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Revealing the Preferences of the US Federal Reserve*

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Abstract

We use Bayesian methods to estimate the preferences of the US Federal Reserve by assuming that monetary policy is performed optimally under commitment since the mid-sixties. For this purpose, we distinguish between three subperiods, i.e. the pre-Volcker, the Volcker-Greenspan and the Greenspan period. The US economy is described by the Smets and Wouters (2007) model. We find that there has been a switch in the monetary policy regime since Volcker, with a focus on output growth instead of the output gap level as a target variable. We further show that both interest rate variability and interest rate smoothing are significant target variables, though less important than the inflation and output growth targets. We find that the "Great Moderation" of output growth is largely explained by the decrease in the volatility of the structural shocks. The Inflation Stabilization, however, is mainly due to the change in monetary policy that took place at the start of Volcker's mandate. During the Greenspan period, the optimal Taylor rule appears to be equally robust to parameter uncertainty as the unrestricted optimal commitment rule.

JEL classification: E42, E52, E58, E61, E65
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1 Introduction

Over the recent years, a considerable amount of researchers inside as well as outside the academic circle have been making efforts to reveal the true incentives of policy makers behind their actions in response to macroeconomic developments. The underlying assumption justifying this approach is that monetary policy follows a systematic strategy, driven by preferences concerning the achievement of certain goals. Without any doubt the announcement of explicit inflation targets by a number of central banks, together with the developments in the literature on this topic, has led to the viewpoint that the actions taken by monetary policy authorities can be placed in the context of either explicit (i.e. announced) or implicit inflation targeting. Looking at monetary policy from the perspective of inflation targeting as it is advocated by e.g. Svensson (1999), policy makers set their monetary policy instruments in order to achieve objectives, i.e. targets, for variables like inflation and output. The corresponding weights assigned to individual target variables depend on the personal value, i.e. the preferences, attached to the achievement of these targets by policy makers.

Hence, knowing the preferences of monetary policy makers not only makes it possible to understand the particular way in which interest rate policy is conducted, but also influences the formation of future expectations by private agents. Since expectations play an important role in the determination of macroeconomic variables, the added value of full information about monetary policy preferences is clear. Despite this, however, monetary policy makers are hardly transparent with respect to their preferences. Besides a clear price stability mandate, and in the case of an explicit inflation targeting regime the public announcement of a numerical inflation target, central banks are generally much less explicit with respect to other goals. This leaves room for uncertainty.

In this paper, we will infer monetary policy preferences for the US post-war monetary policy by using Bayesian methods to estimate the preference parameters along with structural parameters. For this purpose, we assume that the US Federal Reserve has been operating in an environment of (implicit) inflation targeting. The monetary policy strategy is assumed to be described by the minimization of an intertemporal quadratic function under commitment, with alternative arguments that are tested for their relevance in terms of empirical fit. Preferences with respect to objectives as well as their relative weights are subject to change according to the person in charge of monetary policy decisions. In a recent study, Cecchetti et al. (2007) suggest that changes in policy preferences are among the likely explanatory factors behind the scale, duration and end of the Great Inflation. In this respect, a growing dislike for high inflation and its negative consequences has shifted the priorities of policy makers towards a more pronounced inflation stabilization objective. This change in preferences in turn has speeded up the process of ending the Great Inflation period towards an era of low and stable inflation. Therefore, we consider three subsamples in order to distinguish the regimes followed in the period prior to the appointment of Paul Volcker as chairman from the mandate of Paul Volcker and the period during which Alan Greenspan was in charge of the Federal Reserve. The weights assigned to the individual target variables in the loss function are considered to reflect the policy preferences during each subsample. Therefore, we consider the intertemporal loss function as the appropriate measure of (changes in) monetary policy objectives, rather than an estimated reaction function. Although the latter describes monetary policy behaviour well, the variables entering the reaction function mainly play a role in providing monetary policy with information needed to achieve the policy objectives. These variables do not necessarily coincide with the target variables in the loss function and cannot be attributed directly to the monetary policy objectives (Svensson, 2002a, 2003 and Dennis, 2000, 2003 and 2006). The structural model used to represent the US economy is the one proposed by Smets and Wouters (2007), where we replace the empirical Taylor rule in the original set up by an intertemporal loss function for monetary policy.

For each period under consideration, we estimate the model with alternative specifications of the periodic loss function and select the one that gives the best empirical fit. Accordingly, we discuss changes in monetary policy regimes as described by changes in (i) the loss function specification, (ii) the estimated inflation target and (iii) the estimated monetary policy preference parameters. In addition, we perform a counterfactual exercise in order to assess the sources behind the Great Moderation of output growth and the Inflation Stabilization. We compare the performance of the optimal policy regimes to the benchmark of an estimated feedback rule for each subsample. We further investigate the effects of parameter uncertainty on the performance and robustness of the unrestricted optimal commitment rule, the optimal Taylor rule and the estimated Taylor rule for the Greenspan period. In addition, we discuss the forecast error variance decomposition of observable target variables for the same period.

This study differs in three dimensions from others in the literature. First, the majority of previous studies assume that monetary policy is performed under discretion. In this paper, we assume commitment as in Söderlind (1999) and Ilbas (2008) which not only provides a useful comparison with the previous results obtained under discretion, it is also a more realistic assumption for the period under Greenspan's mandate. Our approach differs from the one of

Salemi (2006) and Givens and Salemi (forthcoming) who consider the case of commitment to simple rule. The second difference lies in the methodology: while most similar studies adopt a standard three-equation New-Keynesian framework (e.g. Dennis, 2006, Ozlale, 2003, Favero and Rovelli, 2003 and Salemi, 2006), this paper describes the economy by a more extended and popular medium-scale macroeconomic model with richer dynamics that is estimated with Bayesian inference methods. Third, in this paper we allow for alternative specifications of the monetary policy loss function, which are evaluated for every subsample according to empirical fit. Hence, we allow for possible changes in monetary policy regimes with the change in the person in charge of the Federal Reserve[1].

This paper is organized as follows. In the next part we outline the theoretical framework adopted in this paper. We start from the Smets and Wouters (2007) model and describe the assumed structural behaviour of the private agents in the economy, followed by the introduction of alternative optimal monetary policy regimes. This leads to a set of Euler equations that can be estimated accordingly for three subsamples. The third part explains the data set and the methodology used in the estimation procedure, together with the assumed prior specifications for the structural and policy preference parameters. Part four provides a discussion of the results. A counterfactual exercise enables us to assess the extent to which the volatility decline of the structural shocks can explain the Great Moderation of output growth and the Inflation Stabilization. We compare across alternative optimal monetary policy regimes and test for each period separately the most successful regime against the benchmark case where monetary policy is characterized by an empirical Taylor rule. Furthermore, we look at the effects of parameter uncertainty on the performance of optimal rules and the benchmark empirical Taylor rule, followed by a forecast error variance decomposition for the Greenspan period. Finally, part five concludes.

2 Theoretical Framework

In this part we give a brief description of the structural model that describes the US economy, the Smets and Wouters (2007) model, and the assumptions made concerning monetary policy behaviour. Unlike the original set up in Smets and Wouters (2007), where monetary policy is described by an empirical Taylor rule, we will assume that monetary policy is performed optimally under commitment. This approach will allow us to estimate the preferences of monetary

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[1] Ozlale (2003) also allows for regime changes. Salemi (2006) allows for a regime change by allowing policy rule coefficients and the covariance matrix of shocks, but not the structural parameters, to change.

policy makers over the target variables. This will also enable us to bring monetary policy behaviour more in line with those of the private agents that are optimizing and rational (Svensson, 2002a). Moreover, as outlined in e.g. Svensson (2002a, 2003) and Dennis (2000, 2003 and 2006), estimating the policy preferences rather than the monetary policy reaction function is more suitable because describing monetary policy behaviour in terms of preferences yields more information about incentives underlying policy actions in response to economic developments. In the following, we outline the linearized Smets and Wouters (2007) model for the US economy and introduce the optimizing monetary policy authorities. The resulting model, that takes into account optimal monetary policy behaviour under commitment, can accordingly be estimated with US data.

2.1 The Smets and Wouters 2007 Model for the US economy

The US economy is described by the dynamic stochastic general equilibrium (DSGE) model developed by Smets and Wouters (2007). This model, which is based on Christiano, Eichenbaum and Evans (2005) and the US equivalent of the Smets and Wouters (2003) model for the euro area, is estimated by the authors using Bayesian estimation methods on US data for the period 1966:1-2004:4. Using seven observables and the same number of structural shocks, the model is shown to fit the US data well and is able to compete with Bayesian Vector Autoregression models in out-of-sample forecasting. Although not all empirically important to the same extent, the large set of nominal and real frictions appear to be necessary in capturing the dynamics in the US macro data. Furthermore, as opposed to the euro area (2003) version of the model, the introduction of a labour-augmenting technological progress leads to a deterministic growth rate, which makes detrending the data prior to estimation unnecessary[2]. Below we present the main features and equations of the DSGE model. The variables are linearized around their steady state balanced growth path . We employ the same notation as Smets and Wouters (2007) and indicate steady state values with a star. For a detailed description of the underlying microfoundations, we refer to Smets and Wouters (2007).

The model consists of a household sector that supplies a differentiated type of labour, which is sold to labour packers by an intermediate labour union. The labour packers resell labour to intermediate goods producers in a perfectly competitive market. The goods markets are characterized by intermediate and final goods producers. The former are monopolistically com-

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[2] Additional differences with the euro area (2003) version is that the time-varying inflation target and the labour supply shocks are absent and the Kimball (1995) aggregator is adopted in the goods and labour market, instead of the Dixit-Stiglitz aggregator, in the current version for the US.

petitive, produce intermediate goods and sell these to the perfectly competitive final goods firms who package them into one final good and resell it to the households for consumption and investment.

Households' utility function, which is non-separable and has two arguments, i.e. goods and hours worked, is maximized over the infinite horizon and leads to the following consumption Euler equation:

$$c_t = c_1 c_{t-1} + (1 - c_1) E_t c_{t+1} + c_2 (l_t - E_t l_{t+1}) - c_3 (r_t - E_t \pi_{t+1} + \varepsilon_t^b) \tag{1}$$

where

$$c_1 = \frac{\lambda/\gamma}{1 + \lambda/\gamma}, c_2 = \frac{(\sigma_c - 1)(W_*^h L_*/C_*)}{\sigma_c (1 + \lambda/\gamma)} \text{ and } c_3 = \frac{1 - \lambda/\gamma}{\sigma_c (1 + \lambda/\gamma)}$$

with γ the steady state growth rate and σ_c the intertemporal elasticity of substitution. Consumption c_t is expressed with respect to an external habit variable, which is time-varying and introduces the lagged term in the consumption equation through a nonzero habit parameter λ. Consumption depends also on $(l_t - E_t l_{t+1})$, the expected increase in hours worked, and negatively on the ex ante real interest rate $(r_t - E_t \pi_{t+1})$. The disturbance term ε_t^b, which follows an AR(1) process with i.i.d. normal error term $(\varepsilon_t^b = \rho_b \varepsilon_{t-1}^b + \eta_t^b)$, is assumed to capture the difference between the interest rate set by the central bank and the required return on assets owned by households. In addition, this shock also reflects changes in the cost of capital, which has a similar interpretation as a shock to the net worth of Bernanke, Gertler and Gilchrist (1999), i.e. shock to risk premium.

The labour market is monopolistically competitive and households supply a differentiated type of labour. This allows them to set wages that are subject to labour demand by firms and nominal rigidities as in Calvo (1983). Hence the following equation for the real wage w:

$$w_t = w_1 w_{t-1} + (1 - w_1)(E_t w_{t+1} + E_t \pi_{t+1}) - w_2 \pi_t + w_3 \pi_{t-1} - w_4 \mu_t^w + \varepsilon_t^w \tag{2}$$

where

$$w_1 = \frac{1}{1 + \beta\gamma^{1-\sigma_c}}, w_2 = \frac{1 + \beta\gamma^{1-\sigma_c}\iota_w}{1 + \beta\gamma^{1-\sigma_c}}, w_3 = \frac{\iota_w}{1 + \beta\gamma^{1-\sigma_c}} \text{ and } w_4 = \frac{(1 - \beta\gamma^{1-\sigma_c}\xi_w)(1 - \xi_w)}{(1 + \beta\gamma^{1-\sigma_c})\xi_w((\phi_w - 1)\varepsilon_w + 1)}$$

with β the households' discount factor and ξ_w the probability that wages cannot be re-optimized, i.e. the degree of wage stickiness. Households that are not able to re-optimize their wages in a particular period index their wages partially (with a degree of wage indexation ι_w) to the past inflation rate, which introduces dependence of wages on previous period's inflation rate in equation (2). The symbol ε_w is the curvature of the Kimball labour market aggregator and

$(\phi_w - 1)$ the constant mark-up in the labour market. The wage mark-up is the difference between the real wage and the marginal rate of substitution between consumption and labour:

$$\mu_t^w = w_t - mrs_t = w_t - (\sigma_l l_t + \frac{1}{1-\lambda}(c_t - \lambda c_{t-1})) \tag{3}$$

with σ_l the elasticity of labour supply with respect to the real wage. The final term in (2), ε_t^w, is a shock to the wage mark-up that is assumed to follow an ARMA(1,1) process $\varepsilon_t^w = \rho_w \varepsilon_{t-1}^w + \eta_t^w - \mu_w \eta_{t-1}^w$ with η_t^w an i.i.d. normal error. Households own capital and make capital accumulation decisions by taking into account the adjustment costs in capital. The utilization rate of capital is variable and can be increased by incurring capital utilization costs. Firms make use of capital and rent the capital services from the housholds at a rental price. The investment Euler equation (4), characterized by adjustment costs that depend on the change in investment in order to capture the hump-shaped effect of shocks on investments, is described as follows:

$$i_t = i_1 i_{t-1} + (1 - i_1) E_t i_{t+1} + i_2 q_t + \varepsilon_t^i \tag{4}$$

where

$$i_1 = \frac{1}{1 + \beta\gamma^{1-\sigma_c}}, i_2 = \frac{1}{(1 + \beta\gamma^{1-\sigma_c})\gamma^2\varphi}$$

with φ the elasticity of the capital adjustment cost function in the steady state, q_t the real value of the current capital stock and $\varepsilon_t^i = \rho_i \varepsilon_{t-1}^i + \eta_t^i$ an AR(1) shock to the investment specific technology with i.i.d. error term. The real value of capital (q_t) is represented by:

$$q_t = q_1 E_t q_{t+1} + (1 - q_1) E_t r_{t+1}^k - (r_t - E_t \pi_{t+1} + \varepsilon_t^b) \tag{5}$$

where

$$q_1 = \beta\gamma^{-\sigma_c}(1 - \delta) = \frac{(1 - \delta)}{R_*^k + (1 - \delta)}$$

with δ the depreciation rate of capital and R_*^k the steady state rental rate of capital. Equation (5) depends positively on the expected future (real) rental rate of capital (r_t^k) and negatively on the ex ante real interest rate and shocks to the risk premium. Capital services that are currently used in production (k_t^s) depend on previously installed capital due to the fact that newly installed capital becomes effective only with a lag of one period:

$$k_t^s = k_{t-1} + z_t \tag{6}$$

with z_t the utilization rate of capital, which depends positively on the rental rate of capital:

$$z_t = z_1 r_t^k \tag{7}$$

where

$$z_1 = \frac{1-\psi}{\psi}$$

with ψ normalized between zero and one, a positive function of the elasticity of the capital utilization adjustment cost function. The capital accumulation equation fulfills:

$$k_t = k_1 k_{t-1} + (1-k_1) i_t + k_2 \varepsilon_t^i \tag{8}$$

where

$$k_1 = \frac{(1-\delta)}{\gamma} \text{ and } k_2 = (1-(1-\delta)/\gamma)(1+\beta\gamma^{1-\sigma_c})\gamma^2\varphi$$

As in the case of wage setting by housholds, the intermediate goods producers, which are monopolistically competitive, set their prices in line with Calvo (1983). Firms that are not able to re-optimize adjust their price partially to past inflation with a degree ι_p. This leads to the following New-Keynesian Phillips curve:

$$\pi_t = \pi_1 \pi_{t-1} + (1-\pi_1) E_t \pi_{t+1} - \pi_2 \mu_t^p + \varepsilon_t^p \tag{9}$$

where

$$\pi_1 = \frac{\beta\gamma^{1-\sigma_c}\iota_p}{1+\beta\gamma^{1-\sigma_c}\iota_p} \text{ and } \pi_2 = \frac{(1-\beta\gamma^{1-\sigma_c}\xi_p)(1-\xi_p)}{(1+\beta\gamma^{1-\sigma_c}\iota_p)\xi_p((\phi_p-1)\varepsilon_p+1)}$$

and ξ_p the probability that prices cannot be optimized, i.e. the degree of price stickiness in the goods market, ε_p the curvature of the Kimball aggregator and $(\phi_p - 1)$ the constant mark-up in the goods market. Inflation (π_t) also depends negatively on the price mark-up, μ_t^p, which is the difference between the marginal product of labour and the marginal cost of labour (i.e. the real wage):

$$\mu_t^p = mpl_t - w_t = \alpha(k_t^s - l_t) + \varepsilon_t^a - w_t \tag{10}$$

The price mark-up shock is assumed to follow an ARMA(1,1) process $\varepsilon_t^p = \rho_p \varepsilon_{t-1}^p + \eta_t^p - \mu_p \eta_{t-1}^p$ with η_t^p an i.i.d. normal error. The total factor productivity $\varepsilon_t^a = \rho_a \varepsilon_{t-1}^a + \eta_t^a$ with an i.i.d. normal error term affects the marginal product of labour positively. The cost minimization condition of the firms implies that the rental rate of capital (r_t^k) depends negatively on the capital-labour ratio and positively on the real wage:

$$r_t^k = -(k_t - l_t) + w_t \tag{11}$$

Finally, the goods market equilibrium condition is represented by the following expression, where aggregate output (y_t) equals aggregate demand (first line) and aggregate supply (second line):

$$\begin{aligned} y_t &= c_y c_t + i_y i_t + z_y z_t + g_y \varepsilon_t^g \\ &= \phi_p(\alpha k_t^s + (1-\alpha) l_t + \varepsilon_t^a) \end{aligned} \tag{12}$$

where $z_y = R^k_* k_y$, $c_y = 1 - g_y - i_y$ the steady state share of consumption in output, $i_y = (\gamma - 1 + \delta)k_y$ the steady state share of investment in output, k_y the steady state share of capital in output and g_y the ratio of exogenous spending over output. Exogenous spending $\varepsilon^g_t = \rho_g \varepsilon^g_{t-1} + \eta^g_t + \rho_{ga}\eta^a_t$ follows an AR(1) process and includes an additional total factor productivity shock which is i.i.d. ϕ_p is equal to one plus the share of fixed costs in production and α is the share of capital in production.

Monetary policy is optimal and is introduced in the next section, where we consider alternative monetary policy regimes. Hence, our approach towards modeling monetary policy differs from the original Smets and Wouters (2007) specification, where monetary policy is described by the following empirical feedback rule:

$$r_t = \rho r_{t-1} + (1-\rho)\left\{r_\pi \pi_t + r_y(y_t - y^p_t)\right\} + r_{\Delta y}[(y_t - y^p_t) - (y_{t-1} - y^p_{t-1})] + \varepsilon^r_t \qquad (13)$$

where ρ is the persistence parameter and $\varepsilon^r_t = \rho_R \varepsilon^r_{t-1} + \eta^r_t$ an AR(1) monetary policy shock with i.i.d. normal error term. In addition to inflation and the model-consistent output gap[3], monetary policy in (13) also reacts to the one-period difference in the output gap. As discussed earlier, in order to infer the objectives underlying monetary policy actions, we are mainly interested in the arguments entering policy's loss function and their relative weights rather than an empirical feedback rule of the type (13).

2.2 Monetary Policy Regimes

Monetary policy is assumed to minimize the following type of intertemporal quadratic social loss function, which is commonly adopted in the literature:

$$E_t \sum_{i=0}^{\infty} \zeta^i [Y'_{t+i} W Y_{t+i}], \qquad 0 < \varsigma < 1 \qquad (14)$$

where ς is the discount factor and E_t the expectations operator conditional on information available at time t. The vector $Y_t = [x'_t \;\; r'_t]'$ contains the $n \times 1$ endogenous variables and AR(1) exogenous variables in the model included in x_t and the $p \times 1$ vector of control variables which is a scalar in our case, i.e. the interest rate r_t. W is a time-invariant symmetric, positive semi-definite matrix of policy weights, which reflects the monetary policy preferences of the Central Bank over the target variables.

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[3] The model-consistent output gap is the deviation of actual output from potential output. The latter is defined as the output level that would prevail under total nominal wage and price flexibility and in the absence of the price and wage mark-up shocks.

In formulating the one-period ad hoc loss function for (14), we will consider alternative specifications that are proposed in the literature. The most common specification is one where inflation and output gap stabilization are the only objectives, i.e. flexible inflation targeting as advocated by Svensson (2002b). However, in many monetary policy evaluation applications an additional interest rate variability and/or interest rate smoothing objective is often considered. The constraints implied by the lower bound on the interest rates is captured by an interest rate variability objective (Woodford, 1999). The interest rate smoothing component is adopted to capture the observed inertial behaviour in the interest rates. Although monetary policy gradualism in the form of an explicit preference for interest rate smoothing is a plausible explanation for the observed persistence in the instrument rate, it is difficult to justify from a more theoretical perspective. The ongoing debate in the literature has resulted in alternative explanations for the possible sources of this observed persistence. For example, one could attribute the inertial character of the interest rate to persistence in the macroeconomic variables (inflation and output) that monetary policy reacts to, or to other persistent variables that are omitted from the empirical Taylor rule. This explanation does not relate inertia to an underlying smoothing objective. Rudebusch (2006) relies on term structure evidence and claims that the "the actual amount of policy inertia is quite low". Sack and Wieland (1999) point out three alternative explanations for why interest rate inertia might occur in the case where output gap and inflation are the only objectives of monetary policy, i.e. the presence of forward-looking expectations, data uncertainty and parameter uncertainty. In the estimation exercises performed below, however, we will allow for the possibility of interest rate variability and/or interest rate smoothing as separate monetary policy objectives. Accordingly, we will let the data decide which specification is favoured most. We also allow for an alternative way of introducing persistence by considering changes in the output gap as a separate objective, i.e. a speed limit policy strategy. Walsh (2003) shows that following a speed limit policy reduces the social costs of discretionary monetary policy with respect to the socially optimal commitment strategy, due to the introduction of additional persistence in macroeconomic variables that would otherwise be absent in a discretionary set up. The reason why we consider this case is that a speed limit policy might be more interesting than a standard flexible inflation targeting regime because the former is based on the growth in potential output and therefore less sensitive to measurement erros than a policy based on the level of the output gap (Orphanides et al., 2000). We further examine an Inflation Differential targeting regime, where changes in the inflation rate are targeted, rather than deviation of inflation from the target level. Finally, the presence of nominal wage rigidities makes it interesting to investigate the case where monetary policy targets nominal wage inflation. Erceg et al. (1998, 1999) and Woodford (2003) present a dynamic general equilibrium model featuring staggered wage and price setting and show that rigidities in these both markets at the same time make the Pareto optimal equilibrium unattainable for monetary policy. Moreover, Levin et al. (2005) show that a monetary policy rule with only a nominal wage inflation argument approaches the household's welfare outcome of optimal commitment policy relatively well. Table 1 summarizes the alternative monetary policy regimes considered, described by the type of the one-period loss function for (14)[4]. In all cases, the weight assigned to inflation in the loss function is normalized to one, which is common practice in the literature[5]. Hence, the weights corresponding to the remaining target variables are to be interpreted as relative weights with respect to the inflation target variable.

[Insert Table 1]

The Central Bank minimizes the intertemporal loss function (14), with the periodic loss function respectively given by one of the specifications outlined in Table 1, under commitment subject to the structural equations of the economy (1) - (12) augmented by their flexible price versions. The structural equations are written and represented by the following second order form:

$$Ax_t = BE_t x_{t+1} + Fx_{t-1} + Gr_t + De_t, \qquad e_t \sim iid[0, \Sigma_{ee}] \tag{15}$$

with e_t an $n \times 1$ vector of stochastic innovations to the variables in x_t, having mean zero and variance-covariance matrix Σ_{ee}.

We follow the optimization routine for commitment suggested by Dennis (2007) where, in contrast to e.g. Söderlind (1999), no classification of the variables in a predetermined and a non-predetermined block is needed. We further partition the matrix of weights W in (14) as follows:

$$E_t \sum_{i=0}^{\infty} \zeta^i [x'_{t+i} Q x_{t+i} + r'_{t+i} \Theta r_{t+i}], \qquad 0 < \zeta < 1 \tag{16}$$

where we express the loss function in terms of the variables x_t and r_t. The Euler equations of the monetary policy optimization problem can be represented as follows:

$$A1^* \Upsilon_t = B1^* E_t \Upsilon_{t+1} + C1^* \Upsilon_{t-1} + D1^* e_t \tag{17}$$

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[4] Note that we generalize the term "Flexible Inflation Targeting" here by considering the broad case of not only the output gap target in addition to inflation relative to target, but also interest rate variability and interest rate smoothing. In general, however, with the terminology "flexible" inflation targeting one has in mind only the output gap in addition to inflation entering the loss function.

[5] See, for example, Rotemberg and Woodford (1998), Rudebusch and Svensson (1998), Dennis (2003) and Woodford (2003).

with:

$$\begin{aligned}
A1^* &= \begin{bmatrix} Q & 0 & A' \\ 0 & \Theta & -G' \\ A & -G & 0 \end{bmatrix} \qquad B1^* = \begin{bmatrix} 0 & 0 & \zeta F' \\ 0 & 0 & 0 \\ B & 0 & 0 \end{bmatrix} \qquad (18) \\
C1^* &= \begin{bmatrix} 0 & 0 & \frac{1}{\zeta}B' \\ 0 & 0 & 0 \\ F & 0 & 0 \end{bmatrix} \qquad D1^* = \begin{bmatrix} 0 \\ 0 \\ D \end{bmatrix} \\
\text{and } \Upsilon_t &= \begin{bmatrix} x_t \\ r_t \\ \omega_t \end{bmatrix} = \begin{bmatrix} Y_t \\ \omega_t \end{bmatrix}
\end{aligned}$$

The final term in Υ_t, ω_t, represents the vector of Lagrange multipliers. The economy's law of motion (15) reappears in the last line of the system of Euler equations (18). The structural representation is augmented by the set of first order conditions with respect to x_t and r_t, through which the (leads and lags of the) Lagrange multipliers ω_t enter into the system and the matrices $A1^*, B1^*, C1^*$ have dimension $(2n+p)\times(2n+p)$[6]. In the next part, the Euler equations resulting from the optimization procedure outlined above, i.e. the system (17), is estimated using Bayesian inference methods.

3 Estimation

In this part we discuss the dataset used and the methodology followed in estimating the system (17), which yields joint estimates for the structural and the monetary policy preference parameters. Next, we describe the prior assumptions about these parameters adopted in the estimation procedure.

3.1 Data and Methodology

In analogy with Smets and Wouters (2007), we use a quarterly dataset containing the following seven observables: log difference of the real GDP (*dlGDP*), real consumption (*dlCONS*), real investment (*dlINV*) and real wage (*dlWAG*), log of hours worked (*lHOURS*), log difference of the GDP deflator (*dlP*) and the federal funds rate (*FEDFUNDS*). The details concerning the dataset are described in the Data Appendix. The datasample ranges over the period (1966:1-2005:4), which is split into three subperiods in the estimation exercises, in order to capture changes in the monetary policy preferences and targets over time since the mid-sixties. Following Dennis (2006), we split the entire sample as follows: the period prior to Volcker's appointment as chairman of

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[6] See Juillard and Pelgrin (2007) for a more detailed illustration of the state space expansion and the inclusion of the leads and lags of the Lagrange multipliers.

the Fed, i.e. the Pre-Volcker period (1966:1-1979:3), which is characterized by high inflation and accommodative monetary policy[7], the Volcker-Greenspan period (1983:1-2005:4) covering the period of both chairmen but, as in Dennis (2006), excluding the beginning of the eighties characterized by non-borrowed reserves targeting[8] and finally the period covering Greenspan's appointment as chairman only, i.e. (1987:3-2005:4). The reason why Volcker's period is not studied separately is due to the short sample corresponding to Volcker's appointment. Hence, following Dennis (2006), we combine the latter period with the period covering Greenspan and attribute differences in results with those over the last subsample (the Greenspan period) to the particular regime under Volcker's appointment.

All estimations are initialized using a presample period of 20 quarters (i.e. 5 years), which corresponds to the period (1961:1-1965:4), (1978:1-1982:4) and (1982:3-1987:2) for the first, second and third subsample, respectively. Due to the assumption of commitment in the optimization procedure, we are dealing with a time-inconsistent policy that is reflected by the fact that the initial values of the Lagrange multipliers in (17) are set to zero. However, Ilbas (2008) shows that the estimation results under commitment are in line with those under the timeless perspective when a presample is used that is long enough and serves as a transition period after the initial period of the optimization. Hence, after this transition and at the start of the estimation period, some time has passed after the introduction of the commitment policy and the effects of the initial period have become negligable, allowing us to interpret the results as if we were operating under optimal policy form a timeless perspective.

The set of structural equations (1) - (12) characterizes six structural shocks (ε_t^b, ε_t^w, ε_t^i, ε_t^p, ε_t^a, ε_t^g), which contains one shock less than the original Smets and Wouters (2007) model because the generalized Taylor rule (and the corresponding monetary policy shock ε_t^r) is absent from the system (17). Hence, in order to avoid stochastic singularity due to the fact that we are dealing with seven observables, we introduce an AR(1) shock with an i.i.d. error term $\varepsilon_t^m = \rho_m \varepsilon_{t-1}^m + \eta_t^m$, where $\sigma_m > 0$, to the equation corresponding to the first order condition of the policy instrument r_t in (17). This shock can be regarded as a "monetary policy shock", capturing the elements that monetary policy reacts on, which are not modeled explicitly[9].

We apply Bayesian estimation techniques in order to estimate the system (17), which includes the structural parameters and the monetary policy preference parameters of the alternative

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[7] This period also coincides with the first subsample considered by Smets and Wouters (2007), i.e. the Great Inflation period.

[8] This period, however, will serve as a presample, as explained next in more detail.

[9] These could be, for example, financial market considerations.

regimes outlined in Table 1[10]. After solving for the linear rational expectations solution of the model in (17), we derive the following state transition equation:

$$\Upsilon_t = \Gamma_\Upsilon \Upsilon_{t-1} + \Gamma_e e_t \tag{19}$$

with the following measurement equation that links the state variables Υ_t to the vector of observables Ω_t as follows:

$$\Omega_t = \begin{bmatrix} dlGDP_t \\ dlCONS_t \\ dlINV_t \\ dlWAG_t \\ lHOURS_t \\ dlP_t \\ FEDFUNDS_t \end{bmatrix} = \begin{bmatrix} \bar{\gamma} \\ \bar{\gamma} \\ \bar{\gamma} \\ \bar{\gamma} \\ \bar{l} \\ \bar{\pi} \\ \bar{r} \end{bmatrix} + \begin{bmatrix} y_t - y_{t-1} \\ c_t - c_{t-1} \\ i_t - i_{t-1} \\ w_t - w_{t-1} \\ l_t \\ \pi_t \\ r_t \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ \eta_t^{fed} \end{bmatrix} \tag{20}$$

where η_t^{fed} is an i.i.d. measurement error added to the federal funds rate in order to take account for mismeasurement in the observed series of the nominal interest rate due to potential model misspecification. Since we assume monetary policy to be optimal, this will have implications mostly reflected in the interest rate in case this assumption turns out to be too strong. In order to take into account the discrepancy between the implied optimal rule and the actual interest rate in a particular period, this measurement error will capture the part that cannot be explained by the model. The observed quarterly growth rates in the real GDP, real consumption, real investment and real wages are split into a common trend growth, $\bar{\gamma} = (\gamma - 1)100$, and a cycle growth. Hours worked in the steady state $(\bar{l})$ is normalized to zero. $\bar{\pi} = (\Pi_* - 1)100$ is the quarterly steady state inflation rate, which will be considered as the inflation target in the estimations. Hence, we estimate the inflation target corresponding to the alternative regimes and compare them along the different sample periods. Finally, $\bar{r} = (\frac{\gamma^{\sigma_c}\Pi_*}{\beta} - 1)100$ is the steady state nominal interest rate.

We use the Kalman filter to calculate the likelihood function and derive the posterior density distribution by combining the prior distribution with the likelihood function. We proceed until the parameters that maximize the posterior distribution are found, i.e. until convergence around the mode is achieved. After maximizing the posterior mode, we use the Metropolis-Hastings algorithm for selected specifications of monetary policy's loss function[11] to generate

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[10] For a detailed discussion on Bayesian estimation of DSGE models, we refer to Smets and Wouters (2003-2007), Schorfheide (2006) and An and Schorfheide (2007).

[11] Due to high computational costs and spatial limitations in reporting the results, we restrict the application of the Metropolis-Hastings algorithm only for selected cases that turn out to be most interesting. Moreover, the Laplace approximation usually approaches the Modified Harmonic Mean and can be considered as a reliable approximation for the marginal likelihood for the purpose of comparing alternative model specifications.

draws from the posterior distribution in order to approximate the moments of the distribution and calculate the modified harmonic mean[12]. In discussing the estimation results, however, we will focus mainly on the maximized posterior mode, the Hessian-based standard errors and the corresponding Laplace approximation for the marginal likelihood.

3.2 Prior Specifications

Before discussing the estimation results, we report the assumptions made about the prior distributions of the parameters. We use the same priors for those parameters that correspond to the parameters in the original Smets and Wouters (2007) model. Therefore, we fix the following five parameters. The annual depreciation rate on capital is assumed to be 10 percent, i.e. $\delta = 0.025$. The ratio of exogenous spending to GDP, g_y, is fixed at the value of 0.18. Due to identification issues, the mark-up in the labour market in the steady state (λ_w) is calibrated to be 1.5 and the curvature of the Kimball aggregator in both goods and labour markets (ε_p and ε_w) are set to 10. In addition, we fix the monetary policy discount factor ς in (14) to 0.99. Table 2 reports the prior assumptions for the remaining parameters.

[Insert Table 2]

As the table shows, the standard errors of the seven error terms and the interest rate measurement error are assumed to have an inverted gamma distribution with 2 degrees of freedom and a mean of 0.10. The AR(1) coefficients of six out of seven shock processes and the MA coefficients (in the price and wage mark-up and the exogenous spending shock) are assumed to have a beta distribution with a prior mean of 0.5 and a prior standard error of 0.2 The AR(1) coefficient of the monetary policy shock is assumed to be normally distributed with a mean of 0 and standard error equal to 2. Since this shock is assumed to capture the effect on monetary policy of all omitted variables in the model and we have very limited prior information about them, we opt for a rather loose prior. Therefore, although we expect this shock not to be autocorrelated, we do not impose it and allow for the possibility of (high) autocorrelation . The quarterly trend growth rate is assumed to have a normal distribution with mean 0.4% and standard error 0.1. Inflation in the steady state is assumed to be gamma distributed with a quarterly mean of 0.62% and standard error of 0.1, which corresponds to an average yearly steady state inflation of 2.5%. The discount rate follows a gamma distribution with mean 0.25 and standard error 0.1.

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[12] Estimations are performed using Michel Juillard's software dynare, which can be downloaded from the website *www.dsge.net.*

The intertemporal elasticity of substitution is normally distributed with mean 1.5 and standard error 0.37. The degree of habit persistence is beta distributed with a mean of 0.7 and standard error 0.1. The labour supply elasticity is normally distributed around 2 with standard error 0.75. The elasticity of the capital adjustment cost function in the steady state is normally distributed with mean 4 and standard error 1.5 and the elasticity parameter of capital utilization is assumed to have a beta distribution with a mean of 0.5 and standard error 0.15. The fixed costs' share is assigned a prior mean of 0.25. The Calvo probabilities of both wages and prices are beta distributed with prior mean 0.5 and standard error 0.1. The indexation parameters in the goods and wage equations are assumed to have a beta distribution with mean 0.5 and standard error 0.15. The share of capital in production is normally distributed with mean 0.3 and standard error 0.05.

The monetary policy preference parameters ($q_{yl}, q_{yd}, q_{rl}, q_{rd}$ and q_w), which are estimated together with the structural parameters, are assumed to be normally distributed with 0.5 prior mean and 4 prior standard error. Since we adopt the same prior specifications for all the weights and across the alternative specifications, we specify a loose prior to allow for flexibility. This also enables us to take into account the uncertainty faced concerning plausible values due to competing values proposed in the literature and theoretical objections against nonzero values for q_{rl} and q_{rd}.

4 Results

In this part we discuss the results obtained from maximization of the posterior density for the structural and the monetary policy preference parameters. We first compare across the alternative optimal monetary policy regimes proposed in the previous part, in order to infer which regime provides the best fit to the data for each subsample. Accordingly, we assess the sources behind the Great Moderation of output growth and the Inflation Stabilization. We compare the best performing optimal regime for the respective samples to the benchmark case where monetary policy is represented by an empirical feedback rule. We also investigate the effects of parameter uncertainty on the performance of optimal rules against the benchmark for the Greenspan period. This part is concluded with a section on the forecast error variance decomposition of observed target variables for the best performing optimal monetary policy regime.

4.1 Comparison Across Optimal Regimes

The results for the posterior distribution (posterior mode and standard deviation) of the structural and monetary policy preference parameters are reported in Tables 3, 4 and 5, together with their corresponding marginal likelihood (Laplace approximation), for each of the three subsamples and the four alternative monetary policy regimes.

[Insert Tables 3, 4 and 5]

Based on the comparison of the Laplace approximation of the marginal likelihood, the best fit is provided by the Flexible Inflation Targeting (FIT) framework for the Pre-Volcker period and the Speed Limit Targeting (SLT) regime for both the Volcker-Greenspan and the Greenspan periods. This suggests that before Volcker took office, inflation, output gap, interest rate variability and interest rate smoothing were on average important target variables. During the period that both Volcker and Greenspan were chairmen, inflation remained important. But additionally, the difference in the output gap, interest rate variability and the difference in the interest rate were important target variables. Wage inflation does not appear to have been an important target variable in any of the subsamples, despite the theoretical arguments for wage inflation targeting. This is especially the case for the pre-Volcker period, where the loss function including a wage inflation target clearly worsens the marginal likelihood. In both the Volcker-Greenspan and the Greenspan sample, the Flexible Inflation Targeting Regime performs worst in terms of fit. Due to the fact that the only difference between the latter and the best performing specification, i.e. Speed Limit Targeting, is the way the output gap is defined (in the level rather than the first difference), the output gap difference turns out to be a significant target variable in these two periods[13]. This finding supports the argument that the policy reform introduced by Volcker in 1979 relied much less on gap analysis and increased focus on changes in the output gap since the latter is less sensitive to measurement errors and therefore avoids policy mistakes (Lindsey et al., 2005 and Orphanides et al., 2000). Based on the overall results, it seems that generally there has not been a significant difference in the regimes followed by Volcker and Greenspan. This suggests that the policy approach introduced by Volcker has been adopted by Greenspan as well. It is worthwhile to mention that we tested for the individual importance of the interest rate variability and interest rate smoothing targets for each subsample. In all cases and for each subsample, the absence of either the interest rate variability or the interest

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[13] In the estimation exercises, we also estimated the case of a loss function containing the output gap level together with the output gap growth, in order to test whether the cases are nested. In none of the subsamples, however, does the marginal likelihood improve when both components appear in the same loss function.

rate smoothing term (or both), reduces the marginal likelihood drastically. Therefore, both are considered as significant target variables. Hence, given the assumption that monetary policy has been committed to minimizing one of the specified loss functions, the variability of the interest rate combined with interest rate smoothing have been important objectives for monetary policy throughout the full sample period under consideration (1966-2005).

Before we discuss the details concerning the results for the parameters related to monetary policy, we look at changes in the estimates of the structural parameters and the shock processes over time. As we move from the FIT-regime during the Pre-Volcker period towards the SLT-regime under the Volcker and the Greenspan mandates, the structural parameters, with the exception of a few parameters we will discuss next, do not differ a lot across the three subsamples. This subsample stability indicates that the underlying structural model is stable. When we look at changes between the Pre-Volcker and the Volcker-Greenspan subsample, there is a considerable increase in the degree of price stickiness from 0.5 in the first subsample to 0.72 in the second subsample. At the same time, the degree of indexation to past prices in the goods markets decreases from 0.36 to 0.18. Finally, the volatility of the productivity shock decreases from 0.6 to 0.38. These changes are qualitatively in line with the ones reported by Smets and Wouters (2007) for their "Great Inflation" and "Great Moderation" subsamples.

There is a sign of increased real rigidities in going from the Volcker-Greenspan to the Greenspan subsample. The elasticity of adjusting capital (φ) decreases from 6.34 to 5.38. The intertemporal elasticity of substitution (σ_c) decreases from 1.52 to 1.32 and, finally, the constant labour parameter becomes negative from 1.1 to -0.01.

Table 6 summarizes the estimates for the policy preferences (posterior mode) and the implied inflation target (posterior mode) for the best performing monetary policy model for each one of the subsamples, respectively. In addition, the table reports the model-consistent variance of output growth, inflation, interest rate and the output gap[14].

[Insert Table 6]

Under the Flexible Inflation Targeting regime during the pre-Volcker period, interest rate variability appears with the highest weight in the loss function after inflation, followed by the output gap and the interest rate difference. The estimated annualized implicit inflation target is 2.44%, which is surprisingly lower than we would expect a priori and not much higher than

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[14] These variances are based on quarterly smoothed series of the corresponding variables. Hence, comparison with the results reported in the literature considering yearly data is not appropriate. In order to make these results comparable, the results should be converted into yearly frequency.

the values estimated for the other subsamples. Since the period after the appointment of Volcker is typically considered as the start of the process of Inflation Stabilization and "the Great Moderation" of output growth, i.e. a period characterized by low and stable inflation together with low volatilities in inflation and output growth (Cecchetti et al., 2007), the estimate for the inflation target under the pre-Volcker period is relatively inconsistent with reality[15]. More realistic estimates are obtained under the Volcker-Greenspan and the Greenspan periods, with values of 2.08% and 2.28%, respectively. Dennis (2003) estimates an implicit inflation target similar to those obtained under the Volcker-Greenspan (2.43%) and Greenspan periods (2.38%) in the context of a business cycle model with forward-looking agents. However, comparison of our results to those obtained by Dennis (2003) requires prudence, due to the fact that the theoretical output gap concept used in this study differs from the one in Dennis (2003). The latter describes the output gap as the deviation of output from a linear trend and, in addition, assumes discretionary monetary policy and a different loss function, which is kept constant over the subsamples. Despite these differences, the estimates of the implicit inflation targets are relatively similar, except for the pre-Volcker period, where Dennis (2003) finds a value equal to 5.92%, contrary to 2.44% in our case.

The difference between the regime prior to the appointment of Volcker as chairman and after his arrival, i.e. the Volcker-Greenspan period, is defined by the fact that the difference in the output gap instead of the level of the output gap becomes a target variable in the second subsample. After the appointment of Volcker monetary policy appears to have been concerned to a great extent about the output gap difference, which is equivalent to the deviation of output growth from the constant growth trend. This has continued after Greenspan took office. The weight assigned to this growth rate is the highest, after that for inflation, in the Volcker-Greenspan period. At the same time, there is a decrease in the implied variance of output growth with respect to the pre-Volcker period: from 1 to 0.42 during the Volcker-Greenspan period and 0.44 during the Greenspan period. Hence, the estimated increase in the weight assigned to this variable indicates that the importance of output growth stabilization in the loss function has increased over time. These findings of an important role attached to output volatility in the loss function are, although theoretically justifiable within the flexible inflation targeting literature, somewhat contrary to what is usually reported in the empirical literature. For example, Dennis (2006) does

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[15] This result, however, compares to the estimate of Smets and Wouters (2007). They also find a low annualized target rate of 2.9% for a sample period (what they call the "Great Inflation" period) that corresponds to our Pre-Volcker subsample. This is due to the fact that we, following Smets and Wouters (2007), adopt a rather strict prior for the inflation target in order to take into account the identification problem faced for this parameter.

not find any statistically significant role for output in any of the three subsamples considered in the context of a backward-looking Rudebusch-Svensson model. Similarly, Salemi (2006) and Givens and Salemi (forthcoming) estimate a close to zero and insignificant weight on the output gap in the context of a forward-looking model. Favero and Rovelli (2003) estimate a weight on output close to zero, however relevant, in the context of a backward-looking model. Similar to our results, Ozlale (2003) and Söderlind (1999) find values above zero for the output component. However, as previously mentioned, comparison with results in the literature is not straightforward because we adopt a different output gap concept. Moreover, our (Bayesian) estimation method differs from those studies mentioned. We also adopt a richer macroeconomic framework that features an extended amount of nominal and real frictions and structural shocks. Despite these differences with related literature on the estimation of monetary policy preferences, the finding of an important role for output in the loss function supports the argument of Svensson (1999, 2002b), who claims that a gradual monetary policy where some weight should be assigned to stabilizing the output gap is more desirable. Moreover, it is a more realistic description of current practice by modern central banks and consistent with the dual mandate of the US Federal Reserve. It is also worth to mention that the increasing concern for output growth in the loss function in the Greenspan era compared to the period under Volcker's mandate, is not in contrast with the (nearly unchanged) low inflation volatility in going from the Volcker-Greenspan to the Greenspan sample. The reason is that, as we will show later, the main sources of volatility in the output growth is due to the demand shocks both over short and long horizons. Therefore, stabilizing the output growth is not at odds with the objective of inflation stabilization since demand shocks do not create a tradeoff between the two objectives.

Inflation remains the most important target in all three periods. The stabilization of the policy instrument, i.e. interest rate variability, has received lower weight in the loss function over time with respect to the pre-Volcker period. This is probably due to the fact that the political constraint to vary the interest rate a lot was relaxed after Volcker, which made it possible to focus more on disinflation (Lindsey et al., 2005). This implies that the share of interest rate variability in the loss function has decreased over time. Interest rate smoothing, on the other hand, has become more and more important over time. This component is the second most important target after inflation during the Greenspan period. Overall, the finding that interest rate smoothing is a relatively important target is consistent with other results reported in the literature (e.g. Ozlale, 2003 and Castelnuovo, 2004). Dennis (2003, 2006) reports high values for the interest rate smoothing component as well, although in these studies interest rate smoothing receives a weight even higher than inflation. In our framework, inflation remains the main policy goal, which is intuitively and practically a plausible result and in line with the statements of the majority of the central banks that inflation stabilization is the main objective of monetary policy.

The conclusions based on Table 6 are drawn under the assumption that monetary policy has been optimal and committed in all three periods under consideration. Although this is a plausible assumption for the most recent period, it might be admittedly doubtful for the first, or even second, part of the sample. Moreover, since the pre-Volcker period actually covers the mandates of three chairmen[16], assuming a common monetary policy strategy over this period may not be totally realistic. Therefore, it is desirable to test the results obtained under the assumption of optimal monetary policy against a less restrictive benchmark. We will perform this test in section 4.3.

4.2 What are the sources behind the Great Moderation and the Inflation Stabilization?

In this section we test alternative explanations for the volatility reduction of output growth (i.e. the Great Moderation of output growth) and inflation, together with lower average inflation (i.e. the Inflation Stabilization), observed in the data after the Great Inflation period which coincided with the appointment of Paul Volcker as chairman of the Federal Reserve in 1979[17]. A considerable amount of studies have documented competing explanations for the sources behind the end of the Great Inflation era. Some of these studies attribute this observation to the improved conduct of monetary policy, giving full credit to monetary policy makers that have changed the policy regime towards a more aggressive approach of Inflation Stabilization[18]. According to Meltzer (2005), political and institutional influences (i.e. pressures) on monetary policy makers and their preferences are the main factors behind the duration of the Great Inflation and the end of it after Volcker took office as chairman. In line with this explanation, the switch towards the speed limit targeting regime since the Volcker-Greenspan period discussed previously suggests a shift of monetary policy preferences towards stabilizing the output growth relative to trend rather than the level of the output gap. This supports the reasons provided by Orphanides et al. (2000), i.e. that policy decisions based on output growth are more reliable since they are

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[16] We consider the period under Martin, Burns, and Miller as one period, due to limitations imposed by short data samples.

[17] Note that in this section, as in Cecchetti et al. (2007), we associate the term Great Moderation with the volatility reduction in output growth only. We use the term Inflation Stabilization to indicate the volatility reduction in inflation. However, it is important to note that most of the literature refers to the term Great Moderation as a more general reduction of volatility of macroeconomic variables.

[18] Cecchetti et al. (2007) provide a detailed summary of the relevant literature pointing out the conduct of monetary policy as the source behind both the start and the end of the Great Inflation.

more robust to measurement errors and policy mistakes than information based on measures of potential output. In addition, the observation of a decreasing weight attached to the interest rate variability in the loss function since the Volcker-Greenspan period reflects the fact that the political constraints on the variability of the instrument rate became less binding since the start of Volcker's mandate, which is in line with Lindsey at al. (2005). On the other hand, the increasing weight attached to output growth during the Volcker-Greenspan period can provide a reasonable explanation for the reduced volatility of output growth, i.e. the Great Moderation. However, although both the Great Moderation of output growth and the Inflation Stabilization are very likely to have common sources, they are also possibly explained in part by alternative sources. Although improved conduct of monetary policy has received a lot of attention as a very plausible source behind the Great Moderation of output growth and the Inflation Stabilization, an alternative explanation mentioned in the literature is that of "good fortune". According to these studies, the Great Inflation period is mainly due to unfavourable and more volatile (supply) shocks affecting the economy than during the Volcker-Greenspan period. Hence, it is mainly good luck due to the lower volatility in the shocks that is the explaining factor behind the Great Moderation of output growth and the Inflation Stabilization (Stock and Watson, 2003 and Smets and Wouters, 2007).

In order to assess the extent to which each of the possible sources contribute to the Great Moderation of output growth and the stabilization of inflation, we perform a counterfactual exercise in the line of Smets and Wouters (2007). The exercise is twofold. We will first measure the contribution of the reduced volatility in the structural shocks to the Great Moderation of output growth and the Inflation Stabilization, which coincides in our analysis with the Volcker-Greenspan subsample (1983:1-2005:4). This is done by computing the values that inflation and output growth volatility would take under the assumption that the shocks prevailing in the Great Inflation period, which coincides with the pre-Volcker subsample (1966:1-1979:3), would have continued to affect the economy to the same extent and with the same magnitude. This will help us to understand the role of good luck in the volatility reduction of output growth and inflation. The second part of the exercise tests the importance of the change in the regime and preferences of monetary policy in the Volcker-Greenspan period compared to the pre-Volcker period. This allows us to measure the contribution of monetary policy, which has drastically changed after the appointment of Volcker, as an explanatory factor behind the Great Moderation of output growth and Inflation Stabilization. The analysis is performed by computing the volatility of output growth and inflation under the assumption that the flexible inflation targeting regime under the pre-Volcker period would have remained unchanged during the subsequent Volcker-Greenspan period. Hence, we assess the extent to which the volatilities would be different if monetary policy would have continued to rely on the output gap as target variable instead of switching to the output growth. Next to this assumption of an unchanged loss function specification, we also keep the estimated values for the preference parameters obtained for the pre-Volcker period q_{yl}, q_{rl} and q_{rd} unchanged and assume that these values continue to hold under the Volcker-Greenspan period.

[Insert Table 7]

Table 7 first shows the actual volatilities of output growth and inflation over the corresponding periods based on the data[19]. The model-implied volatilities are the ones based on the best performing Flexible Inflation Targeting regime during the pre-Volcker period and the Speed Limit Targeting regime during the Volcker-Greenspan period, respectively, as discussed in the previous subsection. As the table shows, in both periods the volatilities implied by the models based on optimal monetary policy approach the actual volatilities relatively well, although the output growth volatility is somewhat overestimated in the Volcker-Greenspan period. Following conclusions can be drawn from the counterfactual analysis. If the shock structure characterizing the Great Inflation period remained the same, the volatility of the output growth would have been 21 percentage points higher under the optimal monetary policy regime during Volcker and Greenspan's mandates. Hence, the Great moderation of output growth would have been less pronounced. Analogously, inflation volatility would have been higher as well, although to a lesser extent, i.e. inflation volatility would have been 11 percentage points higher under the optimal regime followed during the Volcker-Greenspan period if the shock structure of the Great Inflation period would have continued to hold. Different conclusions are obtained when we assume that the pre-Volcker Flexible inflation targeting regime based on the ouptut gap analysis were adopted by Volcker with unchanged preferences for the target variables. The volatility of the ouptut growth would have remained nearly unchanged. Inflation volatility, however, would have been more than twice as high compared to the Speed Limit Targeting regime adopted during the Volcker-Greenspan period. Hence, in case no regime change would have taken place after Volcker's appointment as chairman, output growth volatility would have been unaffected and the Great Moderation of output growth would still have taken place. This finding is in line with Smets and Wouters (2007) and Stock and Watson (2003). However, inflation volatility would

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[19] In order to be in line with the exercise performed by Smets and Wouters (2007), we report the standard errors rather than the variances.

have been much higher and the Inflation Stabilization would probably not have occured. In summary, based on the results reported in Table 7, we can conclude that the main source of the Great Moderation of output growth is the favourable economic environment characterized by less volatile shocks than observed previously in the pre-Volcker period. Hence, the reduction in output growth volatility seems to be entirely due to good fortune[20]. The Inflation Stabilization would still have occurred but less pronounced under the Speed Limit Targeting regime during the Volcker-Greenspan period if the shock structure would have remained unchanged. However, Inflation Stabilization would have been absent if a monetary policy regime would not have taken place under Volcker's mandate. In other words, if Volcker would have continued with the pre-Volcker Flexible Inflation Targeting regime with the same preferences for the target variables in the loss function, Inflation Stabilization would not have occurred. This result suggests, following Orphanides et al. (2000), that reliance on output growth in monetary policy analysis made policy less prone to measurement errors in potential output, encouraging the Volcker disinflation.

4.3 Comparison with Benchmark

In this section, we compare the fit of the best performing models under the optimal monetary policy assumption for each period to the benchmark where monetary policy is described by the empirical Taylor rule (13)[21]. As is common in the Bayesian literature, we use the marginal likelihood measure in comparing the alternative specifications. A formal test of the restrictions imposed by the optimal monetary policy assumption is provided by Salemi (2006) who constructs a likelihood ratio test. He reports, as in Givens and Salemi (forthcoming), that imposing optimal monetary policy sharpens the estimates of some structural parameters. Table 8 reports the marginal likelihood of the models when monetary policy is assumed to be optimal for each subsample, against the benchmark[22] assumption that monetary policy is described by the empirical Taylor rule (13).

[Insert Table 8]

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[20] Giannone et al. (2008), however, show that explanations of the Great Moderation of output growth based on the good luck story are based on models that are missspecified and omit important variables. They claim that the Great Moderation can be explained by changes in the transmission mechanisms rather than changes in the shocks. However, this requires models that are larger than the standard medium-scale DSGE models as the Smets and Wouters (2007) model is.

[21] In other words, we estimate the original Smets and Wouters (2007) specification of the model for each of the subsamples and consider these as a benchmark to compare the results obtained under the optimal monetary policy assumption. In doing so, we use again the same presample length of 20 quarters to initialize the estimates.

[22] In performing the estimations for the benchmark we adopt the same prior specifications as in Smets and Wouters (2007). The corresponding results for the posterior distributions of the structural parameters and the shock processes are available on request.

As the table shows, the benchmark clearly outperforms the optimal FIT-regime for the pre-Volcker period and also the optimal SLT-regime for the Volcker-Greenspan period. Hence, this suggests that monetary policy up to the appointment of Greenspan as Fed's chairman can be better described by an empirircal Taylor rule of the type (13) than any of the optimal monetary policy regimes considered. This is especially the case for the period prior to Volcker. The table further indicates that the SLT-regime provides a better fit to the data than the benchmark for the period during which Greenspan was chairman. Therefore, the estimates of the policy preference parameters can be considered representative, with relatively greater confidence, for the Greenspan period. Moreover, within the monetary policy setting considered here and based on the marginal likelihood measure, it seems that the assumption of optimal monetary policy is most likely to hold under the Greenspan period. Accordingly it goes without saying that during the period before Greenspan's arrival monetary policy does not seem to have been committed to minimizing any of the loss functions considered in this paper. This conclusion is in line with Salemi (2006) and Givens and Salemi (forthcoming).

Since the optimal SLT-regime outperforms the benchmark for the Greenspan period, we apply the Metropolis-Hastings sampling algorithm based on 250.000 draws to derive the posterior distributions for both cases, in order to better compare between the two alternatives. We discard the first 20% of the draws and use a step size of 0.2. The acceptation rate is 0.53, convergence is assessed graphically by the Brooks and Gelman (1998) mcmc univartiate diagnostics for each individual parameter and the mcmc multivariate diagnostics for all parameters simultaneously[23]. Tables 9 and 10 report the posterior mean and the corresponding lower and upper bounds, together with the Modified Harmonic Mean for both cases, respectively. In addition, a plot of the prior and the posterior distributions of the parameters for the optimal SLT-Regime are shown in Figures 1-4[24],[25].

[Insert Tables 9 and 10]

[Insert Figures 1-4]

Alternatively, we compare between the benchmark and the optimal policy regime by computing the optimized coefficients of the Taylor rule (13) under the SLT-regime, using the estimated

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[23] These graphs are available on request.

[24] The plots of the prior and posterior distributions for the parameters of the benchmark case are available on request.

[25] Looking at these graphs, it seems that some parameters are difficult to identify. This is especially the case for the habit persistence, the wage stickiness, wage indexation, the constant labour and constant inflation parameters.

values of the policy preferences for the Greenspan period, and compare the optimal coefficients to their estimated counterparts. We assume, for the moment, that there is no uncertainty concerning the estimated parameters and use the posterior mode as the true parameter values[26]. The resulting optimal version of the Taylor rule (13) under the SLT-regime, where $q_y = 0.47, q_{rl} = 0.22$ and $q_{rd} = 0.68$, is the following:

$$r_t = 0.999r_{t-1} + 0.53\pi_t + 0.02(y_t - y_t^p) + 0.39[(y_t - y_t^p) - (y_{t-1} - y_{t-1}^p)] \tag{21}$$

The coefficients resulting from the estimation of the original Smets and Wouters (2007) specification of the model for the Greenspan period yields the following empirical Taylor rule:

$$r_t = 0.876r_{t-1} + 0.2\pi_t + 0.02(y_t - y_t^p) + 0.15[(y_t - y_t^p) - (y_{t-1} - y_{t-1}^p)] \tag{22}$$

[Insert Table 11]

Although both the optimal and the estimated Taylor rule imply a high coefficient on the lagged interest rate, the optimized version requires a higher interest rate persistence with the coefficient on the lagged interest rate very close to one. Hence, the optimal version almost becomes a difference rule. In addition, the optimal coefficients on inflation and the difference in the output gap are higher than the estimated coefficients, which would imply a more active interest rate policy under the optimal approach towards monetary policy. Thus, even if the implied coefficients of the optimal Taylor rule approach those of the estimated Taylor rule, it is not able to replicate the estimated coefficients exactly. The corresponding values of the unconditional loss function under each rule is reported in Table 11, together with the unconditional loss under the unrestricted optimal commitment rule.

4.4 Effect of Parameter Uncertainty

In this section, we investigate the effects of uncertainty in both the structural parameters and those governing the shock processes on the performance of two optimal rules, i.e. the unrestricted optimal commitment rule and the optimal Taylor rule, and the benchmark empirical Taylor rule. We perform this exercise for the Greenspan period under the SLT-regime. We use the mode of the policy preference parameters, reported in the last column of Table 6, as the weights assigned to the individual target variables in the loss function. Therefore, we assume that there is no uncertainty concerning the policy preferences. We intend to investigate the

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[26] We also abstract from model specification uncertainty. Although it might be interesting to investigate the effects of possible misspecifications, we leave this exercise for the future as an extension to this work.

implications of potential parameter misspecification on the conduct of optimal monetary policy and the resulting unconditional loss. Therefore, the evaluation of the optimal rules against the benchmark is taken from the perspective of a policy maker to whom his or her own preferences are known with certainty. The case of uncertainty with respect to the parameters in the policy loss function as considered by Walsh (2005) might be interesting when one considers a welfare-based loss function specification, since in this case the preference parameters are a function of the structural parameters in the model and therefore also subject to misspecification together with the structural parameters. This does not apply to our case since we employ a quadratic loss function. The analysis is done by using the estimated posterior distribution of the structural parameters and those that describe the shock processes resulting from the Smets and Wouters (2007) specification of the model estimated for the Greenspan period. In this respect, each draw from the posterior distribution using the markov chain monte carlo method delivers possible parameter values for which (i) the optimal commitment rule and the optimal Taylor rule can be derived for the given policy preferences, (ii) the corresponding empirical Taylor rule can be estimated and (iii) the unconditional loss under each rule can be computed.

For this purpose, we randomly select 10.000 draws from the posterior distribution of each parameter[27]. For each draw, we compute the optimal commitment rule and the optimal Taylor rule and the corresponding value of the unconditional loss, respectively. As a benchmark, we also compute the unconditional loss when monetary policy is described by the empirical Taylor rule (13). Hence, the methodology can be summarized as follows. We start from the benchmark Smets and Wouters (2007) model including the empirical Taylor rule (13), estimated for the Greenspan period in the previous subsection based on the 250.000 draws for the Metropolis-Hastings algorithm. From these draws, we randomly select 10.000 (excluding the first 20% from the 250.000 draws) for the structural parameters and the shock processes together with the coefficients of the Taylor rule (13) which will serve as a benchmark. In a next step, we discard these Taylor rule coefficients but keep the selected 10.000 draws of the structural and shock parameters. The removed Taylor rule is replaced by the loss function under the optimal SLT-regime, with the preferences previously estimated for the Greenspan period. Keeping these weights in the loss function fixed throughout the exercise, we compute for each of the selected 10.000 draws of the structural and shock parameters the optimal Taylor rule on the one hand and the unrestricted optimal commitment rule on the other hand. The corresponding unconditional

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[27] Obviously, for the computation of the optimal rules we discard the draws for the Taylor rule coefficients in (13).

losses are computed accordingly under the benchmark estimated Taylor rule, the optimal Taylor rule and the unrestricted optimal commitment rule.

[Insert Figure 5]

[Insert Table 12]

Figure 5 shows the resulting distributions of the unconditional loss for the alternative monetary policy rules. The presence of uncertainty has the smallest effect on the performance of monetary policy when it is performed under full commitment. As is clear from the figure and Table 12, which reports selective summary statistics[28], the average unconditional loss is lowest under the unrestricted optimal rule (0.25), followed by the optimal Taylor rule and the estimated Taylor rule. More interestingly, however, is the magnitude of difference between the optimal rules. In general, in applied literature optimal simple rules perform relatively well (e.g. Williams, 2003 and Levin et al., 2005), where the unconditional loss approaches that of the full commitment rule very closely. The results reported here, however, show that the average unconditional loss under the optimal Taylor rule is relatively higher than under the unrestricted optimal rule. The 90% confidence intervals for the unrestricted optimal rule and the optimal Taylor rule are comparable. This indicates that the performance of the optimal Taylor rule, relative to the optimal commitment rule, is equally robust to parameter misspecification.

Hence, the results shown in Figure 5 and Table 12 suggest that under consideration of parameter uncertainty, a full commitment approach towards monetary policy under the SLT-regime is more favourable in terms of lower unconditional loss, since the average loss under this rule is higher than under the optimal Taylor rule. This suggests that, although the optimal Taylor rule is equally robust to parameter misspecification as the optimal commitment rule, there are still relatively high gains to be obtained from a policy based on full commitment in terms of lower average unconditional loss.

4.5 Forecast Errors under the Optimal Speed Limit Targeting Regime

In this section, we study the contribution of each structural shock, together with the measurement error, to the forecast error variances of the target variables output growth, inflation and the interest rate over various horizons[29]. We use the estimated model specified under the SLT-

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[28] In computing the statistics and the distribution for the optimal Taylor rule, we discard five outliers since including them biases the computation of the standard error. Hence, the analysis for the optimal Taylor rule is based on 9.995 instead of the initial 10.000 draws.

[29] The forecast errors are computed using the posterior mode estimates.

regime for the Greenspan period to decompose the variation in the observed target variables. Table 13 shows the results of the forecast error variance decomposition[30].

[Insert Table 13]

As indicated by panel (I) in Table 13, the short run variation in output growth is mainly explained by the exogenous spending shock, followed by the risk premium and the investment specific shocks (i.e. the demand shocks). These shocks jointly take into account around 78% percent of the variation in output growth in the short run. Over the longer horizons, exogenous spending and risk premium shocks remain the main driving forces. The investment specific shock, however, loses importance over time. At the infinite horizon, the share of the wage mark-up shock increases and explains, together with the exogenous spending and risk premium shocks, almost 71% of the unconditional variance of output growth. For all forecast horizons, the share of the monetary policy and the price mark-up shocks are very small. These findings are qualitatively in line with Smets and Wouters (2007), except for the contribution of the productivity shock. While panel (I) suggests a relatively low share of the productivity shock in the variation of output growth both in the short and the long run, this shock plays a more important role in the long run in the former study[31].

The second panel in Table 13 shows that the supply shocks, in particular the price and the wage mark-up shocks, clearly dominate the movements in inflation. Not surprisingly, these two shocks explain 90% of the variation in inflation in the very short run. However, the importance of the price mark-up shock decreases over time, while the wage mark-up shock becomes more important in the long run. The monetary policy shock, which does not contribute to inflation variation in the short run, becomes more important in the medium to long run. The latter shock explains, together with the price and the wage mark-up shocks, around 80% of the unconditional variance of inflation.

Finally, panel (III) indicates that the measurement error only takes account for almost 10% of the variation in the interest rate during the first quarter and has nearly no effect at higher horizons. Over all horizons, the most important shock explaining the variation in the interest rate is the monetary policy shock, which is not a surprising finding, due to the fact that the interest rate is the monetary policy instrument. The demand shocks, as expected, also contribute significantly to the variance of the forecast errors in the interest rate: the exogenous spending

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[30] We base our calculations on the algorithm outlined in the technical Appendix of Ireland (2004).

[31] This difference might be due to the fact that we only consider a subsample, i.e. the Greenspan period, while Smets and Wouters (2007) do the analysis over the full sample.

shock, together with the risk premium and the investment shocks, are responsible for almost 33% of the total variance in the short run. These demand shocks remain important over the medium to the long run. In particular, the investment shock gains more importance in the long run, by explaining up to 21.25% of the unconditional variance in the interest rate.

5 Conclusion

In this paper, we estimate the preference parameters of post-war US monetary policy makers under the assumption of optimal commitment policy for the pre-Volcker period, the Volcker-Greenspan period and the Greenspan period, respectively. Starting from the general equilibrium framework developed by Smets and Wouters (2007), we test for empirical performance of a set of alternative optimal monetary policy regimes using Bayesian estimation methods. The Flexible Inflation Targeting (FIT) regime provides best fit in terms of marginal likelihood for the pre-Volcker period. This suggests that monetary policy has been concerned about inflation, the output gap level, interest rate variability and interets rate smoothing during the period prior to Volcker's appointment with an average yearly inflation target around 2.44%. In the following two periods, the Speed Limit Targeting (SLT) regime performs best. This indicates the importance of inflation, output gap difference, interest rate variability and interest rate smoothing as target variables during the period of both Volcker and Greenspan, with targeted inflation around 2.08% and 2.28%, respectively.

The estimation results further reveal that the weight on output growth stabilization in the loss function has increased over time. Inflation remains the main target of monetary policy in all periods. The importance of interest rate varaibility has decreased, whereas interest rate smoothing has gained more weight over time.

A counterfactual exercise shows that the Great Moderation of output growth is mainly due to the decrease in the volatility of structural shocks. The Inflation Stabilization on the other hand, can be explained to a large extent by the switch in the monetary policy regime after Volcker became chairman of the Federal Reserve. Testing the optimal regimes against the benchmark assumption that monetary policy is described by an empirical Taylor rule, shows that the optimal SLT regime performs better than the benchmark only in the Greenspan period.

In order to investigate the effects of parameter uncertainty, we use random draws from the estimated posterior distribution for the Greenspan period. We compute for each draw the unrestricted optimal commitment rule, the optimal Taylor rule and the benchmark empirical rule for the policy preferences given by the posterior mode. The results show that the lowest average unconditional loss under parameter uncertainty is obtained under the unrestricted optimal rule and that this value is relatively lower than the average unconditional loss under the optimal Taylor rule. However, uncertainty as measured by the confidence bounds affects the performance of both rules to the same extent.

A forecast error variance decomposition, based on the estimated SLT regime model for the Greenspan period, shows that demand shocks explain the largest part of the variation in output growth in the short run. In the long run, the wage mark-up shock becomes more important and is, together with the exogenous spending and risk premium shocks, responsible for 71% of the unconditional variance in output growth. Supply shocks clearly dominate movements in inflation in the short run. However, the price mark-up shock loses share over time, while the wage mark-up shock becomes more important in the long run. Although the monetary policy shock does not contribute to inflation variation in the short run, it gains more importance in the medium to long run. The variance in the interest rate is mainly explained by the monetary policy and the demand shocks over all horizons.

This work can be improved with respect to the following aspects. The results presented in this paper are conditional on the assumption that monetary policy performs optimally under commitment. Therefore, it would be interesting to test the extent to which the conclusions would change if the alternative case of discretion is assumed. Additionally, it would be interesting to study the effects of uncertainty with respect to the underlying structural model. These are issues we would like to focus on in the near future as an extension to this paper.

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Data Appendix

As in Smets and Wouters (2007), we use the following seven observed series: real GDP, consumption, investment, hours worked, real wages, GDP deflator and the federal funds rate. The series on GDP, nominal personal consumption and fixed private domestic investment are downloaded from the Bureau of Economic Analysis database of the US Department of Commerce. Real GDP is expressed in terms of 1996 chained dollars, the series on consumption and investment are deflated with the GDP deflator. Inflation is computed as the log difference of the Implicit price deflator. From the Bureau of Labor Statistics we obtain hours worked and hourly compensation for the non farming business sector for all persons. Real wage is obtained by dividing the latter serie by the GDP price deflator. In order to correct for the limited coverage of the non farming business sector with respect to the GDP, we multiply the average hours index, which is the major sector productivity and costs index, with Civilian Employment figures of 16 years and over. The federal funds rate is taken from the FRED database of the Federal Reserve Bank of St-Louis. Inflation and interest rate are expressed on quarterly basis. The remaining variables are expressed in 100 times log. The real variables are divided by the population over 16, in order to express them in per capita terms. All series are seasonally adjusted.

Tables and Figures

Table 1: **Alternative specifications for the loss function**

Monetary Policy Regime	**Loss function specification**
(1) Flexible Inflation Targeting (FIT)	$(\pi_t - \bar{\pi})^2 + q_{yl}(y_t - y_t^p)^2 + q_{rl}r_t^2 + q_{rd}(r_t - r_{t-1})^2$
(2) Speed Limit Targeting (SLT)	$(\pi_t - \bar{\pi})^2 + q_{yd}((y_t - y_t^p) - (y_{t-1} - y_{t-1}^p))^2$ $+q_{rl}r_t^2 + q_{rd}(r_t - r_{t-1})^2$
(3) Inflation Differential and Speed Limit Targeting (ID-SLT)	$(\pi_t - \pi_{t-1})^2 + q_{yd}((y_t - y_t^p) - (y_{t-1} - y_{t-1}^p))^2$ $+q_{rl}r_t^2 + q_{rd}(r_t - r_{t-1})^2$
(4) Wage Inflation and (WI-SLT) Speed Limit Targeting	$(\pi_t - \bar{\pi})^2 + q_{yd}((y_t - y_t^p) - (y_{t-1} - y_{t-1}^p))^2 + q_r r_t^2$ $+q_{rd}(r_t - r_{t-1})^2 + q_w(w_t - w_{t-1} + \pi_t)^2$

Note: The table shows the alternative one-period loss functions for (14). Each specification corresponds to a separate monetary policy regime.

Table 2: **Prior specifications**

structural parameters				shock processes			
	distrib.	mean	stand. dev.		distrib.	mean	stand. dev.
φ	Normal	4	1.5	σ_a	InvGamma	0.1	2
σ_c	Normal	1.5	0.37	σ_b	InvGamma	0.1	2
λ	Beta	0.7	0.1	σ_g	InvGamma	0.1	2
ξ_w	Beta	0.5	0.1	σ_l	InvGamma	0.1	2
σ_l	Normal	2	0.75	σ_p	InvGamma	0.1	2
ξ_p	Beta	0.5	0.1	σ_w	InvGamma	0.1	2
ι_w	Beta	0.5	0.15	σ_m	InvGamma	0.1	2
ι_p	Beta	0.5	0.15	σ_{fed}	InvGamma	0.1	2
ψ	Beta	0.5	0.15	ρ_a	Beta	0.5	0.2
ϕ_p	Normal	1.25	0.12	ρ_b	Beta	0.5	0.2
$\bar{\pi}$	Gamma	0.62	0.1	ρ_g	Beta	0.5	0.2
$(\beta^{-1} - 1)100$	Gamma	0.25	0.1	ρ_l	Beta	0.5	0.2
L_*	Normal	0	2	ρ_p	Beta	0.5	0.2
$\bar{\gamma}$	Normal	0.4	0.1	ρ_w	Beta	0.5	0.2
α	Normal	0.3	0.05	ρ_m	Normal	0	2
monetary policy preference parameters				ρ_{ga}	Beta	0.5	0.2
$q_{yl} = q_{yd}$	Normal	0.5	4	μ_p	Beta	0.5	0.2
$q_{rl} = q_{rd}$	Normal	0.5	4	μ_w	Beta	0.5	0.2
q_w	Normal	0.5	4				

Table 3: **Posterior distributions pre-Volcker period**

mon. pol. regime	**(1) FIT**		**(2) SLT**		**(3) ID-SLT**		**(4) WI-SLT**	
marg. likelihood	-414.57		-418.18		-419.23		-432.27	
	mode	st. dev.	mode	st. dev.	mode	st. dev.	mode	st. dev.
				structural parameters				
φ	6.58	1.62	4.26	1.73	3.59	1.34	2.55	0.88
σ_c	1.65	0.32	1.56	0.27	1.56	0.27	1.53	0.2
λ	0.76	0.09	0.73	0.07	0.72	0.08	0.67	0.07
ξ_w	0.64	0.15	0.77	0.08	0.74	0.1	0.67	0.2
σ_l	1.49	2.33	1.49	0.93	1.54	0.99	1.39	1.28
ξ_p	0.5	0.08	0.61	0.07	0.6	0.07	0.63	0.09
ι_w	0.63	0.2	0.62	0.13	0.66	0.12	0.59	0.13
ι_p	0.36	0.14	0.54	0.18	0.64	0.19	0.66	0.17
ψ	0.37	0.18	0.25	0.1	0.19	0.08	0.19	0.08
ϕ_p	1.38	0.13	1.58	0.09	1.57	0.09	1.47	0.09
$\bar{\pi}$	0.61	0.1	0.6	0.1	0.6	0.1	0.61	0.1
$(\beta^{-1}-1)100$	0.18	0.08	0.19	0.08	0.16	0.07	0.14	0.06
L_*	0.98	2.56	-0.73	1.24	-0.66	1.22	-0.91	1.27
$\bar{\gamma}$	0.32	0.06	0.29	0.04	0.29	0.04	0.29	0.04
α	0.18	0.04	0.24	0.03	0.25	0.03	0.24	0.03
				shock processes				
σ_a	0.6	0.07	0.55	0.05	0.55	0.05	0.57	0.06
σ_b	0.24	0.04	0.29	0.04	0.3	0.04	0.29	0.04
σ_g	0.54	0.05	0.55	0.06	0.56	0.06	0.55	0.06
σ_l	0.53	0.12	0.71	0.11	0.76	0.11	0.76	0.12
σ_p	0.21	0.03	0.2	0.03	0.2	0.03	0.22	0.04
σ_w	0.23	0.04	0.22	0.03	0.23	0.03	0.23	0.04
σ_m	0.09	0.05	2.11	1.68	1.86	1.12	6.23	10.26
σ_{fed}	0.04	0.01	0.05	0.02	0.06	0.05	0.04	0.01
ρ_a	0.99	0.01	0.99	0.01	0.99	0	0.99	0
ρ_b	0.3	0.15	0.24	0.12	0.21	0.11	0.21	0.15
ρ_g	0.95	0.03	0.89	0.04	0.89	0.04	0.88	0.04
ρ_l	0.68	0.12	0.49	0.1	0.45	0.1	0.5	0.13
ρ_p	0.76	0.22	0.64	0.22	0.64	0.22	0.47	0.34
ρ_w	0.9	0.06	0.89	0.07	0.9	0.06	0.91	0.08
ρ_m	0.999	0.001	0.999	0.001	0.999	0.001	0.999	0.001
ρ_{ga}	0.52	0.11	0.61	0.13	0.63	0.13	0.62	0.12
μ_p	0.6	0.21	0.56	0.2	0.57	0.2	0.48	0.22
μ_w	0.75	0.11	0.81	0.09	0.81	0.08	0.78	0.15
				monetary policy preference parameters				
q_y	0.17	0.27	5.96	4.41	5.98	4.68	1.12	0.4
q_{rl}	0.34	0.23	9.29	7.77	8.36	4.88	15.34	16
q_{rd}	0.04	0.06	1.16	1.35	1.25	1.43	6.17	7.37
q_w	–	–	–	–	–	–	-0.37	1.84

Table 4: **Posterior distributions Volcker-Greenspan period**

mon. pol. regime	**(1) FIT**		**(2) SLT**		**(3) ID-SLT**		**(4) WI-SLT**	
marg. likelihood	-440.58		-416.2		-419.66		-417.54	
	mode	st. dev.	mode	st. dev.	mode	st. dev.	mode	st. dev.
			structural parameters					
φ	7.01	1.15	6.34	1.35	5.97	1.3	6.12	3
σ_c	1.61	0.16	1.52	0.19	1.5	0.15	1.46	0.41
λ	0.71	0.05	0.7	0.06	0.7	0.04	0.69	0.12
ξ_w	0.63	0.06	0.6	0.12	0.61	0.1	0.56	0.36
σ_l	2.26	0.65	1.62	0.83	1.87	0.76	1.62	0.86
ξ_p	0.67	0.07	0.72	0.09	0.72	0.07	0.7	0.38
ι_w	0.54	0.17	0.47	0.16	0.47	0.16	0.47	0.2
ι_p	0.23	0.09	0.18	0.08	0.2	0.08	0.17	0.08
ψ	0.64	0.13	0.52	0.15	0.53	0.14	0.54	0.19
ϕ_p	1.39	0.09	1.5	0.09	1.48	0.09	1.48	0.1
$\bar{\pi}$	0.52	0.05	0.52	0.05	0.59	0.08	0.53	0.07
$(\beta^{-1}-1)100$	0.18	0.07	0.19	0.08	0.17	0.07	0.19	0.07
L_*	2.47	1.48	1.1	1.37	1.06	1.13	1.02	1.45
$\bar{\gamma}$	0.45	0.01	0.47	0.02	0.48	0.02	0.47	0.03
α	0.17	0.02	0.17	0.02	0.18	0.02	0.17	0.02
			shock processes					
σ_a	0.39	0.03	0.38	0.03	0.38	0.03	0.38	0.03
σ_b	0.18	0.03	0.19	0.02	0.2	0.02	0.19	0.03
σ_g	0.4	0.03	0.4	0.03	0.4	0.03	0.4	0.03
σ_l	0.4	0.05	0.43	0.06	0.48	0.06	0.43	0.07
σ_p	0.13	0.02	0.12	0.01	0.14	0.02	0.12	0.01
σ_w	0.24	0.03	0.24	0.04	0.22	0.04	0.26	0.14
σ_m	0.04	0.01	0.06	0.02	0.03	0.008	0.07	0.07
σ_{fed}	0.03	0.005	0.03	0.006	0.03	0.006	0.03	0.006
ρ_a	0.92	0.03	0.93	0.02	0.93	0.02	0.93	0.03
ρ_b	0.3	0.14	0.25	0.13	0.11	0.08	0.27	0.15
ρ_g	0.995	0.003	0.99	0.01	0.98	0.008	0.98	0.02
ρ_l	0.73	0.07	0.68	0.08	0.63	0.07	0.67	0.09
ρ_p	0.84	0.08	0.84	0.11	0.83	0.1	0.87	0.34
ρ_w	0.91	0.04	0.94	0.05	0.93	0.05	0.95	0.11
ρ_m	0.94	0.01	0.93	0.01	0.85	0.04	0.92	0.03
ρ_{ga}	0.42	0.1	0.42	0.11	0.44	0.11	0.42	0.11
μ_p	0.64	0.12	0.69	0.13	0.69	0.12	0.72	0.19
μ_w	0.64	0.12	0.67	0.13	0.6	0.13	0.64	0.27
			monetary policy preference parameters					
q_y	0.03	0.01	0.37	0.15	0.18	0.05	0.44	0.43
q_{rl}	0.16	0.05	0.28	0.1	0.15	0.04	0.3	0.16
q_{rd}	0.16	0.06	0.3	0.14	0.19	0.06	0.37	0.51
q_w	–	–	–	–	–	–	0.07	0.08

Table 5: **Posterior distributions Greenspan period**

mon. pol. regime	**(1) FIT**		**(2) SLT**		**(3) ID-SLT**		**(4) WI-SLT**	
marg. likelihood	-331.98		-315.05		-319.48		-317.8	
	mode	st. dev.	mode	st. dev.	mode	st. dev.	mode	st. dev.
structural parameters								
φ	6.17	1.19	5.38	1.21	4.47	1.23	5.31	1.2
σ_c	1.44	0.14	1.32	0.13	1.31	0.11	1.3	0.13
λ	0.73	0.06	0.73	0.06	0.72	0.05	0.73	0.06
ξ_w	0.5	0.08	0.52	0.08	0.55	0.08	0.48	0.09
σ_l	2.18	0.67	1.7	0.7	1.94	0.7	1.57	0.69
ξ_p	0.54	0.07	0.66	0.07	0.67	0.06	0.66	0.07
ι_w	0.56	0.16	0.48	0.16	0.48	0.16	0.46	0.16
ι_p	0.34	0.13	0.26	0.1	0.29	0.11	0.24	0.09
ψ	0.72	0.12	0.58	0.14	0.56	0.13	0.57	0.14
ϕ_p	1.35	0.09	1.43	0.09	1.44	0.09	1.43	0.09
$\bar{\pi}$	0.59	0.07	0.57	0.07	0.57	0.08	0.57	0.06
$(\beta^{-1}-1)100$	0.15	0.06	0.17	0.07	0.15	0.06	0.17	0.07
L_*	-0.005	1.21	-0.01	1.11	0.33	0.96	-0.06	1.09
$\bar{\gamma}$	0.46	0.02	0.49	0.02	0.5	0.02	0.49	0.02
α	0.19	0.02	0.19	0.02	0.21	0.02	0.19	0.02
shock processes								
σ_a	0.38	0.03	0.37	0.03	0.37	0.03	0.37	0.03
σ_b	0.16	0.03	0.18	0.02	0.18	0.02	0.17	0.02
σ_g	0.41	0.03	0.41	0.03	0.41	0.04	0.41	0.03
σ_l	0.44	0.06	0.49	0.07	0.54	0.07	0.49	0.07
σ_p	0.14	0.02	0.12	0.01	0.14	0.02	0.12	0.02
σ_w	0.31	0.05	0.27	0.04	0.25	0.04	0.29	0.05
σ_m	0.05	0.01	0.07	0.02	0.03	0.01	0.07	0.02
σ_{fed}	0.03	0.004	0.03	0.005	0.03	0.005	0.03	0.005
ρ_a	0.92	0.03	0.91	0.03	0.9	0.03	0.91	0.03
ρ_b	0.28	0.15	0.26	0.13	0.16	0.09	0.28	0.13
ρ_g	0.97	0.01	0.97	0.01	0.96	0.01	0.97	0.01
ρ_l	0.62	0.08	0.54	0.09	0.5	0.09	0.54	0.09
ρ_p	0.91	0.04	0.9	0.04	0.89	0.05	0.91	0.04
ρ_w	0.92	0.03	0.92	0.04	0.9	0.04	0.92	0.04
ρ_m	0.95	0.03	0.93	0.04	0.81	0.08	0.92	0.04
ρ_{ga}	0.5	0.12	0.53	0.12	0.55	0.12	0.53	0.12
μ_p	0.58	0.14	0.73	0.11	0.74	0.1	0.73	0.11
μ_w	0.55	0.14	0.53	0.15	0.49	0.16	0.52	0.15
monetary policy preference parameters								
q_y	0.04	0.02	0.47	0.14	0.2	0.06	0.5	0.16
q_{rl}	0.15	0.08	0.22	0.1	0.12	0.04	0.21	0.11
q_{rd}	0.44	0.15	0.68	0.22	0.38	0.11	0.76	0.27
q_w	–	–	–	–	–	–	0.09	0.09

Table 6: **Summary estimation results policy parameters and implied variances**

Subsample	**Pre-Volcker**	**Volcker-Greenspan**	**Greenspan**
Optimal Policy Regimes	(1) FIT	(2) SLT	(2) SLT
Marginal Likelihood	−414.57	−416.2	−315.05
preference parameters:			
q_{yl}	0.17	–	–
q_{yd}	–	0.37	0.47
q_{rl}	0.34	0.28	0.22
q_{rd}	0.04	0.3	0.68
Inflation Target $\bar{\pi}$ (yearly)	2.44	2.08	2.28
Model-Implied Variances:			
output growth	1	0.42	0.44
inflation	0.28	0.08	0.09
interest rate	0.35	0.14	0.15
interest rate difference	0.06	0.02	0.01
output gap	3.17	13.51	9.31

Note: The table shows for each subsample the marginal likelihood obtained for the loss function specification that provides best fit among the set of loss function specifications outlined in Table 1. For the pre-Volcker sample the flexible inflation targeting (FIT) regime performs best, therefore the weight on the **output gap level** (q_{yl}) is reported since the output gap differential is not included in this specification of the loss function. For both the Volcker-Greenspan and the Greenspan subsamples, the speed limit targeting (SLT) regime performs best, hence the respective weights on the **output gap difference (growth)** (q_{yd}) for each subsample are reported. The reported variances are based on quarterly smoothed series of the corresponding variables.

Table 7: **Counterfactual analysis: sources behind the Great Moderation of output growth and the Inflation Stabilization**

Subsample	**Pre-Volcker (Great Inflation)**		**Volcker-Greenspan (Great Moderation and Inflation Stabilization)**		**Counterfactual Volcker-Greenspan**	
	Actual	Model (FIT regime)	Actual	Model (SLT regime)	Shocks	Regime
standard errors:						
output growth	1.01	1	0.58	0.65	0.86	0.66
inflation	0.55	0.53	0.25	0.28	0.39	0.63

Note: The table shows the actual standard errors of output growth and inflation over the indicated sample, followed by the model-implied standard errors. The counterfactual standard errors under 'Shocks' for the Volcker-Greenspan period are obtained by using the series of shocks prevailing under the Pre-Volcker period. The counterfactual standard errors under 'Regime' are the standard errors that would be obtained if the flexible inflation targeting regime of the pre-Volcker period would have remained unchanged during the subsequent Volcker-Greenspan period.

Table 8: **Optimal policy models vs. benchmark**

Subsample	**Pre-Volcker**	**Volcker-Greenspan**	**Greenspan**
	Optimal Policy Regimes		
	(1) FIT	(2) SLT	(2) SLT
Marginal Likelihood	-414.57	-416.2	-315.05
Inflation Target $\bar{\pi}$ (yearly)	2.44	2.08	2.28
	Benchmark (empirical Taylor rule)		
Marginal Likelihood	-380.94	-413.48	-318.9
Inflation Target $\bar{\pi}$ (yearly)	2.6	2.4	2.36

Table 9: **Posterior distributions SLT-regime vs. benchmark (Greenspan Period)**

monetary policy regime		(2) SLT	
Laplace approx.	-315.05		
Modified Harmonic Mean	-313.97		
	mean	lower bound	upper bound
	structural parameters		
φ	5.38	3.49	7.34
σ_c	1.31	1.1	1.54
λ	0.72	0.63	0.81
ξ_w	0.52	0.39	0.66
σ_l	1.79	0.74	2.86
ξ_p	0.64	0.53	0.75
ι_w	0.48	0.25	0.71
ι_p	0.29	0.13	0.46
ψ	0.58	0.38	0.79
ϕ_p	1.43	1.28	1.58
$\bar{\pi}$	0.58	0.46	0.70
$(\beta^{-1}-1)100$	0.19	0.08	0.29
L_*	0.004	-1.77	2.06
$\bar{\gamma}$	0.49	0.45	0.52
α	0.19	0.15	0.23
	shock processes		
σ_a	0.38	0.32	0.44
σ_b	0.18	0.14	0.21
σ_g	0.42	0.36	0.48
σ_l	0.5	0.39	0.63
σ_p	0.12	0.09	0.14
σ_w	0.28	0.2	0.35
σ_m	0.12	0.05	0.19
σ_{fed}	0.03	0.02	0.04
ρ_a	0.91	0.86	0.96
ρ_b	0.31	0.09	0.52
ρ_g	0.97	0.95	0.99
ρ_l	0.55	0.4	0.7
ρ_p	0.89	0.82	0.97
ρ_w	0.91	0.85	0.98
ρ_m	0.9	0.83	0.99
ρ_{ga}	0.51	0.32	0.71
μ_p	0.65	0.45	0.85
μ_w	0.48	0.25	0.71
	monetary policy preference parameters		
q_y	0.66	0.31	1.03
q_{rl}	0.35	0.05	0.65
q_{rd}	1.2	0.43	2.05

Note: The table shows the marginal likelihood and the estimation results for the posterior distribution (mean, lower and upper bounds) over the Greenspan period under the speed limit targeting (SLT) regime. The results are obtained from the Metropolis-Hastings sampling algorithm based on 250.000 draws, from which the first 20% draws are discarded.

Table 10: **Posterior distributions SLT-regime vs. benchmark (Greenspan Period)**

monetary policy regime	Benchmark Taylor rule		
Laplace approx.	-318.9		
Modified Harm. Mean	-318.91		
	mean	lower bound	upper bound
φ	6.46	4.59	8.22
σ_c	1.49	1.26	1.77
λ	0.69	0.62	0.78
ξ_w	0.76	0.65	0.86
σ_l	2.36	1.36	3.29
ξ_p	0.75	0.67	0.82
ι_w	0.46	0.23	0.69
ι_p	0.33	0.13	0.52
ψ	0.7	0.53	0.87
ϕ_p	1.52	1.37	1.66
$\bar{\pi}$	0.6	0.47	0.72
$(\beta^{-1} - 1)100$	0.14	0.06	0.21
L_*	1.25	-0.05	2.55
$\bar{\gamma}$	0.45	0.41	0.49
α	0.21	0.17	0.25
σ_a	0.37	0.32	0.42
σ_b	0.16	0.12	0.21
σ_g	0.44	0.37	0.5
σ_l	0.42	0.32	0.52
σ_p	0.12	0.09	0.14
σ_w	0.24	0.18	0.29
σ_r	0.11	0.09	0.12
ρ_a	0.94	0.9	0.98
ρ_b	0.27	0.03	0.46
ρ_g	0.97	0.95	0.99
ρ_l	0.65	0.53	0.77
ρ_p	0.62	0.4	0.83
ρ_w	0.71	0.54	0.89
ρ_R	0.35	0.18	0.51
ρ_{ga}	0.47	0.27	0.67
μ_p	0.45	0.2	0.69
μ_w	0.47	0.23	0.73
ρ	0.87	0.84	0.91
r_π	1.67	1.32	2
r_y	0.12	0.06	0.18
$r_{\Delta y}$	0.15	0.1	0.19

Note: The table shows the marginal likelihood and the estimation results for the posterior distribution (mean, lower and upper bounds) over the Greenspan period under the benchmark Taylor rule regime. The results are obtained from the Metropolis-Hastings sampling algorithm based on 250.000 draws, from which the first 20% draws are discarded.

Table 11: **Unconditional loss optimal rules vs. benchmark (Greenspan period)**

Rule	**Unconditional Loss**
Unrestricted Optimal Rule	0.23
Optimal Taylor Rule	0.32
Estimated Taylor Rule	0.39

Table 12: **Characteristics of the loss function under parameter uncertainty (Greenspan period)**

Rule	**Unconditional Loss**				
				90% conf. interval	
	mean	median	st. dev.	lower	upper
Unrestricted Optimal Rule	0.25	0.25	0.04	0.17	0.32
Optimal Taylor Rule	0.35	0.35	0.05	0.27	0.41
Estimated Taylor Rule	0.44	0.43	0.07	0.33	0.54

Note: The summary statistics reported in the table are based on the selected 10.000 draws of the structural and shock parameters, except for the optimal Taylor rule which are based on 9.995 draws since 5 outliers were excluded in order to avoid upward bias in the computation of the standard error.

Table 13: **Forecast error variance decomposition SLT-regime (Greenspan period)**

	monet. policy	meas.	prod.	risk prem.	exog. spend.	price mark-up	invest.	wage mark-up
(I) output growth								
$Q = 1$	3.49	–	10.8	28.71	36.99	3.56	12.34	4.11
$Q = 4$	3.38	–	7.82	26.54	30.93	6.5	9.25	15.58
$Q = 12$	4.99	–	8.04	24.76	27.54	6.78	9.15	18.74
$Q = 40$	4.76	–	8.75	23.04	25.61	7.49	8.56	21.79
$Q = \infty$	4.76	–	8.75	23.03	25.6	7.48	8.55	21.83
(II) inflation								
$Q = 1$	0.12	–	7.35	0.28	1.19	78.32	1.01	11.74
$Q = 4$	1.54	–	11.84	2.05	3.91	55.91	3.71	21.05
$Q = 12$	14.95	–	10.69	2.54	3.44	44.20	3.89	20.3
$Q = 40$	19.78	–	10.34	2.41	3.27	40.25	3.73	20.25
$Q = \infty$	19.84	–	10.33	2.41	3.29	40.21	3.69	20.24
(III) interest rate								
$Q = 1$	55.63	9.81	1.55	13.32	14.99	0.01	4.55	0.14
$Q = 4$	49.39	0.98	1.03	19.74	15.51	0.03	13.03	0.28
$Q = 12$	43.81	0.51	0.68	18.63	14.27	0.1	21.63	0.38
$Q = 40$	44.39	0.5	0.73	18.19	14.09	0.13	21.31	0.66
$Q = \infty$	44.18	0.5	0.74	18.09	14.22	0.13	21.25	0.87

Note: The reported figures are the percentage contributions of the various shocks to the total variance over the alternative horizons, for the Greenspan period under the speed limit targeting (SLT) regime.

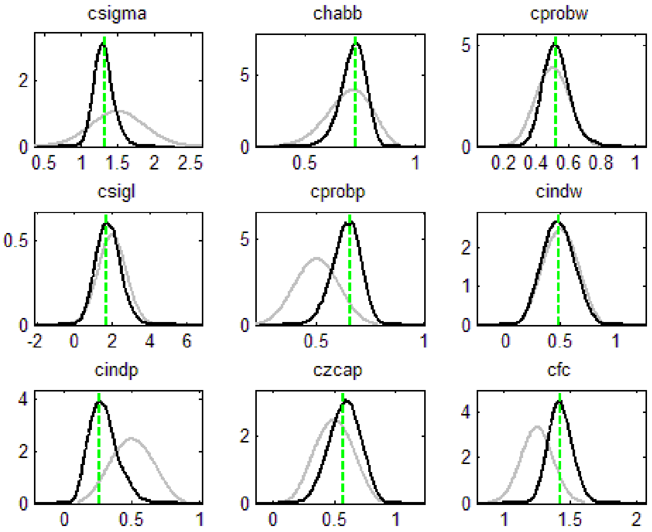

Figure 1. Priors and Posteriors SLT-regime (Greenspan period)

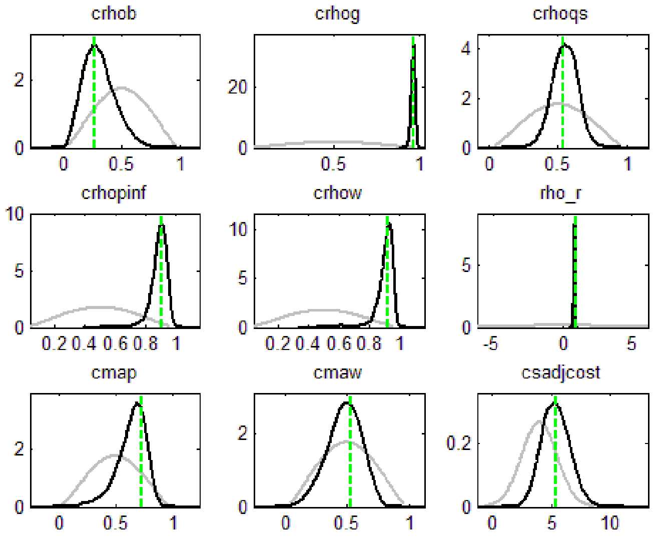

Figure 2. Priors and Posteriors SLT-regime (Greenspan period)

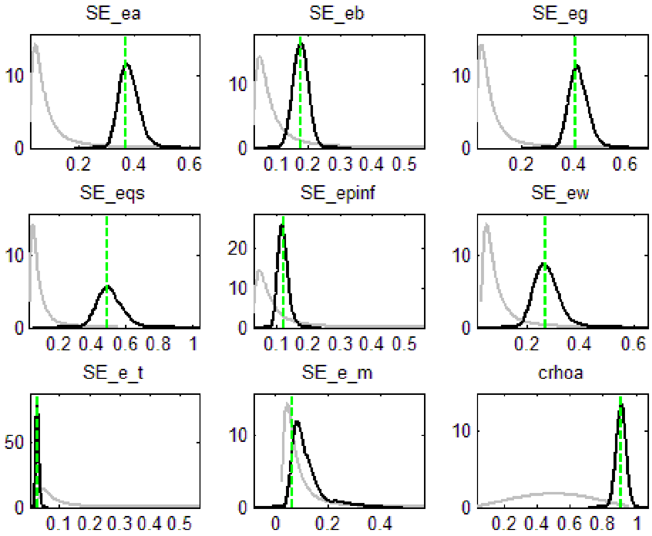

Figure 3. Priors and Posteriors SLT-regime (Greenspan period)

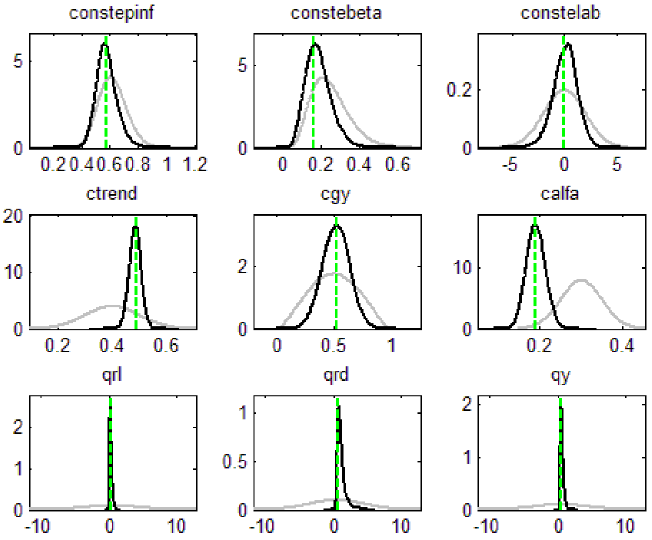

Figure 4. Priors and Posteriors SLT-regime (Greenspan period)

Prior distributions (shaded lines) and estimated posterior distributions (dark lines). The posterior mode is indicated by the vertical lines.

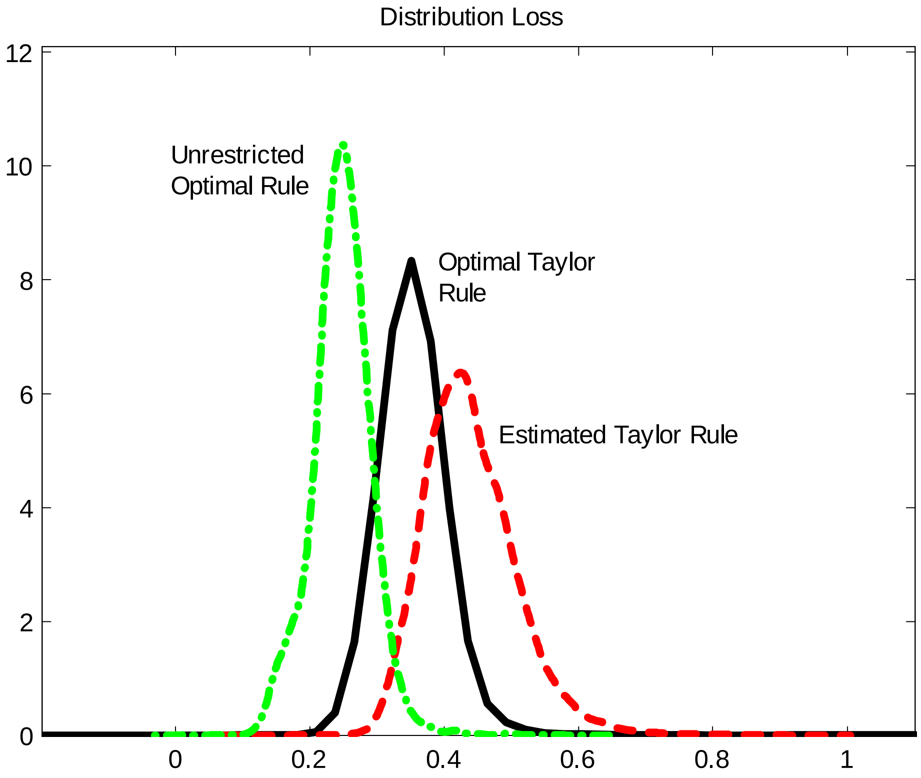

Figure 5. Distribution unconditional loss under parameter uncertainty

The figure shows the distribution of the unconditional loss under the unrestricted optimal rule (dash-dotted line), the optimal Taylor rule (solid line) and the (benchmark) estimated Taylor rule (dashed line) based on randomly selected 10.000 draws from the posterior distribution of the structural and shock parameters over the Greenspan period under the speed limit targeting (SLT) regime. The policy preference parameters are kept fixed throughout the simulations to the values obtained previously.

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