reached a peak value of 92.

The evolution of these five variables i_t, π_t, y_t, α^-_{t-1} and $\psi_{\alpha,t-1}$ are displayed in Figure 1 for the period stretching from August 1987 to October 2008. Asset price deflation is defined in a way to capture financial market crises, in particular the 1987 stock market crash, the burst of the dotcom and the recent subprime mortgage bubble. Asset price volatility tends to increase in periods of uncertainty, but is not clearly related to bubble built-up and burst periods. When the dotcom bubble burst, volatility had increased, but was still relatively low, while it reached impressive high values in the last months of 1987 and 2008.

3.2 Extension of the Taylor rule

As starting point for the analysis, we consider a Taylor rule. The basis equation for the Fed's target instrument is:

$$i^*_t = x'_t\beta \tag{1}$$

with:

$$x'_t = (\pi_t, y_t) \quad \text{and} \quad \beta' = (\beta_\pi, \beta_y). \tag{2}$$

We then specify persistency for the actual Funds rate i_t with the following relationship:

$$i_t = \rho i_{t-1} + (1-\rho)i^*_t + \varepsilon_t \tag{3}$$

where the implicit rate i^*_t follows the rule defined by the Taylor rule (1), $0 < \rho < 1$ is the persistency factor and $\varepsilon_t \sim N(0, \sigma^2_\varepsilon)$ i.i.d.. We then obtain the equation:

$$i_t = \rho i_{t-1} + (1-\rho)x'_t\beta + \varepsilon_t \tag{4}$$

which takes some interest-rate smoothing into account.

Equation (1) with target variables and parameters as defined in (2) can be derived as the optimal reaction function of a central bank targeting inflation and output gap, where β_π and β_y are functions of policymakers' preferences and the parameters of the IS and Phillips curves. The constant which we do not report here reflects the equilibrium real interest rate and the targeted value of inflation. A necessary condition for the response of the real rate target to changes in inflation and in the output gap to be stablilising is that β_π be greater than one and β_y greater than zero.

We now introduce the lagged gap in asset price deflation α^-_{t-1} and in asset price volatility $\psi_{\alpha,t-1}$ as explanatory variables. (1) remains the same with:

$$x'_t = (\pi_t, y_t, \alpha^-_{t-1}, \psi_{\alpha,t-1}) \quad \text{and} \quad \beta' = (\beta_\pi, \beta_y, \beta_{\alpha^-}, \beta_{\psi_\alpha}) \tag{5}$$

We set $\beta_{\psi_\alpha} = 0$ and $\beta_{\alpha^-} = 0$ by turns. We expect the reactions of the Fed to absolute values of asset price deflation or to volatility to be negative. Equation (1) with variables defined as in (5) could be derived as the optimal reaction function of monetary policymakers, were they to target asset price deflation or volatility in addition to inflation and output gap. Since α^-_{t-1} and $\psi_{\alpha,t-1}$ are expressed as gaps, the constant further reflects the equilibrium real interest rate and the targeted value of inflation, but is also affected by the real minimum volatility which we had arbitrarily assumed to be one.

The performance of a Taylor rule depends sensitively on the reliability of real-time data and on the availability of forecasts (Orphanides, 2007). While data on inflation and stock prices are rarely subject to revisions, this is hardly the case when it comes to information regarding the current state of the economy. However, by taking an index on industrial production not only do we have access to a monthly estimate of the output gap, but we also have a proxy of real-time output gap: the industrial production index is only subject to slight revisions during the three or four months after its first release. Thus, we allow ourselves to leave the problem of real-time data aside and to concentrate on monetary policy with forward-looking data in the next section.

The results of the regressions are reported in Tables 1 and 2 for the Greenspan period, i.e. from July 1987 until January 2006, and from July 1987 until October 2008 to include the period where Bernanke was chairman and the latest financial crisis.

HERE Table 1

HERE Figure 2

The OLS estimates for the interest-rate setting with persistency, described in equation (4) and reported in Table 1, provide a good fit with high values for $\overline{R}^2$, but this is mainly due to the weight of the lagged variable and thus the impact of the inflation variable in particular looses its significance. This could be explained by the fact that inflation and the lagged interest rate are highly correlated and strongly collinear, especially since we have monthly data. The qqplots indicate departure from the assumption of normal distribution for residuals. Furthermore, we consider the fact that the significance of lagged interest rate could be due to an omitted variable with an autoregressive pattern as shown by Rudebusch (2002). Gerlach-Kristen (2004) suggested financial stress. Asset price deflation and volatility also display a high autoregressive pattern.

For these reasons, we renounce to persistency in interest-rate setting and thus restrain our analysis to a Taylor rule with no smoothing term, as defined in equation (4) with $\rho = 0$[7]:

$$i_t = x_t'\beta + \varepsilon_t \tag{6}$$

Since the error distribution is not independent of the regressors' distribution,

$$E_t[x_t'\tilde{\varepsilon}_t] \neq 0$$

we will need to introduce a $k \times 1$-vector z_t of instrumental variables such that z_t and x_t are correlated and that the orthogonality conditions $E_t[z_t'\tilde{\varepsilon}_t] = 0$ are satisfied. If

[7] We also control for the significance of higher lags of asset price inflation and volatility; these are not significantly different from zero, but the non-inertial rule has serially correlated shocks. The presence of serial correlation in the residuals could also be due to the autocorrelation of inflation, output gap or some other omitted variables.

the errors are homoskedastic, we can obtain a closed form by using the two-stage least squares. If the errors are diagnosed to be heteroskedastic, we will need to work with the generalised method of moments (GMM). Heteroskedasticity is tested on OLS residuals with the Breusch-Pagan test.[8] In the context of GMM, the orthogonality conditions:

$$m(\beta) = E_t[z_t'(i_t - x_t'\beta)] = 0$$

provide the basis for the estimation of the parameter vector β.[9]

Good instruments should be relevant and valid: they should be correlated with the endogenous regressors and at the same time orthogonal to the disturbance. As in previous studies, the instrument set includes lags of the short-term interest rate, inflation, output gap, M2 growth as well as the spread between the long-term bond rate and the short-term interest rate.

HERE Table 2

The estimations of the conventional Taylor rule with no interest-rate smoothing as described by equation (6) display good results with significant inflation and output gap. The p-value for the J-statistic (Hansen, 1982) relates to the test of over-identifying restrictions. A rejection of the null hypothesis would imply that the instruments are not satisfying the orthogonality conditions required for their employment; the results confirm that the null hypothesis is not rejected. The parameters β_π and β_y are relatively near to the values suggested by Taylor to fit US data well ($\beta_\pi = 1.5$ and $\beta_y = 0.5$), but only for the period from 1987 to 2006, corresponding to the Greenspan period. This confirms the statement that the Taylor rule provides a reasonable description of the past twenty years and that the financial crisis of 2007

[8]The Breusch-Pagan Lagrange Multiplier Test provides a method to test whether errors are homoskedastic. Homoskedastic errors have constant variance: $E_t[\tilde{\varepsilon}_t\tilde{\varepsilon}_t'] = \sigma^2 I_T$. In the case of heteroskedasticity, σ_t^2 is not constant. Assuming that σ_t^2 is a function of some variables: $\sigma_t^2 = f(a_0 + a'z_t)$, the null hypothesis refers to the case where $a' = 0$.

$$LM_{GB} = \frac{1}{2}(\gamma_{BP}' z(z'z)^{-1}z'\gamma_{BP}) \sim \chi_k^2$$

where $\gamma_{BP} = \frac{\tilde{\varepsilon}_t^2}{\frac{\tilde{\varepsilon}_t'\tilde{\varepsilon}_t}{T}} - 1$ and z_t is the $(1 \times k)$-vector of instrument variables.

[9]There must be at least as many moment conditions as there are parameters to estimate in order to achieve identification: in other words, there must be at least as many instrument variables as there are elements in β. In the case where there are more instrument variables than parameters, the system is overidentified and not all the moment restrictions will be satisfied. A weighting matrix W determines the relative importance of matching each moment with instrumental variables:

$$\min_\beta J = m'(\beta)Wm(\beta)$$

An important contribution of Hansen (1982) is to point out that setting $W = S^{-1}$, the inverse of an asymptotic covariance matrix, is optimal in the sense that it yields $\hat{\beta}$ with the smallest asymptotic variance: more weight is given to the moment conditions with less uncertainty. The sample moments are:

$$\overline{g}(\hat{\beta}) = \frac{1}{n}\sum_{t=1}^{T} z_t'\hat{\tilde{\varepsilon}}_t$$

seems to trigger another kind of monetary policy.[10]

The parameter for asset price deflation is statistically significant. Considering the values that α^-_{t-1} can reach, in average 7 percentage points ranging mostly from 0 to 60 over the period stretching from August 1987 to October 2008, its contribution to the interest rate can amount to -1.98 pp in extreme cases; in other words, the gap in asset price deflation could explain up to a 2 pp deviation of the interest rate from the path outlined only by inflation and output gap. As can be observed in Figure 3, the introduction of a gap in asset price deflation as explanatory variable improves the fit especially for the periods between 2002 and 2004, as well as 2008, where α^-_{t-1} reached -60. The easing of monetary policy between 2002 and 2004 is not well explained by only inflation and output gap; asset price deflation explains some 0.15 deviation of the interest rate in average. The introduction of the explanatory variable α^-_{t-1} even improves the $\overline{R}^2$ values; the ratio of explained variation to total variation is improved by some 8% over the whole period.

HERE Figure 3

The regression results do not improve when introducing the volatility to equation (6), because the negative impact, β_{ψ_α}, is partially insignificant. Asset price deflation and volatility although stemming from the same data generating process display quite low correlations (0.45). The fact that volatility is not clearly related to periods of financial crises could explain this insignificance. If the Fed were to react to an increase in uncertainty in financial markets, one would indeed expect volatility to have a negative effect on interest rate, i.e. high volatility inducing a more expansive monetary policy.

The consistency of these first estimations can be tested by computing the Fed's long-term inflation target on the grounds of the economy's long-term average real interest rate. This rate can be taken from the yield on 10-year Treasury inflation-protected securities (TIPS) which measures what the market expects real interest rates to average over the next ten years.[11] For most regressions in Table 2 we derive a target inflation π^* between 2.7 and 3.7; although the values derived for target inflation are higher than 2, they do confirm that the regressions are plausible.

[10] Kevin Warsh, member of the Federal Reserve Board, declared to the International Herald Tribune: "While the Taylor rule provided a reasonable description of the past twenty years, it failed to account for the crisis that unfolded in 2007-2008". The regressions were also performed over the period going from January 1966 to October 2008. Over this period, all parameters are significant except for volatility; β_π is slightly lower than 1 and β_y is around 0.2.

[11] The equilibrium real interest rate r^* and the inflation π^* enter the Taylor rule in the following way:

$$i_t = r^* + \pi^* + \beta_\pi(\pi_t - \pi^*) + \beta_y y_t$$

The term $r^* + (1 - \beta_\pi)\pi^*$ corresponds to the constant which is not reported in the regressions of (6). We will refer to this constant as β_c. While Taylor (1993) suggested $r^* = 2$, $\pi^* = 2$, $\beta_\pi = 1.5$ and $\beta_y = 0.5$, we compute $\pi^* = \frac{\beta_c - r^*}{1-\beta_\pi}$. The TIPS give a long term real rate r^* of 1.8 over the period starting in January 1999 and going until October 2008, such that π^* take values around 3.

3.3 First-order Markov switching model with two states

Has the US central bank pursued different monetary policy targets in the last twenty years? We address this question by defining a model that allows the interest rate to follow a different time series process over different time periods. We will model the regime S_t as the outcome of an unobserved two-state Markov chain. We investigate two different switching models. In the first one, the model assumes the Fed to adapt its overall behaviour to the state of the economy: all target variables considered are state dependent. In the second one, the Fed is assumed to maintain a constant reaction over time to its main targets, inflation and output gap; it adjusts its reaction to financial markets accordingly to the situation: only asset price deflation and volatility are state dependent. Looking at both these models should also allow us to check the results' robustness.

3.3.1 State-dependent target variables

The state variable $x_t = (\pi_t, y_t, \alpha_{t-1}, \psi_{\alpha_{t-1}})$ follows a Markov switching process constrained to two states. Formally, the interest-rate setting can be written as:

$$i_t = x_t' \beta_{S_t} + \varepsilon_t \tag{7}$$

where $\varepsilon_t \sim N(0, \sigma^2_{\varepsilon,S_t})$ i.i.d. and with S_t independent of $\varepsilon_{t'}$ for all t and t'. The reaction parameters and their variances are:

$$\beta_{S_t} = \beta_0(1 - S_t) + \beta_1 S_t \quad \text{and} \quad \sigma^2_{\varepsilon,S_t} = \sigma^2_{\varepsilon,0}(1 - S_t) + \sigma^2_{\varepsilon,1} S_t. \tag{8}$$

Let $\Omega_t = (i_t, i_{t-1}, ..., i_0; x_t', ..., x_0')$ be a vector containing all observations obtained through date t. The exogenous variables consist of a constant term which is not included in the equation (7) and of the target variables x_t'. Since there is substantial variation in the equilibrium real rate (Laubach and Williams, 2001), the constant term would most probably follow another process than the one implied by the target variables. For the sake of simplicity, we assume the constant term to be constant over time and take it as state-independent. The unknown parameters are the state-independent parameter for the constant term which we do not report here and the state-dependent parameters β_{S_t} with $\beta_{S_t,\alpha^-} = 0$ and $\beta_{S_t,\psi_\alpha} = 0$ by turns, as well as the transition probabilities $p_{ij} = Pr\{S_t = j | S_{t-1} = i\}$. The transition probabilities are collected in a matrix P in the following way:

$$P = \begin{pmatrix} p_{00} & p_{10} \\ p_{01} & p_{11} \end{pmatrix}$$

where $p_{00} + p_{01} = 1$ and $p_{01} + p_{11} = 1$.

We set initial values for the probability that at time $t = 0$ one of the regime rules given the information set Ω_0 : $\Pr\{S_0 | \Omega_0\} = 0.5$. On this account, we can maximise the log likelihood with respect to the parameters $\beta_0, \beta_1, \sigma^2_{\varepsilon,0}, \sigma^2_{\varepsilon,1}$ and to the transition probabilities P, by reconstructing the whole process of probabilities, $\Pr\{S_t | \Omega_t\}_{t=1}^T$.[12]

[12] The sample log likelihood:

$$\ln L(\beta_0, \beta_1, \sigma^2_{\varepsilon,0}, \sigma^2_{\varepsilon,1}, P | \Omega_T) \quad = \quad \sum_{t=1}^{T} \ln\{\sum_{j=0}^{1} Pr\{S_t = j | \Omega_t\} f(i_t | S_t = j, \Omega_t)\}$$

HERE Table 3

Taking into account the fact that the Taylor rule fits US data best for the last twenty years, we construct the process on the period going from August 1987 up to October 2008. Fitting the data according to the model defined under (7) with the state variable x'_t and β_{ψ_α} constrained to 0, the estimated parameters reported in Table 3 show evidence that there are two clear regimes. The states are displayed over the time period in the figures reported with the table. The state S_0 is often characterised by a reaction to inflation below 1 and to output gap higher than 0.5, while in state S_1 the answers to inflation and output gap are close to the Taylor values ($\beta_{1,\pi} = 1.071$ and $\beta_{1,y} = 0.220$). The answer to asset price deflation is in both states significant. The process where β_{α^-} is constrained to zero displays also a negative reaction to asset volatility in both regimes $\beta_{0,\psi_\alpha} = -0.284$ and $\beta_{1,\psi_\alpha} = -0.902$. The results obtained reflect the fact that the Fed either responds to asset price deflation or to volatility, implying that it always reacts to asset prices in a way or the other. Note also that excluding financial variables, in other words constraining the target variables only to inflation and output gap, does not reveal the presence of two states.

In both computed cases, we obtain similar results and the two processes can be described as:

$$S_t = \begin{cases} 1 & \text{for an ordinary monetary policy} \\ 0 & \text{for a destabilising monetary policy} \end{cases} \tag{9}$$

with x_t as defined in (5).

In summary, the regime $S_t = 1$ stands for the regime where the Fed follows an ordinary monetary policy with a significant reaction to asset prices, whereas $S_t = 0$ corresponds to the Fed pursuing a destabilising monetary policy. A destabilising monetary policy is characterised by at least one of the following features: a destabilising response to inflation $\beta_{0,\pi} < 1$, an overactive response to output gap $\beta_{0,y} > 0.5$ and negative reactions to asset price absolute deflation $\beta_{0,\alpha^-} < 0$ or to volatility

is maximised with respect to $\beta_0, \beta_1, \sigma^2_{\varepsilon,0}, \sigma^2_{\varepsilon,1}$ and P. The process $\Pr\{S_t|\Omega_t\}_{t=1}^T$ which is needed to calculate the log likelihood is reconstructed following two iterations:

We set $\Pr\{S_0|\Omega_0\}$.
For any given t ranging from 1 to T:

Step 1 Given $\Pr\{S_{t-1}|\Omega_{t-1}\}$, we calculate:

$$\Pr\{S_t = j|\Omega_{t-1}\} = \sum_{i=0}^{1} p_{ij} \Pr\{S_{t-1} = i|\Omega_{t-1}\} \quad \text{for } j = 0, 1.$$

Step 2 We then proceed to the updating of $\Pr\{S_t|\Omega_t\}$:

$$\begin{aligned} \Pr\{S_t = j|\Omega_t\} &= \Pr\{S_t = j|i_t, x'_t, \Omega_{t-1}\} \\ &= \frac{f(i_t, S_t = j|x'_t, \Omega_{t-1})}{f(i_t|x'_t, \Omega_{t-1})} \\ &= \frac{\Pr\{S_t = j|\Omega_{t-1}\} f(i_t|S_t = j, x'_t, \Omega_{t-1})}{\sum_{i=0}^{1} \Pr\{S_t = i|\Omega_{t-1}\} f(i_t|S_t = i, x'_t, \Omega_{t-1})} \end{aligned}$$

.

$\beta_{0,\psi_\alpha} < 0$. On the other hand, an ordinary monetary policy with a tendency to react to asset prices has a stabilising behaviour towards inflation $\beta_{1,\pi} > 1$, reacts less to economic growth $\beta_{1,y} < 0.5$, but would also react to asset prices: $\beta_{1,\alpha^-} < 0$ or $\beta_{1,\psi_\alpha} < 0$. Here again, the results suggest that the Fed reacted to asset prices over the whole period. Descriptive statistics for each state[13] show that the state $S_t = 1$ is characterised by high interest rate, a positive output gap and a relatively low asset price deflation in average, while in state $S_t = 0$ the interest rate is low, the output gap is negative and asset price deflation high.

3.3.2 State-independent and dependent target variables

In the previous section, all target variables were state dependent. Suppose now that the reactions to inflation and output gap were time independent and that only the reactions to asset prices were state dependent. Thus, the regimes are only concerned with the behaviour towards asset price deflation and volatility. The interest-rate setting is defined according to:

$$i_t = X_t'A + x_t'\beta_{S_t} + \varepsilon_t \tag{10}$$

where $\varepsilon_t \sim N(0, \sigma^2_{\varepsilon,S_t})$ i.i.d.. The state-independent variables and parameters are:

$$X_t' = (\pi_t, y_t) \quad \text{and} \quad A' = (\beta_\pi, \beta_y). \tag{11}$$

The state-dependent variables are:

$$x_t = (\alpha^-_{t-1}, \psi_{\alpha,t-1}) \quad \text{and} \quad \beta_{S_t} = (\beta_{S_t,\alpha^-}, \beta_{S_t,\psi_\alpha}).$$

As in the previous section, we define two different processes to capture the reaction of the Fed to negative developments in asset prices. For the first process, we set $\beta_{S_t,\psi_\alpha} = 0$, while for the second one it is the reaction to asset price deflation which is equal to 0, i.e. $\beta_{S_t,\alpha^-} = 0$. Both processes display two regimes which can be characterised in the following way:

$$S_t = \begin{cases} 1 & \text{with a smaller reaction to asset prices,} \\ 0 & \text{with a greater reaction to asset prices.} \end{cases} \tag{12}$$

In other terms, for the first process we have $\beta_{0,\alpha^-} < \beta_{1,\alpha^-} < 0$, while for the second process, we obtain: $\beta_{0,\psi_\alpha} < \beta_{1,\psi_\alpha} < 0$.

HERE Table 4

The processes found for the interest-rate settings (7) and (10) display similar regimes; in fact, the Fed pursues a more expansive monetary policy during periods of financial crises, i.e. end of the eighties, beginning of the nineties, the aftermath of the dotcom bubble and as from 2008.

In the next section, we will introduce a forward-looking Taylor rule and check whether we can improve the coincidence between the states and the data characteristics.

[13] State 0 was defined with a probability $Pr\{S_t = 0|\Omega_t\}$ smaller than 0.1, while state 1 with a probability $Pr\{S_t = 1|\Omega_t\}$ greater than 0.9. Conditional mean and standard deviation for the interest rate and each target variables were computed in order to provide some characteristics specific to each state.

4 Analysis with leading indicators and changes in regime

4.1 Forward-looking Taylor rule

At this point of our analysis, we introduce a forward-looking rule: a more general case than the Taylor rule introduced in (6). We define the forward-looking variables $x_{t,n}$ such that each of its elements $x_{t,n}^{(j)}$ takes the value, $n^{(j)}$ months afterwards:

$$x_{t,n}^{(j)} = x_{t+n^{(j)}}$$

where $n = (n^{(1)}, ..., n^{(x)})$. For example, $x'_{t,n} = (\pi_{t+6}, y_{t+3}, \alpha^{-}_{t+1}, \psi_{\alpha,t+1})$ where the forward vector n is defined as $n = (6, 3, 1, 1)$.

The interest-rate setting follows a forward-looking Taylor rule according to:

$$\begin{aligned} i_t &= E_t x'_{t,n}\beta + \varepsilon_t && (13) \\ &= x'_{t,n}\beta + \tilde{\varepsilon}_t && (14) \end{aligned}$$

where $\varepsilon_t \sim N(0, \sigma^2_\varepsilon)$ i.i.d. and $\tilde{\varepsilon}_t = \varepsilon_t - (x_{t,n} - E_t x_{t,n})'\beta$. The variables $x_{t,n}$ and β are defined as in the previous chapter.

If a linear combination of present inflation and output gap is a sufficient statistic for forecasting future inflation and output gaps, then equation (14) reduces to the contemporaneous Taylor rule defined in equation (6). As pointed out by Clarida, Galì and Gertler (1998), approximate forms of this rule are optimal for a central bank that has a quadratic loss function. Moreover, forward-looking policy rules have provided reasonably good descriptions of the way major central banks around the world behave.

Including future values of asset prices might contradict the intuition of the efficient market hypothesis. According to this hypothesis, financial markets process available information rationally, so a stock price always equals the best estimate of the value of the underlying business and changes in stock market are impossible to predict from available information. However, the large movements in stock prices, whether rational or not, have macroeconomic implications. Fluctuations in asset prices often go hand in hand with fluctuations in the economy more broadly. We thus consider future values of asset prices as a sheer source of information for the Fed.

Here again, the error distribution is not independent of the regressors' distribution,

$$E_t[x'_{t,n}\tilde{\varepsilon}_t] \neq 0$$

and we make use of the same instruments for the estimation method introduced for (6).

We provide results for:

$$x_{t,n} = (\pi_{t+1}, y_{t+1}, \alpha^{-}_{t+3}, \psi_{\alpha,t+1})$$

and

$$x_{t,n} = (\pi_{t+3}, y_{t+3}, \alpha^{-}_{t+3}, \psi_{\alpha,t+1})$$

in Table 5. Central banks base their interest rate decisions on expected inflation rather than current inflation. π_{t+6} or even π_{t+12} should be included rather than π_{t+1} since it takes at least six months before the effects of change in monetary policy can be noticed in practice. The correlation between the lags of the instrumental variables and inflation fade drastically after the first three months, and the results loose thereon in their significance. We therefore had to constrain the analysis to only π_{t+1} and π_{t+3}.

HERE Table 5

Although the fit is not as good as in the contemporaneous regression, the p-value for the J-statistic still confirms that the instruments satisfy the orthogonality conditions required for their employment. The parameters β_π, β_y, β_α and β_{ψ_α} obtained are mostly significant and quite similar to the ones found with contemporaneous variables. Here, the estimate β_π is greater than 1 for the period including Bernanke as chairman.

4.2 First-order Markov switching model with two states

4.2.1 State-dependent target variables

Our specifications belong to a class of Markov-switching regression models in which regressors are correlated with the disturbance term:

$$\begin{aligned} i_t &= x'_{t,n}\beta_{S_t} + \tilde{\varepsilon}_t & (15) \\ x_{t,n} &= (I_k \otimes z'_t)\gamma_{S_t} + v_t & (16) \end{aligned}$$

where $\tilde{\varepsilon_t} \sim N(0, \sigma^2_{\tilde{\varepsilon}_t, S_t})$ i.i.d. and $v_t \sim N(0, \Sigma_{v,S_t})$ i.i.d.

We will assume that the parameters in (16) are time-invariant to simplify the estimation procedure: $\gamma_{s_t} = \gamma$ and $\Sigma_{v,S_t} = \Sigma_v$. The instrumental variables are valid if they are uncorrelated with $\tilde{\varepsilon_t}$, but correlated with $x_{t,n}$:

$$\begin{aligned} E[z'_t\tilde{\varepsilon}_t] &= 0 \\ E[v'_t\tilde{\varepsilon}_t] &= C_{v\tilde{\varepsilon}} = C_{0,v\tilde{\varepsilon}}(1 - S_t) + C_{1,v\tilde{\varepsilon}}S_t. \end{aligned}$$

The state-dependent variables are:

$$\beta_{S_t} = \beta_0(1 - S_t) + \beta_1 S_t \quad \text{and} \quad \sigma^2_{\tilde{\varepsilon},S_t} = \sigma^2_{\tilde{\varepsilon},0}(1 - S_t) + \sigma^2_{\tilde{\varepsilon},1}S_t.$$

The maximum likelihood estimation of a Markov-switching regression model based on the Hamilton filter, as we used in the previous section, is not valid in the presence of endogenous explanatory variables. However, Kim (2003) shows that there exists an appropriate transformation of the model that allows to directly employ the Hamilton filter. The transformed model is:

$$i_t = x'_{t,n}\beta_{S_t} + (x_{t,n} - (I_k \otimes z'_t\gamma))'\delta_{1,S_t} + \delta_{2,S_t}\omega_{2,t} \qquad (17)$$

where $\omega_{2,t} \sim N(0,1)$ i.i.d.. The explanatory variables and the disturbance term $\omega_{2,t}$ are no longer correlated by construction.[14] The expression:

$$(x_{t,n} - (I_k \otimes z'_t\gamma))'\delta_{1,S_t}$$

[14]By rewriting $(v'_t, \tilde{\varepsilon}_t)'$ as a function of two independent shocks $\omega_{1,t}$ and $\omega_{2,t}$, we can use the transformed model with a vector of bias correction terms as additional regressors to proceed with

works as a correction bias term. The state-dependent parameters in front of the correction bias term are:

$$\delta_{i,S_t} \quad = \quad \delta_{i,0}(1 - S_t) + \delta_{i,1} S_t$$

for $i = 1, 2$.

We now refer to the information set which contains the endogenous variables i_t and the instruments known at date t, as well as the forward-looking variables $x_{t,n}$:

$$\Omega_{t,n} = (i_t, i_{t-1}, ..., i_0; x'_{t,n}, x'_{t-1,n} ..., x'_0; z'_t, z'_{t-1} .. z'_0)$$

The estimation process occurs in two steps. First, we estimate (16) with OLS and get $\hat{\gamma}$. Given $\Pr\{S_0|\Omega_{0,n}\}$ and $\hat{\gamma}$, we here again maximise the quasi log likelihood with respect to the parameters β_0, β_1, $\sigma^2_{\tilde{\varepsilon},0}$, $\sigma^2_{\tilde{\varepsilon},1}$, $\delta_{1,0}$, $\delta_{1,1}$, $\delta_{2,0}$, $\delta_{2,1}$ and P, by reconstructing the whole process $\Pr\{S_t|\Omega_{t,n}\}_{t=1}^{T-n}$.[15]

The two processes found for $x_{t,n} = (\pi_{t+1}, y_{t+1}, \alpha^-_{t+3}, \psi_{\alpha,t+1})$ and $x_{t,n} = (\pi_{t+3}, y_{t+3}, \alpha^-_{t+3}, \psi_{\alpha,t+1})$ are defined as in (9).

HERE Table 6

This setting captures the same two regimes for the Fed's behaviour, as described in the contemporaneous analysis. In the first one, the reaction to inflation is not stabilising, while in the other regime monetary policy has a reaction factor above 1. It is during the stabilising regime that the reaction to asset price inflation was more

a quasi maximum likelihood estimation procedure. Considering the Cholesky decomposition of the covariance matrix of $(v'_t, \tilde{\varepsilon}_t)'$, we have:

$$\begin{pmatrix} v'_t \\ \tilde{\varepsilon}_t \end{pmatrix} = \begin{pmatrix} b_{11} & 0 \\ b_{21,S_t} & b_{22,S_t} \end{pmatrix} \begin{pmatrix} \omega_{1,t} \\ \omega_{2,t} \end{pmatrix} \quad \text{where} \quad \begin{pmatrix} \omega_{1,t} \\ \omega_{2,t} \end{pmatrix} \sim N(0, I_{x+1}) \text{ i.i.d.}$$

The term b_{11} is equal to $\Sigma_v^{1/2}$. I_{x+1} is the identity matrix with dimensions equal to the number of variables in $x_{t,n}$ plus one. By substituting the above relations in (15), we obtain:

$$i_t \quad = \quad x'_{t,n}\beta_{S_t} + (x_{t,n} - (I_k \otimes z'_t\gamma))'\delta_{1,S_t} + \delta_{2,S_t}\omega_{2,t}$$

where $\delta_{1,S_t} = b_{21,S_t}\Sigma_v^{-1/2}$ and $\delta_{2,S_t} = b_{22,S_t}$.

[15] Given the transformed model, the sample log likelihood is:

$$\begin{aligned} &\ln L(\beta_0, \beta_1, \sigma^2_{\tilde{\varepsilon},0}, \sigma^2_{\tilde{\varepsilon},1}, \gamma, \delta_{1,0}, \delta_{1,1}, \delta_{2,0}, \delta_{2,1} P|\Omega_{T-n,n}) \\ &= \sum_{t=1}^{T-n} \ln\{\sum_{j=0}^{1} Pr\{S_t = j|\Omega_{t-1,n}\} f(i_t|S_t = j, x'_{t,n}, z'_t, \Omega_{t-1,n}) f(x_{t,n}|S_t = j, z_t, \Omega_{t-1,n})\} \\ &= \sum_{t=1}^{T-n} \ln\{\sum_{j=0}^{1} Pr\{S_t = j|\Omega_{t-1,n}\} f(i_t|S_t = j, x'_{t,n}, z'_t, \Omega_{t-1,n})\} + \sum_{t=1}^{T-n} f(x_{t,n}|z_t, \Omega_{t-1,n}) \end{aligned}$$

is maximised with respect to β_0, β_1, $\sigma^2_{\tilde{\varepsilon},0}$, $\sigma^2_{\tilde{\varepsilon},1}$, $\delta_{1,0}$, $\delta_{1,1}$, $\delta_{2,0}$, $\delta_{2,1}$ and P. The process $\Pr\{S_t|\Omega_{t,n}\}_{t=1}^{T-n}$ is again decomposed as in footnote (12) with $\Omega_{t,n}$ instead of Ω_t and with:

$$f(i_t|S_t = j, x'_{t,n}, z'_t, \Omega_{t-1,n})$$

instead of $f(i_t|S_t = j, x'_t, \Omega_{t-1})$, since $f(x_{t,n}|z'_t, \Omega_{t-1,n})$ simplifies in the numerator and denominator.

substantial, while volatility in asset price seems to be taken into account in periods where not so much weight is given to inflation. In other words, the weight in the targeting is shifted away from inflation.

4.2.2 State-independent and dependent target variables

As in the contemporaneous analysis with Markov switching regimes, we also introduce the case where the effect of π_t and y_t on the interest-rate setting is time independent and the regimes are only concerned with the behaviour towards asset price inflation and volatility.

$$
\begin{aligned}
i_t &= X'_{t,n}A + x'_{t,n}\beta_{S_t} + \tilde{\varepsilon}_t &(18)\\
\Xi_{t,n} &= \begin{pmatrix} X'_{t,n} \\ x'_{t,n} \end{pmatrix} = (I_k \otimes z'_t)\gamma + v_t. &(19)
\end{aligned}
$$

As in (17), we obtain a transformed model with a correction bias term due to the forward-looking terms:

$$
i_t \;=\; X_{t,n}A + x'_{t,n}\beta_{S_t} + (\Xi_{t,n} - (I_k \otimes z'_t\gamma))'\delta_{1,S_t} + \delta_{2,S_t}\omega_{2,t}. \tag{20}
$$

The two processes are defined as in (12).

HERE Table 7

The state-independent reactions to one-month and one-quarter ahead values of inflation and output gap are in most settings stabilising, that is β_π is greater than one and β_y is positive. Here again, asset price deflation gap has a negative effect on interest rates: a strictly positive α^-_{t-1} will urge to an easing of monetary policy conditions. The volatility gap in asset prices has a negative impact on the interest-rate setting, and this again mostly in the periods where asset prices were on the descent: the first half of the nineties and in the aftermath of the dotcom bubble.

Let us conclude by concentrating on three main events of the last two decades and observe how the Fed reacted on the grounds of these results. The first episode is the stock market crash which occurred in October 1987, referred to as the Black Monday. Second, we will observe the dot-com economic boom at the end of the nineties. Finally, we will spend a few words on the economic downturn which followed at the beginning of the century. These examples should illustrate the asymmetric reaction of the US central bank to asset prices: tightenings of monetary policy happen less frequently and in a smaller extent in case of financial exuberance than a loosening of the monetary policy stance in case of financial distress.

The late eighties were characterised by increasing inflation, gloomy economic prospects, undervalued stock prices and high volatility in financial markets. The Markov switching process (12) with target variables (2) is at that moment in state 1; it captures a slight negative reaction to asset price deflation (-0.020 and -0.026), as well as a significant negative reaction to volatility (-0.494 and -0.172). In the twelve months following October 1987, the average gap in asset price deflation was -25 and the average volatility was 3. The reaction of the Fed implied a loosening by some 0.5 to 1.5 percentage points from what is considered an ordinary monetary policy. Some ten years later, the US economic situation was much different: inflation was low, economic growth was positive, asset prices were soaring and volatility in stock prices was high. The gap in asset price inflation amounted to 43 in the years 1997–1998. A few quarters later, the dot-com bubble burst; inflation was still low, the output gap reached negative values, financial markets were on the descent and volatility was high: in the year 2002 it reached 3.1. At the beginning of the century, the process switched to the state 0; the reactions to volatility varied around -1.535 and -1.145, while the reactions to asset price deflation moved around -0.097 and -0.077. The Fed reacted to the situation by lowering rates by some 3.5 percentage points from what an ordinary Taylor rule would have given.

5 Conclusion

This study looked into the reaction of the Fed to asset prices over the past decades and whether its attitude had undergone changes during specific phases. The Taylor rule was extended with variables considering misalignments in stock prices, as well as financial uncertainty with volatility.

Whether we assume that monetary policy decision makers have reacted to inflation and output gap in a constant way over time or not, there is evidence that the Fed has taken either asset price deflation or volatility into account. Over the past twenty years, the Fed has reacted to forecasts of inflation in a stabilising manner: the forward-looking Taylor rule with state-independent reactions to one quarter-ahead inflation and output gap is well defined in that sense. But, the role that asset prices played in monetary policy and financial stability frameworks is also significant. The US central bank might have had asset prices in mind when setting interest rates beyond its responsibility as a lender of last resort. There have been periods stretching beyond the moments of acute financial distress where the Fed has reacted to share prices over the reaction implied by the pursuit of output and inflation stabilisation. Our results do not exhibit a too lenient behaviour of the US central bank in the late nineties, contrarily to what has been reported in the literature. However, there is reason to think that an expansive monetary policy took place during the dot-com crisis. Furthermore, everything seems to indicate that as from February 2008, the Fed entered a regime where monetary policy conditions are loosened in accordance with the the financial markets.

Agents' confidence in a stronger response of the US central bank to significant market declines urging to an easing of monetary conditions in their favour was therefore not unfounded over the last twenty years.

6 Literature

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7 Tables and Figures

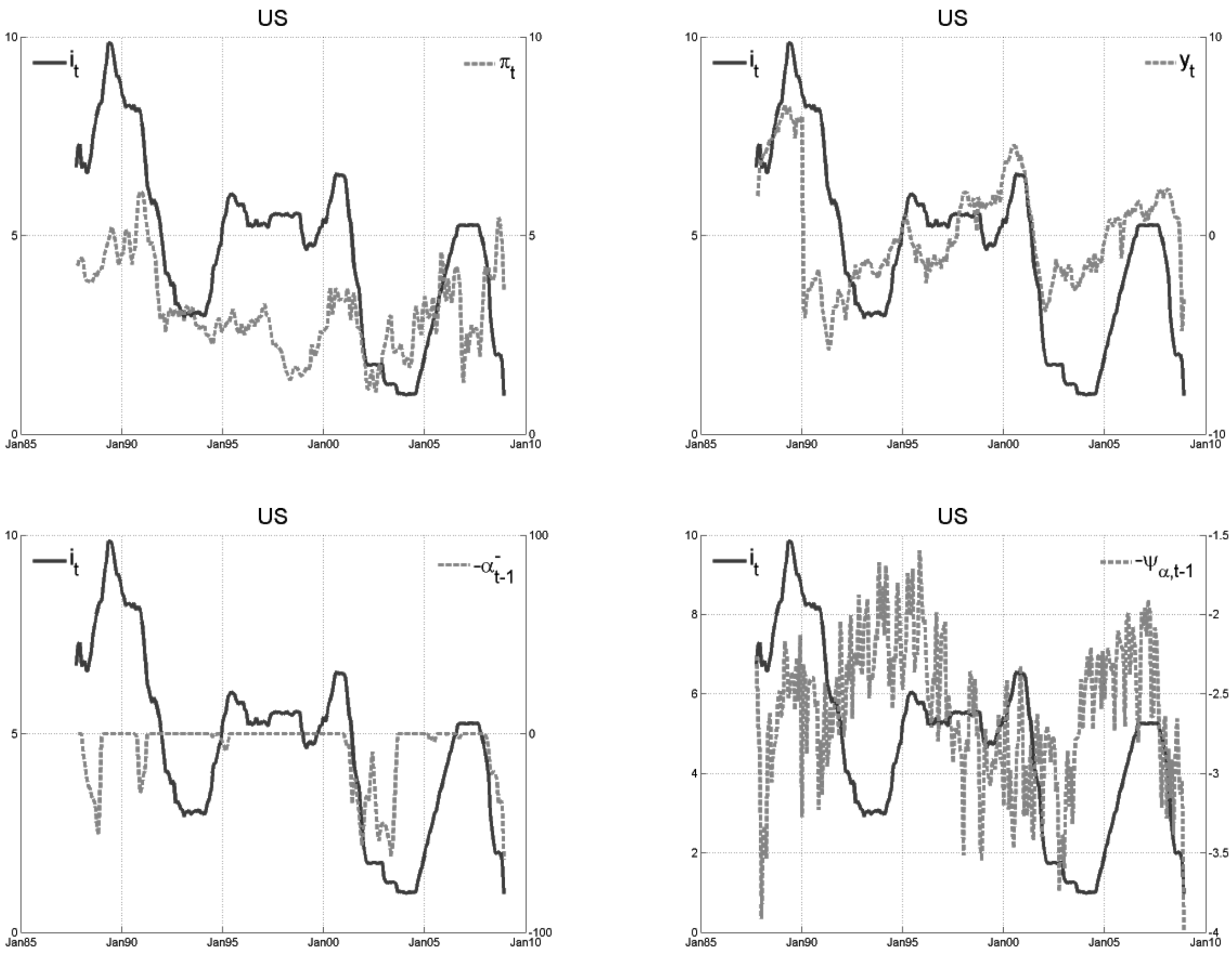


Figure 1: Federal Funds rate with potential targeting variables. On the left-hand scale, the short-term interest rate i_t. On the right-hand scale, inflation π_t, output gap y_t, the negative gap in asset price deflation $-\alpha^-_{t-1}$ and in volatility $-\psi_{\alpha,t-1}$.

period	1987.08–2006.01			1987.08–2008.10		
nobs	222			255		
ρ	0.963***	0.957***	0.965***	0.984***	0.975***	0.979***
	(0.009)	(0.009)	(0.008)	(0.008)	(0.008)	(0.070)
β_π	0.749*	0.751**	0.513	-0.561	0.053	-0.215
	(0.433)	(0.369)	(0.431)	(0.918)	(0.564)	(0.627)
β_y	1.011***	0.891***	1.192***	1.883***	1.193***	1.708***
	(0.142)	(0.121)	(0.142)	(0.350)	(0.212)	(0.243)
β_{α^-}		-0.064***			-0.139***	
		(0.019)			(0.034)	
β_{ψ_α}			-4.581***			-9.271***
			(0.778)			(1.274)
$\overline{R}^2$	0.993	0.994	0.994	0.991	0.992	0.993
logL	61	70	78	47	55	71

Table 1: Taylor rule with interest-rate smoothing, defined as in equation (4): $i_t = \rho i_{t-1} + (1-\rho)x_t'\beta + \varepsilon_t$ with target variables $x_t' = (\pi_t, y_t, \alpha_{t-1}^-, \psi_{\alpha,t-1})$. */**/*** denotes significance at the 10/5/1 percent level; the standard errors are reported in brackets. A constant is included in the estimation, but not reported here. Regression method: OLS estimation.

period	1987.08–2006.01			1987.08–2008.10		
nobs	222			255		
β_π	1.254***	1.197***	1.283***	0.937***	0.915***	0.952***
	(0.125)	(0.125)	(0.071)	(0.166)	(0.162)	(0.153)
β_y	0.350***	0.334***	0.353***	0.393***	0.345***	0.413***
	(0.042)	(0.043)	(0.034)	(0.062)	(0.060)	(0.051)
β_{α^-}		-0.025**			-0.032***	
		(0.007)			(0.008)	
β_{ψ_α}			-0.036			-0.504***
			(0.144)			(0.166)
$\overline{R}^2$	0.619	0.626	0.613	0.465	0.501	0.476
Jstat	24	22	27	25	23	30
p-value	0.977	0.997	1	0.913	0.983	0.999

Table 2: Taylor rule without interest-rate smoothing defined as in equation (6): $i_t = x_t'\beta + \varepsilon_t$ with target variables $x_t' = (\pi_t, y_t, \alpha_{t-1}^-, \psi_{\alpha,t-1})$. */**/*** denotes significance at the 10/5/1 percent level; the standard errors are reported in brackets. A constant is included in the estimation, but not reported here. Regression method: GMM estimation.

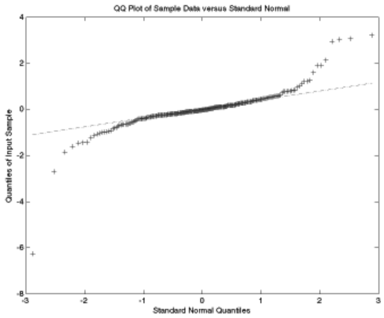
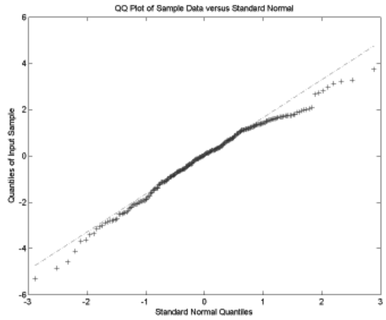
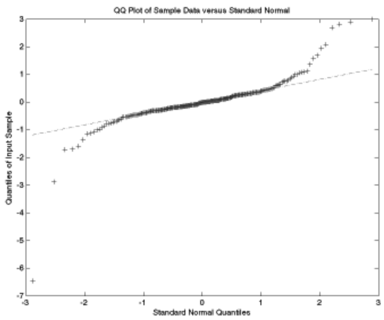
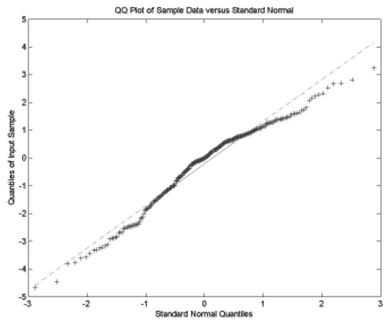
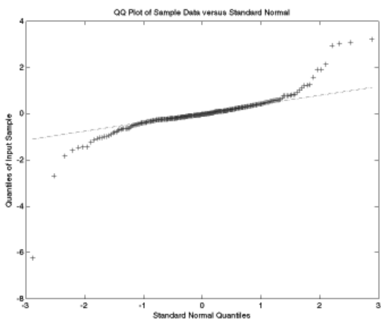
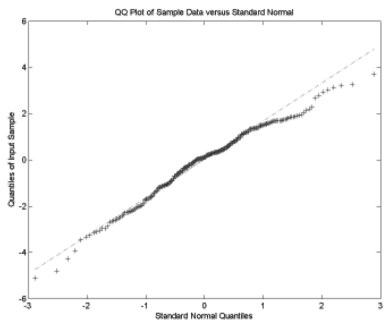
<table>
<tr><td>period</td><td colspan="2">1987.08–2008.10</td></tr>
<tr><td></td><td>with interest-rate smoothing</td><td>without interest-rate smoothing</td></tr>
<tr><td colspan="3">explanatory variables: π_t, y_t</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td colspan="3">explanatory variables: $\pi_t, y_t, \alpha^-_{t-1}$</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
<tr><td colspan="3">explanatory variables: $\pi_t, y_t, \psi_{\alpha,t-1}$</td></tr>
<tr><td></td><td>
</td><td>
</td></tr>
</table>

Figure 2: Testing statistical assumptions for the residuals $\varepsilon_t \sim N(0, \sigma^2_\varepsilon)$ i.i.d. with the help of quantile vs quantile plots. The qqplots refer to the regressions reported in the Table 1 and Table 2.

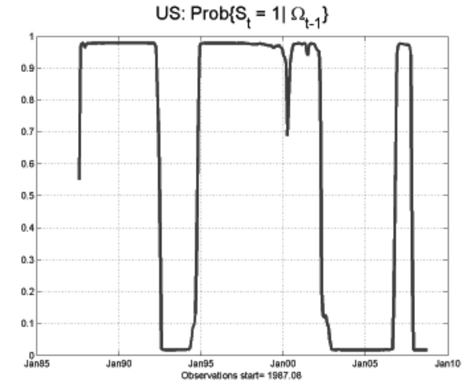
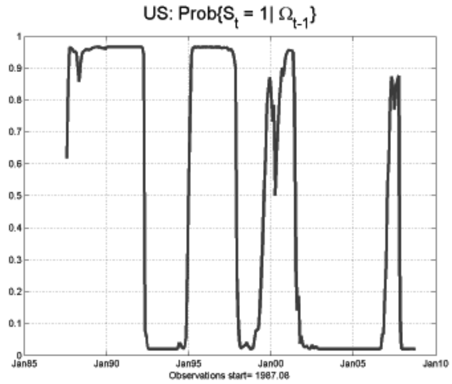
period	1987.08–2008.10	
nobs	255	
p_{11}	0.979* (0.552)	0.966* (0.525)
$\beta_{1,\pi}$	1.071*** (0.048)	1.118*** (0.053)
$\beta_{1,y}$	0.220*** (0.018)	0.208*** (0.016)
β_{1,α^-}	-0.027*** (0.004)	
β_{1,ψ_α}		-0.902*** (0.127)
$\bar{i}_1$	5.949 (1.640)	6.574 (3.846)
$\overline{\pi}_1$	3.190 (1.165)	3.742 (1.498)
$\overline{y}_1$	0.651 (3.095)	0.210 (3.607)
$\overline{\alpha}_1^-$	6.101 (12.935)	5.218 (12.310)
$\overline{\psi}_{\alpha,1}$	2.657 (0.409)	2.589 (0.413)
		
p_{00}	0.983 (0.789)	0.980 (0.743)
$\beta_{0,\pi}$	0.204*** (0.056)	-0.161* (0.087)
$\beta_{0,y}$	0.354*** (0.067)	0.635*** (0.057)
β_{0,α^-}	-0.021*** (0.005)	
β_{0,ψ_α}		-0.284** (0.126)
$\bar{i}_0$	2.672 (3.509)	3.056 (1.471)
$\overline{\pi}_0$	3.025 (0.841)	2.664 (0.943)
$\overline{y}_0$	-0.687 (1.988)	-0.560 (1.645)
$\overline{\alpha}_0^-$	9.059 (17.745)	9.761 (17.762)
$\overline{\psi}_{\alpha,0}$	2.500 (0.486)	2.579 (0.465)
$\overline{R}^2$	0.867	0.857
$logL$	-304	-306

Table 3: Taylor rule defined as in equation (7): $i_t = x_t'\beta_{S_t} + \varepsilon_t$ with target variables $x_t' = (\pi_t, y_t, \alpha_{t-1}^-, \psi_{\alpha,t-1})$. The processes can be summarised by: (9). */**/*** denotes significance at the 10/5/1 percent level; the standard errors are reported in brackets. A constant is included in the estimation, but not reported here. Each state is summarised with the mean, as well as the standard deviation in brackets, of the interest rate and of each target variable. Method: ML estimation of a Markov switching process.

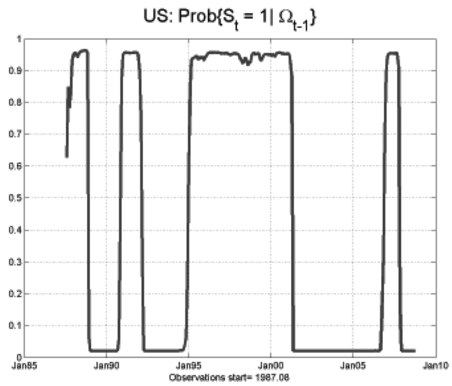
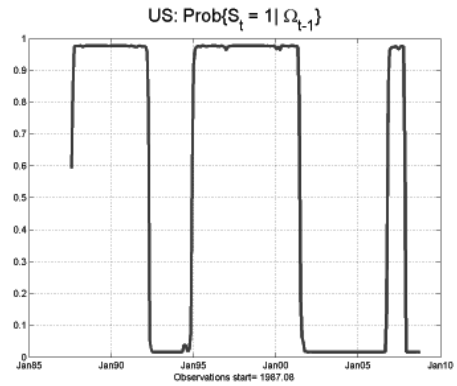
period	1987.08–2008.10	
nobs	255	
β_π	0.529*** (0.041)	0.888*** (0.043)
β_y	0.107*** (0.016)	0.186*** (0.017)
p_{11}	0.964* (0.495)	0.977* (0.554)
β_{1,α^-}	-0.027*** (0.004)	
β_{1,ψ_α}		-0.323** (0.125)
$\overline{i}_1$	5.722 (0.790)	6.198 (3.775)
$\overline{\pi}_1$	2.883 (0.905)	3.266 (1.223)
$\overline{y}_1$	0.945 (2.699)	0.949 (3.616)
$\overline{\alpha}_1^-$	3.636 (10.085)	3.941 (12.990)
$\overline{\psi}_{\alpha,1}$	2.686 (0.410)	2.659 (0.435)
		
p_{00}	0.980 (0.624)	0.985 (0.781)
β_{0,α^-}	-0.075*** (0.009)	
β_{0,ψ_α}		-1.402*** (0.131)
$\overline{i}_0$	3.793 (3.210)	2.690 (1.244)
$\overline{\pi}_0$	3.210 (1.168)	2.846 (0.890)
$\overline{y}_0$	-0.460 (2.875)	-0.938 (1.517)
$\overline{\alpha}_0^-$	10.654 (19.276)	12.144 (19.172)
$\overline{\psi}_{\alpha,0}$	2.686 (0.410)	2.550 (0.462)
$\overline{R}^2$	0.396	0.829
$logL$	-377	-320

Table 4: Taylor rule defined as in equation (10): $i_t = X_t'A + x_t'\beta_{S_t} + \varepsilon_t$ with target variables $x_t' = (\pi_t, y_t, \alpha_{t-1}^-, \psi_{\alpha,t-1})$. The processes can be summarised as in (12). */**/*** denotes significance at the 10/5/1 percent level; the standard errors are reported in brackets. A constant is included in the estimation, but not reported here. Each state is summarised with the mean, as well as the standard deviation in brackets, of the interest rate and of each target variable. Method: ML estimation of a Markov switching process.

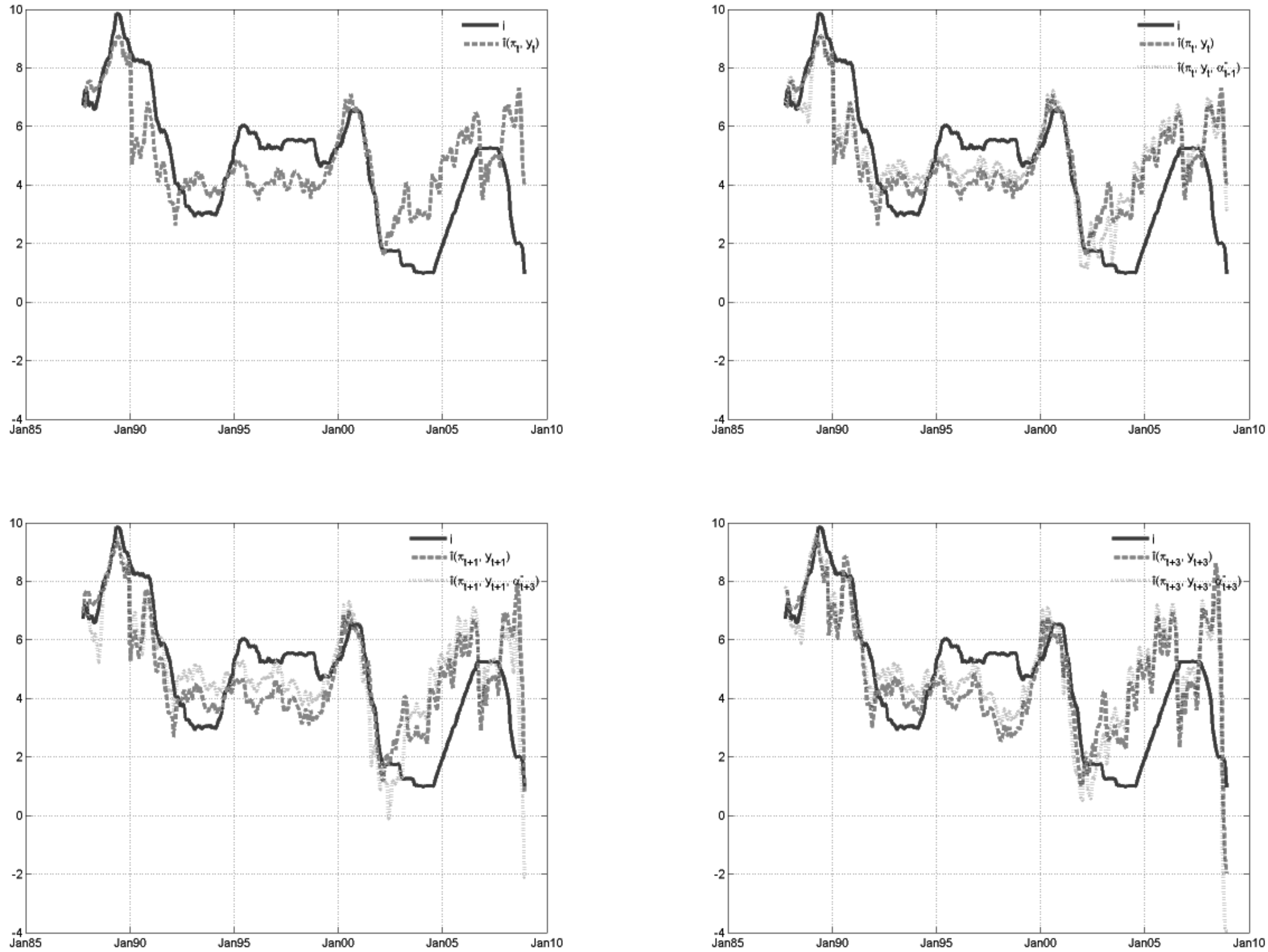


Figure 3: Introducing asset price deflation as explanatory variable: Federal Funds rate compared to $\hat{\imath}_t = x_t'\beta$ and $\hat{\imath}_t = x_{t,n}'\beta$ with $x_t' = (\pi_t, y_t)$, $x_t' = (\pi_t, y_t, \alpha_{t-1}^-)$, $x_{t,n}' = (\pi_{t+1}, y_{t+1}, \alpha_{t+3}^-)$ and $x_{t,n}' = (\pi_{t+3}, y_{t+3}, \alpha_{t+3}^-)$.

period	1987.08–2008.10			1987.08–2008.10		
explanatory variables	π_{t+1}, y_{t+1}, α^-_{t+3}, $\psi_{\alpha,t+1}$			π_{t+3}, y_{t+3}, α^-_{t+3}, $\psi_{\alpha,t+1}$		
nobs	255			255		
β_π	1.229***	1.164***	1.155***	1.526***	1.447***	1.515***
	(0.170)	(0.161)	(0.167)	(0.204)	(0.199)	(0.181)
β_y	0.338***	0.285***	0.379***	0.241***	0.219***	0.252***
	(0.054)	(0.045)	(0.050)	(0.055)	(0.054)	(0.052)
β_{α^-}		-0.045***			-0.034***	
		(0.009)			(0.011)	
β_{ψ_α}			-0.579**			-0.178
			(0.245)			(0.311)
$\overline{R}^2$	0.445	0.479	0.450	0.338	0.332	0.333
Jstat	22	19	26	22	20	25
p-value	0.886	0.947	0.998	0.441	0.595	0.981

Table 5: Forward-looking Taylor rule defined as in equation (14): $i_t = E_t x'_{t,n}\beta + \varepsilon_t$ with target variables $x_{t,n} = (\pi_{t+1}, y_{t+1}, \alpha^-_{t+3}, \psi_{\alpha,t+1})$ and $x_{t,n} = (\pi_{t+3}, y_{t+3}, \alpha^-_{t+3}, \psi_{\alpha,t+1})$. */**/*** denotes significance at the 10/5/1 percent level; the standard errors are reported in brackets. A constant is included in the estimation, but not reported here. Regression method: GMM estimation.

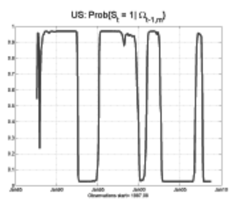
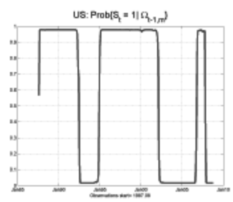
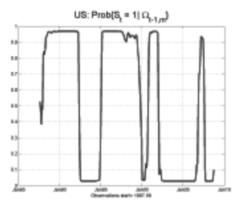
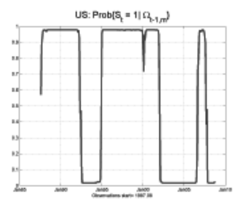
period	1987.08–2008.10		1987.08–2008.10	
explanatory variables	π_{t+1}, y_{t+1}, α^-_{t+3}, $\psi_{\alpha,t+1}$		π_{t+3}, y_{t+3}, α^-_{t+3}, $\psi_{\alpha,t+1}$	
nobs	255		249	
p_{11}	0.969* (0.493)	0.978* (0.552)	0.969* (0.509)	0.984 (0.786)
$\beta_{1,\pi}$	1.139*** (0.051)	1.076*** (0.052)	1.185*** (0.070)	1.158*** (0.054)
$\beta_{1,y}$	0.261*** (0.017)	0.231*** (0.020)	0.202*** (0.020)	0.187*** (0.020)
β_{1,α^-}	-0.034*** (0.004)		-0.019*** (0.004)	
β_{1,ψ_α}		-0.742*** (0.195)		-0.454** (0.176)
$\bar{i}_1$	5.834 (3.307)	6.009 (3.668)	6.075 (3.622)	6.055 (3.752)
$\bar{\pi}_1$	3.173 (1.265)	3.212 (1.186)	3.270 (1.270)	3.230 (1.197)
$\bar{y}_1$	0.029 (3.157)	0.747 (3.435)	0.103 (3.222)	0.699 (3.458)
$\bar{\alpha}^-_1$	7.201 (14.459)	5.87 (13.916)	6.379 (14.427)	5.946 (14.044)
$\bar{\psi}_{\alpha,1}$	2.648 (0.409)	2.676 (0.434)	2.624 (0.381)	2.657 (0.430)
				
p_{00}	0.975 (0.640)	0.984 (0.785)	0.972 (0.793)	0.978* (0.553)
$\beta_{0,\pi}$	0.331*** (0.067)	0.414*** (0.149)	0.380*** (0.086)	0.610*** (0.128)
$\beta_{0,y}$	0.635*** (0.053)	0.305*** (0.110)	0.585*** (0.077)	0.279*** (0.067)
β_{0,α^-}	-0.018*** (0.006)		-0.003 (0.007)	
β_{0,ψ_α}		-1.042*** (0.158)		-0.839*** (0.169)
$\bar{i}_0$	3.129 (1.597)	2.695 (1.283)	2.881 (1.426)	2.639 (1.242)
$\bar{\pi}_0$	3.061 (0.791)	2.928 (0.871)	2.946 (0.864)	2.908 (0.899)
$\bar{y}_0$	-0.176 (1.925)	-0.724 (1.439)	-0.459 (1.803)	-0.789 (1.470)
$\bar{\alpha}^-_0$	7.586 (16.914)	10.880 (19.487)	10.224 (18.986)	11.229 (19.502)
$\bar{\psi}_{\alpha,0}$	2.505 (0.477)	2.529 (0.506)	2.581 (0.513)	2.554 (0.505)
$\overline{R}^2$	0.895	0.886	0.896	0.896
$logL$	-273	-286	-277	-280

Table 6: Taylor rule defined as in equation (17): $i_t = x'_{t,n}\beta_{S_t} + (x_{t,n} - (I_k \otimes z'_t\gamma))'\delta_{1,S_t} + \delta_{2,S_t}\omega_{2,t}$ with target variables $x_{t,n} = (\pi_{t+1}, y_{t+1}, \alpha^-_{t+3}, \psi_{\alpha,t+1})$ and $x_{t,n} = (\pi_{t+3}, y_{t+3}, \alpha^-_{t+3}, \psi_{\alpha,t+1})$. The processes can be summarised as in (9). */**/*** denotes significance at the 10/5/1 percent level; the standard errors are reported in brackets. A constant is included in the estimation, but not reported here. Each state is summarised with the mean, as well as the standard deviation in brackets, of the interest rate and of each target variable. Method: Quasi ML estimation of a Markov switching process transformed with a vector of bias correction terms (Kim, 2003).

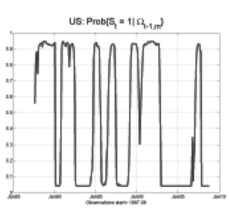
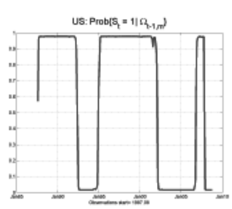
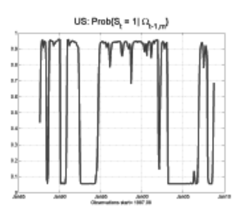
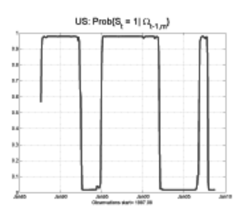
period	1987.08–2008.10		1987.08–2008.10	
explanatory variables	π_{t+1}, y_{t+1}, α^-_{t+3}, $\psi_{\alpha,t+1}$		π_{t+3}, y_{t+3}, α^-_{t+3}, $\psi_{\alpha,t+1}$	
nobs	255		255	
β_π	1.262*** (0.035)	0.979*** (0.042)	1.179*** (0.037)	1.107*** (0.042)
β_y	0.264*** (0.004)	0.215 (0.000)	0.231*** (0.008)	0.176 (0.216)
p_{11}	0.947** (0.431)	0.978* (0.551)	0.960* (0.503)	0.978* (0.552)
β_{1,α^-}	-0.020*** (0.003)		-0.026*** (0.004)	
β_{1,ψ_α}		-0.494 (0.000)		-0.172 (0.149)
$\bar{i}_1$	5.665 (2.965)	6.059 (3.680)	5.624 (2.893)	6.063 (3.735)
$\bar{\pi}_1$	3.276 (1.189)	3.238 (1.198)	3.077 (1.090)	3.239 (1.186)
$\bar{y}_1$	0.637 (3.796)	0.797 (3.473)	0.654 (3.410)	0.797 (3.487)
$\bar{\alpha}^-_1$	12.071 (18.554)	5.797 (13.821)	7.189 (15.211)	5.622 (13.994)
$\bar{\psi}_{\alpha,1}$	2.683 (0.421)	2.683 (0.438)	2.680 (0.521)	2.677 (0.433)
				
p_{00}	0.960* (0.490)	0.984 (0.783)	0.945* (0.550)	0.984 (0.786)
β_{0,α^-}	-0.097*** (0.009)		-0.077*** (0.014)	
β_{0,ψ_α}		-1.535 (0.000)		-1.145*** (0.152)
$\bar{i}_0$	3.690 (1.987)	2.717 (1.295)	3.380 (2.105)	2.647 (1.256)
$\bar{\pi}_0$	2.977 (1.027)	2.898 (0.885)	3.192 (0.962)	2.903 (0.893)
$\bar{y}_0$	-0.495 (1.618)	-0.735 (1.445)	-0.653 (1.652)	-0.795 (1.459)
$\bar{\alpha}^-_0$	6.202 (15.531)	10.613 (19.246)	5.424 (12.626)	11.211 (19.511)
$\bar{\psi}_{\alpha,0}$	2.541 (0.456)	2.523 (0.502)	2.406 (0.350)	2.541 (0.503)
$\overline{R}^2$	0.668	0.871	0.608	0.886
logL	-337	-301	-355	-289

Table 7: Taylor rule defined as in equation (20): $i_t = X_{t,n}A + x'_{t,n}\beta_{S_t} + (\Xi_{t,n} - (I_k \otimes z'_t\gamma))'\delta_{1,S_t} + \delta_{2,S_t}\omega_{2,t}$ with target variables $x_{t,n} = (\pi_{t+1}, y_{t+1}, \alpha^-_{t+3}, \psi_{\alpha,t+1})$ and $x_{t,n} = (\pi_{t+3}, y_{t+3}, \alpha^-_{t+3}, \psi_{\alpha,t+1})$. The processes can be summarised as in (12) . */**/*** denotes significance at the 10/5/1 percent level; the standard errors are reported in brackets. A constant is included in the estimation, but not reported here. Each state is summarised with the mean, as well as the standard deviation in brackets, of the interest rate and of each target variable. Method: Quasi ML estimation of a Markov switching process transformed with a vector of bias correction terms (Kim, 2003).

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