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Monetary Policy under Imperfect Commitment: Reconciling Theory with Evidence

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Abstract

In the standard forward looking models of the recent literature, theoretical optimal monetary policy rules imply much higher inertia of interest rates than estimated historical policy rules. Motivated by the observation that theoretical policy rules often assume perfect commitment on the part of the monetary authority, this study formulates the monetary policy behavior with a *continuum* from discretion to full commitment, and using this setup seeks to match the theory with evidence. It is shown that, optimal instrument rules under imperfect commitment exhibit less inertia on the policy instrument; the degree of inertia declining as the policy moves from full commitment to discretion. Therefore, under the assumption that the monetary authorities operate somewhere in between discretion and commitment, historically observed policy behavior can be reconciled with the optimal policy rules—even in a purely forward looking framework. As a by-product, we propose a method to measure the stance of monetary policy from the perspective of discretion versus commitment. To test our proposal, we estimate a structural monetary policy rule for the Federal Reserve Bank, which nests discretion and commitment as special cases. Empirical results suggest that recent practice of monetary policy has been closer to commitment than the policy pursued in the 70's.

Keywords: Optimal monetary policy, instrument rules, discretion, commitment.
JEL Classification: E52, E58

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1 Introduction

In the standard forward looking models of the recent literature, theoretical optimal monetary policy rules under commitment imply much higher inertia of interest rates than estimated historical policy rules. For example, Rotemberg and Woodford (1998), and Giannoni and Woodford (2003) derive optimal policy rules under commitment using standard baseline forward looking models. These authors e.g., emphasize that *theoretical* optimal rules involve not only intrinsic inertia in the dynamics of the funds rate, but also are actually "super inertial", i.e., the implied dynamics involves a root larger than 1, resulting an explosive path. However, as is also emphasized in these and many other studies, *estimated* historical rules typically do not have this property. On the other hand, optimal rules computed under discretion in forward looking models are far less inertial — if not inertial at all — than the estimated rules. This observation suggests that a policy rule somewhere in between commitment and discretion may reconcile the observed degree of inertia with the theoretically implied ones in forward looking models.

This paper, then, attempts to match recommendations of the theoretical models with actual estimates of the historical rule, by incorporating some degree of imperfection to typical full commitment solutions. We introduce the notion of "imperfect commitment" to emphasize that the policy maker acts in a state between discretion and commitment. Accordingly, we construct a continuous metric for the stance of monetary policy from a discretion versus commitment standpoint, in which full discretion and full commitment correspond to 1 and 0, respectively, while imperfect commitment is in between. Using this metric, we seek to answer how much discretion (or equivalently how much commitment) must be introduced into the standard baseline model, so that the degree of inertia implied by theoretically optimal policy rule matches the historical one.

Recently, there have been a number of attempts to match the theoretical rules with the estimated rules. However, these studies consider backward looking models, where discretionary solution is exactly the same as the solution under commitment—incorporating no intrinsic inertia in the behavior of the policy maker other than that is embedded in the structural law of motions. Moreover, these studies either motivate an *ad hoc* interest rate smoothing objective as e.g., in Sack and Wieland (2000), or introduce uncertainty as e.g., in Rudebush (2001) to obtain more inertial theoretical rules. Therefore, the problem they need to address is how to obtain *more* history dependence in theoretical rules—exactly the opposite of what we have in this study.

We argue that, deviations of the actual monetary policy rule from the full commitment rule can be decomposed into two main sources: first, commitments are imperfect, because they do not last forever. One interpretation may be that, due to publicly known factors such as reappointments of the central bank administrations, large aggregate shocks, or institutional environment, policy maker reoptimizes with a fixed probability that is common knowledge. Hence, in such a case, central bank's overall credibility of ability is not perfect, but it is stable and perfectly known. Second, commitments are imperfect because the central bank lacks some credibility of intention, in the sense that private agents in general expect the commitment to last shorter than that is intended by the central bank.

We show that, under imperfect commitment, observed behavior of the instrument of the central bank will be related to past values of the instrument itself and other target variables in a less inertial way, rendering the implied theoretical policy behavior closer to the estimated ones. In fact, within the setting, by choosing the "appropriate" degree of commitment, any degree of interest rate inertia can be obtained from the central bank's optimization problem.

On the other hand, our theoretical approach to represent instrument rules under imperfect commitment suggests a method to construct a performance measure of the policy pursued by the central banks. For once the dynamic inefficiency is parametrized and incorporated into the policy rule, it can be identified directly by estimating the structural instrument rule. This provides a stance of monetary policy on the ground of proximity to full commitment behavior. If one regards the full commitment with perfect credibility as the ideal policy making, then it can be argued that, the more the policy behavior deviates from it, the less efficient is the policy rule.

Accordingly, we specify an instrument rule embedding the assumptions just mentioned, and estimate the theoretically constructed commitment parameter for the terms of three Fed Governors. Empirical findings suggest that, monetary policy during Volcker and Greenspan tenures were conducted with a similar degree of commitment. Moreover, provided that the policy makers had a similar model in their mind, post 1980 (Volcker-Greenspan) policy was closer to commitment than the policy followed during 1970's (Burns-Miller).

The model does not involve time inconsistency in the sense of Barro and Gordon (1983) since the objective of the policy maker involves target variables that are consistent with the steady state. However, as shown by Woodford (1999) and Clarida, Galí, and Gertler (1999) there is still inconsistency resulting from forward looking behavior of the agents — namely "dynamic time inconsistency" or stabilization bias, as called by Svensson (1997). In such an environment, credible commitment to a policy rule can improve the constraints faced by the policymaker, delivering a more efficient output-inflation frontier. In that sense, the measure we derive for the stance of monetary policy can be interpreted as a measure of dynamic efficiency, where the most efficient policy corresponds to full commitment under perfect credibility, and the least efficient is the period by period optimization.

While estimating the policy preferences directly from the policy rule is common in recent studies,[1] to our knowledge, there is no reported attempt in the literature to quantify a measure of dynamic efficiency (or proximity to a commitment regime) of the monetary policy by directly estimating a structural policy rule. In that sense, we believe, our approach is novel.

To illustrate the main theme, next section summarizes the instrument rule (or the policy reaction function) derived by Giannoni and Woodford (2003). Third section derives an imperfect commitment version of the rule and discusses in what conditions it can match theory with evidence. Fourth section carries out a structural empirical exercise to estimate the stance of monetary policy during different periods by using the metric introduced in the previous section, leaving the fifth section to conclude.

2 A Standard Optimal Interest Rate Rule

Giannoni and Woodford (2003) derive an instrument rule that is in the same form as estimated Taylor-wise rules. Using a similar setup explained below, these authors' proposed policy rule consistent with the optimal state contingent plan takes the

[1] See Favero and Rovelli (2002), and Özlale (2002) for example.

form

$$i_t = (1 - \rho_1 + \rho_2)i^* + \rho_1 i_{t-1} - \rho_2 i_{t-2} + \phi_\pi \pi_t + \phi_x \Delta x_t \tag{1}$$

where

$$\rho_1 = 1 + \frac{\kappa}{\sigma\beta} + \beta^{-1} > 2, \qquad \rho_2 = \beta^{-1} > 1, \tag{2a}$$

$$\phi_\pi = \frac{\kappa}{\sigma\lambda_i} > 0, \qquad \phi_x = \frac{\lambda_x}{\sigma\lambda_i} > 0, \tag{2b}$$

and $\sigma, \beta, \kappa, \lambda_x, \lambda_i$ are structural parameters and policy preference parameters to be explained below.[2] One can use the calibrated values of structural parameters to contrast the theoretical rule under full commitment with the empirical ones. Using the values estimated by Judd and Rudebush (1998) for the period 1987-1996 of Greenspan's term , and the parameters calibrated in Woodford (2003), for example, Giannoni and Woodford (2003) obtain

	ρ_1	ρ_2	ϕ_π	ϕ_x
estimated	1.16	.43	.42	.30
theoretical	2.16	1.01	.64	.33

.

Note that in the empirical reaction function, ϕ_x represents the coefficient on the level, rather than the change in the output gap. This is because estimated historical rule shows no reaction to past output gaps for the Greenspan period.[3] It is clear that, in parametric terms, the theoretical rule, which is derived under infinitely lasting and perfectly credible commitment, explains *qualitatively,* how forward looking models can deliver the interest rate inertia that is observed in empirical reaction functions. Moreover, the signs of the reaction parameters are consistent with the historical evidence.

Nevertheless, the table reveals an important *quantitative* distinction. Estimated rules (like all other estimated rules in recent studies) exhibit much less inertia on the part of the instrument than the theoretical rule would suggest: as explained above, micro foundations for the theoretical model imply that $\sigma > 0$, $\kappa > 0$ and $0 < \beta < 1$,[4]

[2] When the policy is time dependent, initial conditions of $x_1 = i_0 = i_1 = 0$ has to be added to (1).

[3] It involves a significant reaction to difference of the output gap for the Volcker period though.

[4] See Woodford (2002) chapter 4.

and thus ρ_1 and ρ_2 has to satisfy conditions (2a), implying super-inertial behavior of the instrument *regardless of any specific calibration of the model.*[5] Therefore, not only the two rules look different in terms of magnitudes of the reaction coefficients, but indeed, there are no feasible parameter values reconciling the super-inertial behavior of theoretical rule with the historical ones!

3 Optimal Instrument Rule under Imperfect Commitment

In this section, we introduce a generalized version of the instrument rule (1). Our purpose is twofold: First we wish to explore the implications of relaxing the assumption of full commitment (or perfect credibility) to allow for partial degree of discretion, and to see if this can be helpful in matching empirically observed rules with the theoretical ones. Second, we want to prepare grounds for deriving a method to measure the dynamic efficiency of the Fed policy by direct structural estimation of the instrument rule, and conducting an assessment of past US monetary policy on this ground.

3.1 The model

The structural model and the objective of the central bank is identical to Giannoni and Woodford (2003) except that we assume the central bank targets a positive rate of inflation.[6] The baseline model is a standard forward looking model consisting of an IS curve and an AS curve which have increasingly became the workhorse of contemporary monetary policy analysis.[7]

The model consists of two structural equations that are derived from optimizing behavior of private sector: an aggregate supply equation derived from the first order condition for optimal price setting by the representative supplier and an IS curve

[5]This can be seen by writing the instrument rule as $i_t = (1 - \rho_1 + \rho_2)i^* + (\rho_1 - \rho_2)i_{t-1} - \rho_2\Delta i_{t-1} + \phi_\pi \pi_t + \phi_x \Delta x_t$ and observing that $\rho_1 - \rho_2 = 1 + \frac{\kappa}{\sigma\beta} > 1$, and $\rho_2 = \beta^{-1} > 0$.

[6]This assumption only affects the constant term in the theoretical instrument rule.

[7]See for example, Clarida, Galí and Gertler (1999), Woodford (1999a, 1999b, 2002) among others.

derived from an Euler equation for the optimal timing of purchases. The New-Keynesian aggregate-supply equation (AS) takes the form

$$\pi_t = \kappa x_t + \beta E_t \pi_{t+1} + u_t \tag{3}$$

where π_t is the period t inflation rate defined as the percent change in the price level from $t-1$ to t, x_t is the output gap which is defined as the percentage by which output exceeds its potential, $0 < \beta < 1$ is a discount factor, κ is a positive coefficient and u_t is an exogenous disturbance term. We use the notation $E_t \pi_{t+1}$ to denote private sector expectations regarding of $t+1$ conditional on information available in period t. Equation (3) relates inflation to output gap in the spirit of a traditional Phillips curve. In contrast to traditional Phillips curve, current inflation depends on the expected future course of the economy, and thus on the expectations of future monetary policy, because firms set prices based on expected marginal costs. The parameter κ can be interpreted as a measure of the speed of the price adjustment. Output gap x_t captures the marginal costs associated with excess demand. This specification allows for a shock u_t, which shifts the distance between the potential output and the level of output that would be consistent with zero inflation. These shifts are not considered to represent variation in potential output, and thus appear as a residual in (4). We will name u_t simply as the "supply shock". Within the framework, monetary policy affects real economy, because sellers cannot change their price every period.

The aggregate demand (IS) equation takes the form

$$x_t = -\sigma^{-1} \left[i_t - E_t \pi_{t+1} - r_t^n \right] + E_t x_{t+1} \tag{4}$$

where i_t is the central bank's instrument which is a short term nominal interest rate, σ is a positive coefficient (the intertemporal elasticity of substitution), and r_t^n is the natural rate of interest. Deviations of output from the potential output depends upon real interest rate, expected future output gap and the natural rate of interest. These structural equations can be derived as log-linear approximations to equilibrium conditions of a simple dynamic general equilibrium model in which the infinitely lived representative household maximizes its lifetime utility. For analytical tractability of the solution, exogenous disturbances u_t and r_t^n are assumed to be i.i.d.

and $E(r_t^n - \bar{r}) = E(u_t) = 0$. The two structural equations (1) and (2) together with a policy rule determine the equilibrium evolution of endogenous variables π_t, x_t and i_t.

Objective of the monetary policy is of the form

$$W = E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left[(\pi_t - \pi^*)^2 + \lambda_x (x_t - x^*)^2 + \lambda_i (i_t - i^*)^2 \right] \right\} \tag{5}$$

where π^*, x^* and i^* are target values for inflation, output gap, and interest rate respectively. Although their theoretical value can be derived from the quadratic approximation of the representative agent's utility function, we will assume that the parameters λ_x and λ_i can be treated as policy maker's preferences, and the analysis in this study goes through any objective function that can be represented in the form as (5), whether it represents theoretical welfare or not. It is important to note here that unlike many empirical studies that attempt to match the inertial nature of the empirical reactions functions with the theoretical ones,[8] the objective (5) does not contain an *ad hoc* interest rate *smoothing*. Introducing interest rate *targeting* into objective function, on the other hand, is justified in Woodford (2004). Accordingly, the only source of inertia in this study will stem from the *optimal* inertia that the monetary authority follows due to forward looking behavior.

The problem of the policy maker is to choose a policy rule to implement the equilibrium processes which minimize (5) subject to (3) and (4). There are two main approaches in the literature to solve this problem: under full comitment (the assumption of infinitely lasting commitment with perfect credibility), central bank optimizes once and for all, and announces a state contingent policy rule that will be implemented forever. Under the discretionary approach, central bank re-optimizes each period.

3.2 Formulating Imperfect Commitment

A convenient way to introduce an intermediate behavior between discretion and full commitment is to divert from the two main assumptions underlying commonly used

[8] See forexample, Rudebush (2001) or Sack and Wieland (2000) among others. These authors use purely backward looking model of the economy hence, in their framework, dynamic inconsistency does not exist. Therefore, imperfect commitment behavior is irrelevant to these studies.

full commitment setup in the literature. The first assumption is that commitment lasts forever. Following Roberds (1987) and Schaumburg and Tambalotti (2001), we generalize this condition by assuming an exogenous process that generates stochastic reformulation of the commitment, thereby creating finite lasting commitments on average. On the other hand, second crucial assumption in full commitment models is that central bank has perfect credibility of intentions. That is, private sector expects the future course of monetary policy to be in line with central bank's true intentions. We relax this assumption and introduce imperfect credibility of intentions into the model by allowing the private sector's expected regime duration to differ from the policymaker's intended average duration of a commitment.

3.2.1 Finite Commitment Regime

Suppose there is an exogenous stochastic signal realized at the beginning of each period which takes the values "optimize" with probability α^o and "do not optimize" with probability $(1-\alpha^o)$, i.e., the central bank reformulates the policy with probability α^o each period. In this case, average duration of a commitment regime turns out to be $\frac{1}{\alpha^o}$, hence, the commitment will be finite for nonzero values of α^o. In an environment where α^o is common knowledge, we will say the commitment regime is imperfect but the central bank has perfect credibility of intentions, since the private agents' expectations about the future course of credibility match exactly those of the policy maker's. Therefore, the private agents take the probability of a reoptimization correctly into account and the policymaker is aware of the fact that she may have to reformulate the policy with probability α^o. After each reoptimization, the central bank commits to a rule which is optimal as of the most recent period. The new commitment is also expected to end with probability α^o, and so on...

3.2.2 Imperfect Credibility of Intentions

Now, assume that the central bank still expects to reoptimize with probability α^o, however private sector thinks the regime will, on average, last shorter than$\frac{1}{\alpha^o}$. Namely, the private agents expect the central bank to reformulate the policy with a probability $\alpha^o + \mu$ where a nonzero μ represents the imperfect credibility of intentions.[9]

We will assume that μ is exogenously given and cannot be changed by the central bank in the short run. Given α^o, the higher is μ, the less credible is the central bank. When $\mu = 1 - \alpha^o$, private agents expect the central bank to reoptimize every single period, reflecting complete lack of credibility. If $\mu = 0$ the monetary authority has fully credible intentions, since private sector expects the regime to last on average $\frac{1}{\alpha^o}$ periods, as intended by the policymaker.

The central bank, on the other hand, knows that she is not perfectly credible, and takes this into account while computing the optimal rule. Consequently, the policy is conducted in such a way that incorporates these two imperfections impeding the commitment behavior. Solving optimal monetary policy problem subject to these two assumptions will yield a policy rule that nests discretion and commitment as special cases. The case of $\alpha^o = \mu = 0$, for example, will correspond to full commitment under perfect credibility, while $\alpha^o > 0$ and $\mu > 0$ represents imperfect commitment under imperfect credibility.[10]

To summarize, $1 - (\alpha^o + \mu)$ stands for the overall proximity to full commitment behavior. In this set up, commitment is imperfect because of two reasons: α^o represents the finite nature of the commitment, while μ represents the imperfect *credibility* of intentions. In what follows, we will use a composite index to denote the overall imperfection in the policy (or equivalently the degree of dynamic inefficiency), simply as $\alpha^o + \mu = \alpha$, which also denotes the private agents' subjective belief of the probability of a reoptimization.

[9]This can happen e.g., when there is a sudden shift to a longer commitment regime, due to natural or administrative factors, which may not be perceived by the private agents immediately.

[10]Note that there are many credibility definitions in the literature. For example, Miller (1997) decomposes credibility in two terms: credibility of ability, and credibility of intentions. From that perspective α^o can be used to quantify credibility of ability and μ can be used for credibility of intention and consequently, $1 - \alpha^o - \mu$ stands for the overall credibility of the central bank.

3.3 Central Bank's Problem under Imperfect Commitment

In general, Lagrangian of the monetary authority under full commitment can be constructed as

$$E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \Big[(\pi_t - \pi^*)^2 + \lambda_x (x_t - x^*)^2 + \lambda_i (i_t - i^*)^2 \right.$$

$$\left. + \varphi_{1,t+1}(\pi_t - \kappa x_t - \beta E_t \pi_{t+1} - u_t) + \varphi_{2,t+1}(x_t + \sigma^{-1}\left[i_t - E_t \pi_{t+1} - r_t^n\right] - E_t x_{t+1}) \Big] \right\} \quad (6)$$

In an environment where commitments end stochastically and the central bank has only partial credibility, the problem is not trivial. The key question here is whether the peculiar nature of the policymaker's and the private sector's expectations can be incorporated into the conventional Lagrangian form or it will be more convenient to use a Bellman-type setting. As will be seen below, the answer turns out to be both.

Following Schaumburg and Tambalotti (2001), it will be useful to decompose the private sector expectations into intra-regime and inter-regime components. For example, one period ahead expectations of the private sector can be written as

$$E_t[z_{t+1}] = \alpha E_t[z_{t+1} | inter\ regime] + (1 - \alpha) E_t[z_{t+1} | intra\ regime], \quad (7)$$

where inter-regime means conditional on a regime change (i.e., period t and $t+1$ belong to different regimes), and intra-regime means the current regime goes through next period (i.e., periods t and $t+1$ belong to the same regime), and z_t stands for any endogenous forward looking variable at time t..

Note that, due to quasi-discretionary nature of the policy formulation, the problem is circular. In order to compute the optimal rule and the equilibrium processes, one has to solve for the expectations; on the other hand, in order to solve for expectations one has to determine the optimal equilibrium. Fortunately, this problem can be solved analytically by exploiting the purely forward-looking nature of the structural model, and with the help of a plausible guess. The main idea is to represent private sector expectations with intra-regime terms only (i.e., steering away the overlapping expectations problem), so that all the choice variables in the optimization problem belong to the same commitment regime.

In order to understand fully the monetary authority's problem, it will be helpful to note the recursive nature of the problem at a glance. Let $\Delta\tau$ be the (random) duration of the regime which started at time 0. Then, minimum achievable value of (5) can be expressed recursively as

$$\begin{aligned} V_0 &= \min_{\pi_t, x_t, i_t} E_0 \left\{ \sum_{t=0}^{\Delta\tau - 1} \left[(\pi_t - \pi^*)^2 + \lambda_x (x_t - x^*)^2 + \lambda_i (i_t - i^*)^2 \right] + \beta^{\Delta\tau} V_{\Delta\tau} \right\} \quad (8) \\ & \text{subject to (3) and (4).} \end{aligned}$$

where V_t is defined as a value function associated with the central banker's optimal loss at time t. This term appears because the central bank is assumed to take into account not only the losses accrued during her own regime but also the losses of all subsequent regimes. The latter is summarized by a terminal payoff $V_{t+\Delta\tau}$ in the objective function.

Central bank's loss function involves a random running cost function (the first term on the right hand side). When the commitment term ends unexpectedly, say, at $t + \Delta\tau$, her successor faces exactly the same type of problem. The recursive formulation implies that the solution to (8) will be optimal for the successive central bankers as well.

We will be looking for a solution in which the endogenous variables will be linear functions of the state of the economy. To break in the recursive nature of the problem, one can exploit the linear structure by proposing an "educated guess" of the state variables and the solution form.

Claim 1 *Optimum equilibrium processes for the endogenous variables at time t can be expressed as a linear combination of the Lagrange multipliers $\varphi_{1,t}$, $\varphi_{2,t}$, and the exogenous processes u_t, r_t^n.*

Verification

Using the claim, one can obtain a simple characterization of the one period ahead private sector expectations by noting that

$$E_t[\hat{z}_{t+1} | inter\ regime] = E_t[a_1 \varphi_{1,t+1} + a_2 \varphi_{2,t+1} + b_1 u_{t+1} + b_2 \hat{r}_{t+1}^n | inter\ regime] = 0 \quad (9)$$

where $\hat{z}$ denotes the deviation of a variable z from the steady state and $\hat{r}^n_{t+1} = r^n_{t+1} - \bar{r}$. The second equality in (9) is obtained by noting that Lagrange multipliers will be zero at the period of policy reformulation, reflecting the notion that the central bank is not bound by any past promises. Thus (7) can be simplified to

$$E_t[\hat{z}_{t+1}] = (1-\alpha)\tilde{E}_t \hat{z}_{t+1} \tag{10}$$

where $\tilde{E}$ stands for the expectation operator conditional on the regime staying same. On the other hand V_t will be a quadratic function of the state variables, namely $\varphi_{1,t}$, $\varphi_{2,t}$ and the exogenous processes u_t, r^n_t at the regime starting at time t.[11] However, at the beginning of a new regime the Lagrange multipliers will be set to zero, indicating the disregard of past commitments. Therefore, the value function will only depend on the exogenous processes u_t and $\hat{r}^n_t$. Accordingly, Lagrangian of the central bank can be written as

$$E_0 \left\{ \sum_{j=0}^{\infty} (1-\alpha^o)^{j-1} \alpha^o \Big[\beta^j V(u_j, \hat{r}^n_j) + \sum_{t=0}^{j-1} \beta^t \frac{1}{2} (\hat{\pi}_t^2 + \lambda_x \hat{x}_t{}^2 + \lambda_i \hat{\imath}_t^2) \right.$$
$$\left. + \varphi_{1,t+1}(\hat{\pi}_t - \kappa \hat{x}_t - \beta(1-\alpha)\hat{\pi}_{t+1} - u_t) + \varphi_{2,t+1}(\hat{x}_t + \sigma^{-1}\left[\hat{\imath}_t - \hat{\pi}_{t+1} - \hat{r}^n_t\right] - (1-\alpha)\hat{x}_{t+1}) \Big] \right\},$$

which can be simplified to

$$E_0 \left\{ \sum_{t=0}^{\infty} ((1-\alpha^o)\beta)^t \Big[\alpha^o \beta V(u_{t+1}, \hat{r}^n_{t+1}) + \frac{1}{2} (\hat{\pi}_t^2 + \lambda_x \hat{x}_t{}^2 + \lambda_i \hat{\imath}_t^2) \right.$$
$$\left. + \varphi_{1,t+1}(\hat{\pi}_t - \kappa \hat{x}_t - \beta(1-\alpha)\hat{\pi}_{t+1} - u_t) + \varphi_{2,t+1}(\hat{x}_t + \sigma^{-1}\left[\hat{\imath}_t - \hat{\pi}_{t+1} - \hat{r}^n_t\right] - (1-\alpha)\hat{x}_{t+1}) \Big] \right\}.$$

First order necessary conditions with respect to π_t, x_t and i_t are

$$\hat{\pi}_t + \varphi_{1,t+1} - \varphi_{1,t} \frac{1-\alpha}{1-\alpha^o} - (\beta\sigma^{-1})\varphi_{1,t} = 0 \tag{11}$$

$$\lambda_x \hat{x}_t - \kappa \varphi_{1,t+1} + \varphi_{2,t+1} - \frac{1-\alpha}{1-\alpha^o} \beta^{-1} \varphi_{2,t} = 0 \tag{12}$$

$$\lambda_i \hat{\imath}_t + \varphi_{2,t+1} = 0, \tag{13}$$

[11] See Ljungquist and Sargent (2000), Chapter 4.

at each date $t \geq 0$, within the regime starting at time 0. In addition, initial conditions $\varphi_{2,0} = \varphi_{1,0} = 0$ has to be added, reflecting the fact that at the period of optimization, the monetary authority is not bound by past promises. One has to note that these first order conditions define the optimal behavior of the policymaker at any regime: once a reoptimization takes place at time t, it will lead to exactly the same policy as the previous ones, given the initial conditions $\varphi_{2,t} = \varphi_{1,t} = 0$.[12] In that sense, first order conditions represent the optimal policy behavior inside *any* commitment regime.

Moreover, since the problem is linear quadratic, first order conditions (11), (12), (13) and the constraints (4) and (3) together with the initial conditions are sufficient to determine the optimal plan. Using (13) to substitute for the interest rate, the dynamic system (11), (12),(4) and (3) can be represented in the matrix form as

$$\begin{bmatrix} E_t \hat{z}_{t+1} \\ \varphi_{t+1} \end{bmatrix} = H \begin{bmatrix} \hat{z}_t \\ \varphi_t \end{bmatrix} + G\xi_{t+1}, \tag{14}$$

where $\hat{z}_t \equiv [\hat{\pi}_t, \hat{x}_t]^{\prime}$, $\varphi_t = [\varphi_{1,t}, \varphi_{2,t}]^{\prime}$, $\xi_t = [u_t, \hat{r}_t^n]$ and H and G are matrices whose elements involve structural parameters. This system has a unique bounded solution if and only if H has exactly two eigenvalues outside the unit circle. It turns out that the system satisfies this condition, in which case the solution for the endogenous variables can be expressed as

$$q_t = A\varphi_t + \sum_{j=0}^{\infty} B_j E_t \xi_{t+j} = A\varphi_t + B_0 \xi_t, \tag{15}$$

verifying the guessed solution (9).

Theoretical interest rate rule under imperfect commitment. Following Woodford and Giannoni (2003), it is possible to rearrange the first order conditions to obtain an instrument rule for the interest rates. From (12) and (13) one can solve the Lagrange multipliers as functions of x_t, i_t and i_{t-1}. Using these expressions to substitute out the Lagrange multipliers in (11), one can obtain a linear relation

[12] It may appear that the conditions (11), (12), and (13) reflect the once-and-for-all solution to the optimization problem as in the full commitment case. However in this set up, monetary authority optimizes more than once, leading to a completely different equilibrium than the equilibrium characterized by solving (11), (12), and (13) together with (4) and (3).

among the variables π_t, x_t, i_t, i_{t-1} and i_{t-2}, which can also be expressed as an *instrument rule* of the form[13]

$$i_t = \bar{\delta} + \bar{\eta}_1 i_{t-1} - \bar{\eta}_2 i_{t-2} + \phi_\pi \pi_t + \phi_x x_t - (1-\alpha)\phi_x x_{t-1}, \tag{16}$$

with initial conditions of

$$i_{-1} = 0, \; i_{-2} = 0. \tag{17}$$

where

$$\bar{\eta}_1 = \frac{1-\alpha}{1-\alpha^o}\rho_1, \; \bar{\eta}_2 = (\frac{1-\alpha}{1-\alpha^o})^2 \rho_2,$$

As explained above, (16) and (17) represent behavior of the central bank *within* a specific commitment regime. In other words, (16) is the average instrument rule inside any regime (starting at time 0 here, without loss of generality), conditional on the regime staying the same forever. However, overall behavior of the central bank will be different since there will be reoptimizations with an average frequency of α. This exactly amounts to incorporating the finite commitment effect.[14] Accordingly, one can characterize the overall behavior of the instrument rule by summing over regime shocks, i.e., by taking into account that there will be a reoptimization with probability α^o each period. The instrument rule averaged over regime shocks will be given by

$$i_t = \delta + (1-\alpha)\rho_1 i_{t-1} - (1-\alpha)^2 \rho_2 i_{t-2} + \phi_\pi \pi_t + \phi_x x_t - (1-\alpha)\phi_x x_{t-1}, \tag{18}$$

where

$$\delta = (1 - \eta_1 + \eta_2)i^* + \frac{1}{\lambda_i \sigma}(\kappa \pi^* - \alpha x^*). \tag{19}$$

Here, α reflects the overall degree of commitment. Imperfections in the commitment process can be decomposed into two sources. Recall that $\alpha = \alpha^o + \mu$ where α^o reflects the finite duration of the commitment regime (or ability of the central bank), and a non-zero μ represents imperfect credibility of intentions. Suppose, for example, that $\alpha^o = .2$ and $\mu = .3$. In this case, the central bank contemplates an average regime duration of 5 quarters ($\frac{1}{\alpha^o}$), while the private sector expects on average the commitment to end every 2 quarters ($\frac{1}{\alpha^o+\mu} = \frac{1}{\alpha}$). Now, two commitment

[13]Had the optimality conditions not involved the contemporenous interest rate, then they would have been called targeting rules as defined by Giannoni and Woodford (2003).

[14]Recall that imperfect credibility effect is already embedded in (16).

is imperfect because of two reasons: First, commitment is finite (lasts 5 quarters on average) because of limited ability of the bank, i.e., the central bank *does* reoptimize every five quarters on average. Moreover, there is a credibility gap (μ) causing the policy response to deliver less inertial policy rates than it would have been under full credibility.

If both of the parameters are zero, then α is equal to zero, i.e., central bank can commit for an infinite number of periods *and* the private sector expects the current commitment to last forever. Not surprisingly, in this case instrument rule (18) replicates the rule under infinite-lasting commitment with perfect credibility. On the other hand, when α^o is equal to one and $\mu = 0$, i.e., if the central bank optimizes each period so that credibility is irrelevant, policy instrument only reacts to current levels of inflation and the output gap, involving no intrinsic inertia. This corresponds exactly to full discretion. For the values in between, (18) reflects the average behavior of the policy instrument under varying degrees of "efficiency".[15] Accordingly, the term $1 - \alpha$ can be named as "proximity to commitment", "degree of commitment", or "degree of dynamic efficiency". As a consequence, $1 - \alpha$ may yield a reasonable metric to rank past monetary policy from the perspective of how efficiently gains from commitment are accrued by the central bank.

3.4 Empirical Rule versus Theoretical Rule: A Comparison Under Imperfect Commitment

The theoretical instrument rule (1) derived under full commitment and perfect credibility involves much higher inertia than empirically observed ones. A natural question to ask at this point is:Can the concept of imperfect commitment of the kind introduced here reconcile this discrepancy? Or, to what extent the observed lack of super-inertia can be justified by the imperfect commitment behavior?

Parameters of the instrument rule (18) under imperfect commitment already suggest an interesting result: for any $\alpha \in (0, 1)$, (18) will imply less inertial interest rate path than the rule with full commitment under perfect credibility. This can be seen simply by noting that the largest root of the lag polynomial $(1 - \rho_1 z^{-1} + \rho_2 z^{-2})$

[15] We define the optimal policy rule under full commitment as the most dynamically efficient rule.

is greater than the largest root of the polynomial $(1-\rho_1(1-\alpha)z^{-1}+\rho_2(1-\alpha)^2z^{-2})$. The former is a measure of the inertia under full-commitment rule, while the latter reflects the inertia of the rule under imperfect commitment. It is straightforward to show that the ratio of the latter to the former is $(1-\alpha)$, i.e., the degree of inertia is monotonically decreasing in α. This also implies that, given any specific couple of theoretical and empirical interest rates, there exists a level of commitment (equivalently some level of α) that reconciles theory with evidence. More importantly, this result *does not depend on any specific calibration* of the model, or any of the estimated coefficients.

What is the range of α that implies a super-inertial rule? This can be answered directly by examining the largest root of the lag polynomial involving the interest rate in (18). Using the calibration in Woodford (2003), we find that for $\alpha < .32$, (18) exhibits a super-inertial behavior on the part of the instrument. Note that this result is independent of the policy parameters λ_x and λ_i but depends on the calibrated ratio $\frac{\kappa}{\sigma}$. Therefore, for robustness concerns, the same exercise is carried among a range of $\frac{\kappa}{\sigma}$ in Table 1. For a wide range of $\frac{\kappa}{\sigma}$, the lowest α that does *not* deliver a super inertial behavior varies between .2 and .4. Moreover for every plausible $\frac{\kappa}{\sigma}$, it is possible to find some degree of commitment under which the policy instrument does not exhibit super-inertial behavior. On the other hand, (18) reveals that under imperfect commitment, interest rate responds more to current output gap than past output gap—qualitatively similar to the estimated historical policy rules.

How much imperfection—whether it originates from finite duration or lack of credibility of intention—has to be introduced into a forward looking model, to deliver an optimal policy behavior that mimics the historically estimated rules? One can make a better quantitative judgement by constructing a table of coefficients for a range of α's. Table 2 tabulates the coefficients of the optimal rule under varying degrees of commitment. For some range of α's (between .4 and .5), theoretical rules and estimated rules look surprisingly close. Therefore, imperfect commitment of the kind that is analyzed here may be helpful in reconciling the theoretical policy rules with the empirically observed behavior of the policy makers.

It is important to remind at this point that we do not provide any explanation about why imperfect commitment may occur,[16] since the existence of a finite lasting commitment along with some degree of lack of credibility is exogenously given. Nor, we claim that the mechanism introduced in this study is the only way to model inertia in the interest rates. What is crucial here is to realize that if monetary authorities are assumed to operate under imperfect commitment, implied theoretical instrument rules—even under the purely forward looking model considered here—may be largely consistent with observed instrument rules.

4 Federal Reserve Bank and the Dynamic Efficiency of Instrument Rules

The shift in US monetary policy after the 80's is a widely documented evidence among the scholars of monetary policy. Several authors have already reported this finding by either directly estimating Taylor type rules, or by counter-factual model exercises .[17] Nevertheless, these studies generally use a reduced form instrument rule, or a mechanic reaction function to represent the systematic component of monetary policy, and thus, do not reveal much information about the possible behavioral sources of changes. On the contrary, this study seeks to add another dimension by explaining the documented changes in the instrument rules by a behavioral change—namely, shift towards commitment.

Therefore, the goal is to derive a measure of the behavioral shift in the Fed policy from the perspective of efficiency in exploiting the gains from commitment. Indeed, our characterization of imperfect commitment in the previous section already suggests a method to measure the overall stance of monetary policy, in terms of how close it appears to the full commitment regime: recall that the parameter α reflects the overall imperfections in the commitment process. Thus, the model suggests that once the parameter α is identified and estimated it can be used to construct a

[16] Or, we do not seek to explain why—with the common terminology—a perfect commitment technology may not be available.

[17] For the evidence using Taylor type reaction functions, see Clarida, Gali and Gertler (2000), and Judd and Rudebush (1998). For a fully specified counter-factual model exercise, see Giannoni and Bovin (2003).

measure for proximity to commitment.

4.1 Specification

Recall that the theoretical interest rate rule is given by

$$\begin{aligned} i_t &= \bar{c} + \frac{\kappa}{\sigma\lambda_i}\pi_t + \frac{\lambda_x}{\sigma\lambda_i}x_t - (1-\alpha)\frac{\lambda_x}{\sigma\lambda_i}x_{t-1} \\ &\quad +(1-\alpha)(1+\frac{\kappa}{\sigma\beta}+\beta^{-1})i_{t-1} - (1-\alpha)^2\beta^{-1}i_{t-2}, \end{aligned} \tag{20}$$

where

$$\bar{c} = (1-(1-\alpha)(1+\frac{\kappa}{\sigma\beta}+\beta^{-1}) + (1-\alpha)^2\beta^{-1})i^* - \frac{1}{\lambda_i\sigma}\pi^*(\kappa + \frac{\lambda_x\alpha(1-\beta)}{\kappa}), \tag{21}$$

since $\pi^* = \frac{\kappa}{1-\beta}x^*$.

An empirical counterpart of the instrument rule would be

$$i_t = c + \eta_1 i_{t-1} + \eta_2 i_{t-2} + \phi_\pi \pi_t + \phi_{1x}x_t + \phi_{2x}x_{t-1} + \epsilon_t, \tag{22}$$

where ϵ_t can be interpreted as money demand shocks. It is clear that coefficients of the reduced form instrument rule are combinations of the structural parameters $\alpha, \beta, \sigma, \kappa$, relative weights λ_x and λ_i, the target values π^*, x^*, i^*, and the degree of commitment, $(1-\alpha)$. An empirically observed change in the instrument rule may result from a change in any of these parameters. Direct estimation of the reduced form instrument rule (22) will not reveal much information about the behavioral shifts in the conduct of monetary policy across regimes. It is rather necessary to identify the "deep" parameters in order to assess the sources of changes in policy behavior.

Indeed, there are studies in the literature estimating the preference parameters (λ_x and λ_i) from interest rate rules.[18] However, there is no reported attempt on extracting information about the commitment behavior of the central bank. Our setup provides a simple way to fill this gap, since the degree of deviation from the perfect commitment behavior, α, appears directly in the instrument rule (20)

[18] See Lippi, 1999 Ch.8, Cecchetti, McDonnel and Perez-Quiros, 1999, Favero and Rovelli (2002), and Özlale (2002) among others.

along with other structural parameters. Once α is identified, it is straightforward to rank policy rules across regimes in terms of proximity to full commitment, since, according to our setup, the lower is α, the closer is the policy to full commitment.

It is clear that not all the structural parameters can be identified by estimating (20). One way to solve this problem is to borrow calibrated values of some of the parameters from other studies that use a similar model, and estimate the rest. The parameters β, σ, and κ have been already calibrated in the literature by using the structural equations (4) and (3). In what follows, we will adopt the calibrated values from Giannoni and Woodford (2003) which can be tabulated as

β	σ	κ
0.99	0.16	0.024

,

and maintain the assumption that these parameters do not depend on policy.[19]

On the other hand, relative weights on output gap and interest rate variability, λ_x and λ_i will be allowed to change across different tenures. We believe that this is plausible, since these parameters reflect the policy preferences and may vary with the changes in the composition of the Federal Open Market Committee, especially with changes in the Fed Chairmanship. Therefore, calibrated values of λ_x and λ_i used to determine the theoretical rule in the previous section, will not be used for the empirical exercise; instead they will be identified directly from the structural instrument rule. Doing so will provide the estimates of chairmen-specific policy preferences—an extra by-product of the analysis.[20] Therefore, it will be possible to contrast across regimes the policy preferences as well as the degree of commitment, $(1-\alpha)$.

As it is clear from equations (20) and (21), the target variables π^* and i^* cannot be identified simultaneously. For two terms are embedded in the constant term c, and thus cannot be pinned down separately.[21] Of course, one can assume a specific

[19] Note that β, σ and κ are deep parameters originating from individual behavior of agents. Since they are determined by micro foundations, it is reasonable to argue that these parameters should stay constant across different policy regimes — a property necessary to be immune to the Lucas (1976) critique.

[20] Note that the values of λ_x and λ_i do not affect the inertia of the policy instrument but they matter for the response of monetary policy to inflation and the output gap.

[21] Note that x^* and $\bar{r}$ can be identified once the values of π^*, i^* are determined.

value for the inflation target; then through the estimates of the other parameters, it is possible to obtain an estimate of the funds rate target. Conversely, assuming a specific funds rate target, one can pin down inflation target. However, given the uncertainty in choosing the values for i^* and π^*, we will not put much emphasis on target rates, yet treat the parameter δ as an independent constant. Moreover, since α does not enter the intercept, the constant term adds no additional information about the policy behavior (of the type we analyze here)

Consequently, equation (20) will be used to identify the degree of dynamic efficiency of the policy rule, $(1 - \alpha)$, as well as the policy preferences λ_x, λ_i.

4.2 Estimation

4.2.1 Some Structural Issues

Defining the ideal (most efficient) policy making as full commitment under perfect credibility, we explore, how close to ideal was the policy conducted during the tenures of different Fed chairmen. Our main hypothesis is that the documented changes in the behavior of the monetary policy instrument in the US after 1980's can be largely reconciled with a shift towards full commitment behavior.[22] In order to conduct this test, we simply estimate the parameters α, λ_x, and λ_i for the terms of three Fed chairmen, using the structural specification of the instrument rule. The value $1-\alpha$ is of particular interest, since it reflects the performance of the policy according to the criterion we propose.

The parameters of interest can be directly pinned down by simply estimating equation (20) using nonlinear least squares. However, the theoretical model imposes some complications. Note that the output gap, inflation and the interest rates are determined simultaneously: instrument reacts to the contemporaneous values of the endogenous variables but also affects them. It is possible to solve this problem by using a delayed effect version of the structural model, as proposed by Giannoni and Woodford (2003), where the inflation and output gap are determined one period in advance. In this case, the policy rule stays exactly the same, except that we

[22]Note that, according to the model, this shift can be either due to increased credibility or increased ability of the Fed.

can use the nonlinear least squares estimation using the contemporaneous values of the variables, since shocks to the policy are not correlated with the right hand side variables due to the delayed effect.[23] In what follows we will simply refer to Giannoni and Woodford and estimate (20) using the method of nonlinear least squares.

4.2.2 Results

In the remainder of this section we present the estimates of the structural instrument rule. We document the role of the policy preferences and the proximity to full commitment for the policy reaction function. First we estimate the parameters of interest for each chairmen using nonlinear least squares, and then, construct various stability tests across periods.

Our estimates use quarterly time series, spanning the period 1970:3-2001:4, i.e., mostly the term of three chairmen: Burns,Volcker and Greenspan.[24] All the data were drawn from Federal Reserve Bank of St. Luis database (FRED). We use average federal funds rate in the first month of each quarter, expressed in annual rates, as the interest rate variable. Our inflation variable is annualized rate of change of the GDP deflator between two subsequent quarters. Our "output gap" series is constructed as the deviation of the logarithm of GDP from a fitted quadratic function of time.[25]

Table 3 reports the nonlinear least squares estimation of the coefficients α, λ_x and, λ_i for the tenure of three Fed Chairmen. Recall that overall efficiency of policy is measured by $(1-\alpha)$. Namely, we consider the ideal policy making as $\alpha = 0$, i.e., when the monetary authority operates under full commitment with perfect credibility, while $\alpha = 1$ corresponds to period by period optimization or zero credibility.

One noteworthy feature of the estimations is that (post 1982) Volcker and Greenspan

[23] See Giannoni and Woodford (2003) for a detailed exposition. These authors also consider a more general case than that is mentioned here.

[24] We skip the Miller period since it is not long enough to test the rule. The terms are 1970:3-1978:2 for Burns, 1979:3-1987:2 for Volcker and 1987:3-2003:4 for Greenspan. However, since the operating instrument was borrowed reserves during 1979:3-1982:3, we prefer to discard this period from the estimations.

[25] We also repeated the estimations based on CPI and CBO output gap. The results did not change much, hence we do not report them here.

periods involve a similar degree of efficiency (0.47 and 0.49), while the monetary policy in Burns period seems to have been conducted under a less efficient way (with a degree of 0.29). In other words, these results point out that Volcker and Greenspan pursued a policy that is closer to the ideal case of full commitment than the policy in the 70's. These findings suggest that there has been an improvement either in policy ability or in policy credibility after 1980's. Whether the change originates from favorable natural factors or from improvement of Fed's credible track, the conclusion is the same: Fed's implied instrument rule suggests a more efficient rule after 80's compared to 70's.

The bottom panel of Table 3 tabulates several stability tests across periods. It is clear that the hypothesis that α is equal in Volcker and Greenspan periods cannot be rejected. On the other hand, monetary policy under Burns period seems to have been conducted under a significantly different style than post 1980's chairmen. Therefore, recent approach of analyzing the monetary policy under two different eras—before and after Volcker—seems to be appropriate.

Moreover, the estimated policy preferences are very similar in Volcker and Greenspan periods. However, we cannot reject the hypothesis that, during former's term, policy maker's objective was pure inflation targeting, while we can reject it during the latter's term. This result is remarkable, since it suggests that although the policy preferences seem to be different, the regimes were similar in terms of dynamic efficiency. In other words, the policy was conducted in a relatively efficient way in both periods, exploiting the forward looking expectations in such a way that the central bank faces an improved output-inflation trade-off compared to Burns' period.

One other noteworthy feature of the estimations is the sizeable change in the magnitude of the weight on interest rate stabilization after 1980's. Nevertheless, this result should not be strongly emphasized since the stability tests cannot be rejected for this parameter.

5 Summary and Conclusion

The purpose of this study has been twofold. First, we attempted to reconcile the theoretical rule implied by a purely forward looking model with the historically estimated Taylor-like rules. Second we aimed to construct and estimate a measure of monetary policy on the grounds of dynamic efficiency—namely proximity to a full commitment regime.

To achieve these goals, first, the concept of imperfect commitment is introduced into the standard optimal monetary policy problem of recent forward looking models. A theoretical rule that nests discretion and commitment as special cases, is used to identify the dynamic efficiency of the commitment policy. It is shown that the notion of imperfect commitment, by and large, explains the discrepancy between theory and evidence. In particular, it is possible to obtain non super inertial rules by using the appropriate degree of dynamic efficiency—a feature that theoretical rule under full commitment have not delivered.

Second, we estimate the preference parameters of the monetary authority and the proximity to full commitment, directly from the structural policy rule for three different Fed Chairmen. Empirical results suggest that late Volcker and Greenspan periods were conducted under a similar philosophy, in the sense that, both periods reveal a similar degree of efficiency, exploiting the forward looking expectations in such a way to achieve a more favorable trade-off between target variables. On the other hand, monetary policy under the tenure of Burns was relatively less efficient.

Finally, recall that the definition of proximity to commitment was derived under two assumptions, that is, commitment regimes are finite, and the private sector expects the commitment to end, on average, sooner than originally intended by the central bank. Stretching our imagination, these assumptions can be combined under two related definitions of credibility, namely, credibility of ability and credibility of intention. Therefore, our analysis implicitly proposes a method to measure the overall credibility of the monetary authority, and the empirical findings confirm that the Fed's credibility has improved after 1980's.

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Table 1: Imperfect Commitment and the Degree of Inertia in Interest Rates

κ/σ	**Highest α implying super-inertial behavior**
.05	.21
.1	.27
.15	.32
.20	.36
.25	.39
.30	.42

Table 2: Comparison of Estimated Rules with Theoretical Rules under Imperfect Commitment.

		i_{t-1}	i_{t-2}	π_t	x_t	x_{t-1}
ESTIMATED		**1.16**	**-0.43**	**0.42**	**0.30**	**-0.03**
THEORETICAL	α=0	2.16	-1.01	0.64	0.33	-0.33
	α=.1	1.94	-0.82	0.64	0.33	-0.30
	α=.2	1.73	-0.65	0.64	0.33	-0.26
	α=.3	1.51	-0.49	0.64	0.33	-0.23
	α=.4	**1.30**	**-0.36**	**0.64**	**0.33**	**-0.20**
	α=.5	1.08	-0.25	0.64	0.33	-0.17
	α=.6	0.86	-0.16	0.64	0.33	-0.13
	α=.7	0.65	-0.09	0.64	0.33	-0.10
	α=.8	0.43	-0.04	0.64	0.33	-0.07
	α=.9	0.22	-0.01	0.64	0.33	-0.03
	α=1	0.00	0.00	0.64	0.33	0.00

Table 3: Structural Estimate of the Instrument Rule

	α	λ_x	λ_i
Greenspan	0.51 (0.04)	0.087 (0.042)	0.98 (0.47)
Volcker	0.53 (0.09)	0.11 (0.12)	0.9 (1.1)
Burns	0.71 (0.06)	0.11 (0.05)	0.53 (0.23)
Structural Change		p-values	
Greenspan-Volcker	0.43	0.88	0.86
Greenspan-Burns	<0.01	0.87	0.32
Volcker-Burns	0.023	0.99	0.069

Note : Samples are Greenspan 1987:3-2003:4, Volcker: 1982:3-1987:2, Burns: 1970:3-1978:2