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Questioning The Taylor Rule

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Questioning The Taylor Rule

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Keywords: Taylor rule, Kalman Filter, Hidden variables, GMM

JEL Codes: E52, C32, C51

QUESTIONING THE TAYLOR RULE[1]

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Abstract

This article estimates a forward-looking Taylor-rule-type reaction function exclusively during Greenspan's tenure and shows a considerable loss in both magnitude and significance of the inflation coefficient compared with the extended sample that otherwise includes Volcker's tenure. That fact indicates that the interest rate pushing up in the early 1980s drives the coefficient towards being greater than one, when in fact it varies. A key variable in determining its size is the output gap, which is unobservable. Therefore, the paper approaches the Kalman filter to estimate the Taylor rule reaction function *jointly* with output gap, in order to characterize the monetary policy in the U.S. from 1960 to 2005. The results show that the point estimation of inflation is overall smaller than one-to-one when the sample is split into either before and after Volcker's appointment as Federal Reserve chairman or before and after Greenspan's tenure. When the model allows for a drifting inflation coefficient, then the estimate is barely greater than one and often negative. Such a dynamics matches up with Greenspan's claim that monetary policy is discretionary and that the Federal Reserve does not follow any simple rule. Consequently, an inflation coefficient inferior to one may be associated with monetary stability, disrupting the Taylor's principle.

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1 Introduction

This article estimates a forward-looking Taylor-rule-type reaction function exclusively during Greenspan's tenure and shows a considerable loss in both magnitude and significance of the inflation coefficient compared with the extended sample that otherwise includes Volcker's tenure. That fact indicates that the interest rate pushing up in the early 1980s drives the coefficient towards being greater than one, when in fact it varies. A key variable in determining its size is the output gap, which is unobservable. Therefore, the paper approaches the Kalman filter to estimate the Taylor rule reaction function *jointly* with output gap, in order to characterize the monetary policy in the U.S. from 1960 to 2005. The results show that the point estimation of inflation is overall smaller than one-to-one when the sample is split into either before and after Volcker's appointment as Federal Reserve chairman or before and after Greenspan's tenure. When the model allows for a drifting inflation coefficient, then the estimate is barely greater than one and often negative. Such a dynamics matches up with Greenspan's claim that monetary policy is discretionary and that the Federal Reserve does not follow any simple rule. Consequently, an inflation coefficient inferior to one may be associated with monetary stability, disrupting the Taylor's principle.

Clarida, Galí and Gertler (2000), henceforth CGG, separate the U.S. monetary policy into before and after Volcker took over the Federal Reserve - Fed - as chairman in 1979. They explain the low inflation afterwards due to an active monetary policy characterized by an interest rate response to inflation greater than one-to-one. Conversely, there was inflation instability in the U.S. before Volcker, because the monetary policy was accommodative, such that the inflation parameter was smaller than one-to-one. Their results are partly consistent with Orphanides (2004), who uses real-data for inflation expectations, and are supported theoretically by Woodford (2003, ch. 4, mainly Proposition 4.4).

However, a number of questions must be addressed before taking CGG's findings for granted. First, Greenspan (2004, p. 39) claims that *"[...] simple rules will be inadequate as either descriptions or prescriptions for policy. Moreover, such rules suffer from much of the same fixed-coefficient difficulties."* Is the former chairman trustful? To answer this question, one must show the flaws of CGG's model and then, at least, estimate a rule with drifting parameters. To some extent, that is what Boivin (2006) tries to do by enabling the parameters in the Taylor rule to vary.

Second, their choice on the sample break is rather arbitrary. But, are their findings robust to other sample breaks? That question is fundamental because Blinder and Reis (2005, p. 19) report subsample instability over Greenspan's time as chairman. If that instability is not accounted for, then how reliable are their coefficients?

Third, it is the combination between a proxy for inflation and the output gap methodology that determines the size and significance of the model's parameters. The Greenbook used by Orphanides (2004) and Boivin (2006) has expectations on the employment rate, but not on the output gap. Hence, as others studies, they estimate exogenously the output gap used in the Taylor reaction function, and so their parameters are still questionable. That observation motivates one to use the interest rate and gross domestic product as signals to estimate *simultaneously* the rule itself and the output gap to which effectively the Federal Open Market Committee, Fomc, might have responded by the time they set the interest rate.

I thus set out three sequential steps to address these issues. In the first one, I expand CGG's sample and estimate a forward-looking Taylor rule from the third quarter of 1979, when Volcker took the helm at the Federal Reserve, to the last quarter of 2005, by the generalized method of moments (Hansen, 1982), GMM. I show that the interest rate response to inflation is even stronger than the outcomes in CGG. Then, I restrict the sample to start when Greenspan took office in the third quarter of 1987. I find that the response to inflation and the parameter significance shrink remarkably, sometimes making the coefficient statistically nonsignificant, and some other times making it significant but statistically inferior to one. Such a low magnitude of the inflation coefficient was also observed by Blinder and Reis (2005, p. 20), who estimate a coefficient less than one in a similar sample. In the same line, Bueno (2008) empirically shows inflation stability under a passive Taylor rule and inflation instability under an active Taylor rule in Brazil. Cochrane (2007, p. 27) says it is theoretically possible to have inflation stability despite a passive Taylor rule.

Still in the first step, the paper uses three proxies for inflation and three for output gap as robustness checks. These checks are important because *"different methods give widely different estimates of the output gap [...] and often do not even agree on the sign of the gap"* as pointed out by Orphanides and Norden (2002). In general, output gap is obtained by detrending output through a linear or a quadratic deterministic trend model (see Fuhrer, 1997). The Congressional Budget Office (CBO) has its own methodology to estimate the potential output, mixing economic models and statistics (see Arnold, 2004). Thus, the three output gaps that stem from these methodologies are combined with the consumer price index, the personal consumption expenditures and the GDP deflator as proxies for inflation to estimate the rule coefficients.

The second step is to estimate the output gap jointly with the Taylor rule parameters and to verify how that variable affects the response to inflation. Such estimation is important, because different output gaps may generate distinct responses to inflation (see Orphanides, 2003) and help explain the outcomes from the GMM method. Since the econometrician does not have the same information as does the Fomc, I construct a model which has a time-varying intercept to proxy for non-observables, including noisy information. Hence, using the interest rate and GDP as signals to obtain the gap by Kalman filter is a natural choice, although to the best of my knowledge nobody has done that yet. Notice that the Kalman filter procedure accounts for mismeasurements and data revisions of GDP in the Taylor rule, because the estimated output gap adapts itself optimally to the rule.

We shall conclude that, regardless of the inflation proxy, the parameters of the model are practically the same across proxies for inflation and that the interest rate response to inflation is smaller than one-to-one even lately. Consequently inflation stability may be associated with a loose monetary policy.

Finally, the third step extends the Kalman filter framework to allow the inflation parameter to vary over time. Indeed, if the rule is discretionary, then the interest rate response to inflation should vary. Following Cooley and Prescott (1976) and Boivin (2005), time variation is structured as a driftless random walk. We shall see that the inflation parameter is not only very volatile, but also that it is often less than one, and sometimes negative along the sample. Furthermore, I exhibit a picture in which we can grasp how the interest rate pushing up in the early 1980s affects the inflation coefficient.

The paper is organized as follows. The benchmark forward-looking Taylor rule model, based on CGG, is discussed in Section 2. Variables used in this work and details about data construction and sample breaks are in Section 3. The first empirical analysis by GMM is in Section 4. The Kalman filter modeling, empirical results and preliminary conclusions are explored in Section 5. Finally, the last section concludes.

2 The Taylor Rule

The policy reaction function to be estimated by GMM is defined in Clarida, Galí and Gertler (2000) as

$$i_t = g_i i_{t-1} + (1 - g_i) \left[(r^* - (g_\pi - 1)\, \pi^*) + g_\pi \pi_{t,k} + g_x x_{t,q} \right] + \varepsilon_t, \tag{1}$$

where

$\varepsilon_t = \upsilon_t - (1 - g_i) \left\{ g_\pi \left[\pi_{t,k} - E_t (\pi_{t,k}) \right] + g_x \left[x_{t,q} - E_t (x_{t,q}) \right] \right\}.$

r^* is the long-run equilibrium real rate;

π^* is long-run target for inflation;

$(r^* + \pi^*) \equiv i^*$ is the desired nominal rate when both inflation and output are at their target levels;

$E_t (\cdot) \equiv E [\cdot | \, \Omega_t]$ is the expectation taken with respect to the information set, Ω_t, available at t;

$\pi_{t,k}$ is the inflation rate between periods t and $t + k$;

$x_{t,q}$ is the output gap between the beginning of t and the beginning of $t + q$;

$g_i \in [0, 1)$ indicates the degree of smoothing of the interest rate changes;

υ_t is a zero-mean exogenous shock on the interest rate.

This paper estimates the forward-looking model by setting $(k, q) = (1, 1)$. However, equation (1) nests other plausible models as, for example, Taylor's (1993), whose rule works with lagged inflation and output. Rudebusch and Svensson (1999) use current inflation and output gap in the rule and estimate a model with very high R^2.[1]

[1] In fact, I have estimated two alternative reaction functions, but I only report one. In the first, I set $(k, q) = (1, 1)$. In the second one, I approximate Rudebush and Svensson's (1999) model by setting $(k, q) = (0, 0)$. Both models are qualitatively alike.

The error term ε_t contains exogenous shocks and forecast errors, such that any vector of instruments $\mathbf{z}_t \in \Omega_t$, orthogonal to the information set when i_t is determined, yields the moment conditions:

$$E_t\left(\varepsilon_t \mathbf{z}_t\right) = 0.$$

The model uses an optimal weighting matrix to account for possible serial correlation in $\{\varepsilon_t\}$. Furthermore, there is some interest in knowing the target inflation π^*, but it is impossible to identify it separately from $[r^* - (g_\pi - 1)\,\pi^*]$. Thus, following Clarida, Galí and Gertler (2000), I impose that the equilibrium real rate r^* is the observed sample average and introduce such restriction directly into equation (1), in order to estimate π^* jointly with the other parameters.

3 Data and Sample Breaks

3.1 Variables

Basic statistics of the data downloaded from the Fed of Saint Louis are in Appendix A. All variables are in log and are seasonally adjusted when appropriate. As usual, the Effective Federal Funds Rate is the interest rate. As proxies for inflation, I follow Jondeau, Bihan and Gallès (2004) and use the GDP deflator (GDPP), consumer price index (CPI), and the personal consumption expenditure index (PCE). CBO is the potential output calculated by the Congress Budget Office and used to obtain the output gap. The instrument set includes lags of the Funds rate, output gap, inflation, M2 growth, and the spread between the 10-year bond rate and the 3-month Treasury bill rate. Variations are calculated between quarters.

Inflations, Funds rate and M2 are monthly data. Thus, monthly variations are accrued over the quarter and then annualized in order to obtain the quarterly equivalent. To be precise, let $i_{j\,t}$ be the interest rate in month $j_t = 1, 2, 3,$ of quarter t. Then, the interest rate corresponding to quarter t is:

$$i_t = \ln \prod_{j_t=1}^{3} \left(1 + i_{j_t}\right).$$

Of course, the other quarterly variables derived from monthly measures follow similar reasoning. Moreover, the proxies for inflation are weakly correlated between t and $t-4$ as shown in Table 1.

Table 1: Correlation between Inflations 1961:1-2005:4

	GDPP	**CPI**	**PCE**
GDPP	1	-0.215	-0.196
CPI		1	0.976
PCE			1

Variations are taken between t and $t-4$.

GDPP: Gross domestic product deflator; CPI: Consumer price index; PCE: Personal consumption expenditures.

In view of this table, if the qualitative results remain unaltered by changing the inflation proxy in the model, the conclusions will be more reliable.

3.2 Deterministic Trend Models

The output gap is a key variable in the rule, because the interaction between it and inflation determines the magnitude of the parameters. Moreover, output gap is unobservable, but it is linked to output, from which the gap can be extracted. On the other hand, output is imprecisely calculated and certainly will be revised a few times after it is released. Those characteristics may contaminate any methodology for obtaining the gap and yield a distorted idea about the conduct of monetary policy. A way of circumvent these limitations is to check the robustness of the estimates using alternative schemes for obtaining the gap. If the coefficients are robust to variations in the output gap, then the importance of mismeasurement reduces considerably. In view of these concerns, I provide details about how I have estimated the output gap before running the GMM.

CGG estimate the output gap through the Hodrick-Prescott filter. Such choice translates into using data unavailable by the time that the Fomc makes decisions. Hence, the procedure is not totally reliable. Thus, I adopt another strategy in the GMM estimates.

There are two usual alternative ways of extracting output gap from output from using only data available until period t, linear and quadratic detrending (Fuhrer, 1997). Such a procedure tends to mitigate the criticism by Orphanides and Norden (2002) regarding the threats of not employing real-time data. On the other hand, since the main point rests on the Kalman filter and since such an approach accounts for mismeasurements and later revision, real-time output is not a big concern here.[2]

Thus, I define the potential output, q_t^n, as a deterministic model:

$$q_t^n = \alpha_t + \beta_t t + \gamma_t t^2. \tag{2}$$

The subindices on α, β and γ denote the coefficients are obtained from an ordinary least squares regression with a sample of t observations. Consequently, to calculate the output gap, x_t, subtract the potential output so estimated from the output, q_t

[2] Even using real-time data based on the Greenbook, as does Boivin (2006), poses some problems. The forecasts may be correlated with the errors and it is difficult to test this hypothesis statistically.

at each time t,:

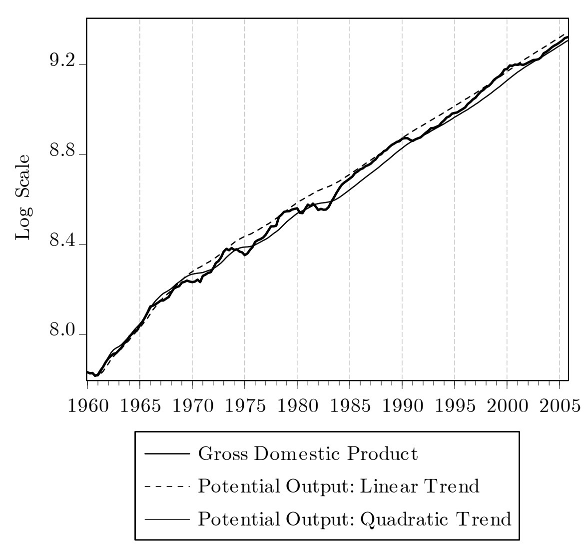
$$x_t = q_t - \widehat{q}_t^n, \ t = 1, 2, \ldots, T.$$

where $\widehat{q}_t^n = \widehat{\alpha}_t + \widehat{\beta}_t t + \widehat{\gamma}_t t^2$ stands for the potential output fitted at time t.

Despite the fact x_t is an estimated variable and thus the standard-deviation of its coefficient in the Taylor rule should take that into account, I shall consider it as observed in accordance with many authors like CGG, Blinder and Reis (2005), Taylor (1999), among others.

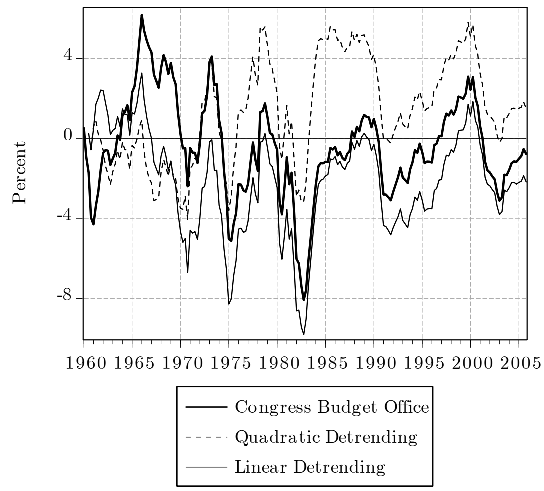
The emphasis is on the arrival of new information as we move over time. By imposing $\gamma = 0$, one can linearly detrend the output to obtain the gap. Figure 1 shows the potential outputs estimated from the gross domestic product - GDP. Notice that the linear potential output is not linear, in view of the method used to estimate it.

Figure 1: Output and Potential Outputs - quarterly data



The distinction between output gaps is important because it may yield conflicting policy recommendations as Figure 2 shows. However, if the rule coefficients are robust to changes in the output gap methodology, then the conclusions will be stronger.

Figure 2: Output Gaps from Detrending Output and from the Congress Budget Office - quarterly data in %



In Figure 2 I have estimated the output gap by detrending the GDP and by subtracting the potential output estimated by the Congress Budget Office - CBO - from the GDP. Although all series have roughly the same tendency, quadratic detrend and linear detrend conflict with each other, whereas the CBO stays in between. For instance, in the 1990s, quadratic detrend indicates expansion, whereas linear detrend indicates recession.

3.3 Sample Breaks

Table 2 presents the standard deviation of inflation and output gap in three unequal samples. We can see that the variance of these variables has been falling over time.

Table 2: Aggregate Volatility Indicators - Quarterly Frequency

Date	Period	Standard Deviation of: Inflation GDPP	CPI	PCE	Output Gap CBO
1960:1 1979:2	Pre-Volcker	2.71	3.31	2.80	2.67
1979:3 2005:4	Volcker-Greenspan	2.05	3.02	2.24	2.12
1987:3 2005:4	Greenspan	0.99	1.53	1.21	1.60

Data seasonally adjusted and annualized. Variations are taken between t and $t-1$. GDPP: Gross domestic product deflator; CPI: Consumer price index; PCE: Personal consumption expenditures; CBO: Congress budget office.

In particular, both the inflation volatility and the output volatility dropped sharply by a half during the Greenspan's period. Therefore his chairmanship merits further investigation, in order to understand whether, in fact, he was stricter than Volcker in terms of reacting to inflation as the Taylor rule intuition leads us to believe.

4 Empirical Analysis: GMM

I estimate a forward-looking Taylor-rule-type reaction function for each subsample by the GMM. In order to minimize any arbitrariness regarding the choice of output gap and inflation, I combine three possibilities of each variable and obtain nine estimates per period.

In this section, I concentrate on discussing and presenting the numbers stemmed from the use of CPI as a proxy for inflation. That variable was used by CGG and by Blinder and Reis (2005), so the outcomes here are comparable. Moreover, to be straightforward, I analyze the last two periods as defined in Table 2, but relegate the numbers corresponding to the samples found in CGG, including those referring to the pre-Volcker period, to Appendix B.1. Of course, the qualitative arguments would not change had I chosen to discuss either PCE or GDPP, and I refer to them when pertinent (see Appendices B.2 and B.3).

Table 3 shows that the entire sample after Volcker makes the size of the parameters seem alike across output gap proxies, except for the interest rate response to the output gap. Other combinations with inflation may increase the magnitude of coefficient g_π and change g_x, however, the size and significance of the other parameters π^* and g_i remain practically the same as shown herein.

The analysis is rather distinct when one restricts the sample to the Greenspan's time. Both magnitude and significance of all parameters but g_i change abruptly, regardless of the choice of inflation. First, the coefficient π^* becomes dissimilar across output gap proxies. It may be negative or highly positive and nonsignificant. In fact, it becomes very unpredictable.

Second, the magnitude and significance of the g_x parameters increase, indicating a greater concern with the economic activity than before. Furthermore, the parameters across all combinations seem to align with each other around 0.3, depending on the inflation proxy.

Third, in all combinations, the size of the inflation coefficient decreases remarkably towards 1, and Wald tests confirm this claim. Sometimes, they become statistically inferior to one. Concerning the standard deviation, it decreases if the coefficient falls below one, but increases if the coefficient remains above one. The combination of higher standard deviation with smaller size makes g_π nonsignificant or almost nonsignificant in several examples. Blinder and Reis (2005) reinforce the findings, because they estimate an inflation coefficient around 0.6 using the unemployment rate to obtain the output gap.

Table 3: Inflation Proxy: Consumer Price Index $(k, q) = (1, 1)$

Sample	**Volcker and Greenspan (1979:3-2005:4)**			**Greenspan**		
Gap Proxy	CBO	L. Trend	Q. Trend	CBO	L. Trend	Q. Trend
π^*	3.330*	3.215*	3.672*	4.913*	1.476	−1.712
	(0.289)	(0.433)	(0.568)	(0.775)	(4.129)	(1.532)
g_π	2.651*	2.646*	2.616*	0.595*	1.435***	0.557*
	(0.405)	(0.424)	(0.409)	(0.167)	(0.767)	(0.114)
g_x	0.129**	0.069	0.014	0.285*	0.164	0.266*
	(0.064)	(0.060)	(0.072)	(0.044)	(0.112)	(0.021)
g_i	0.898*	0.901*	0.901*	0.844*	0.906*	0.855*
	(0.020)	(0.020)	(0.020)	(0.013)	(0.038)	(0.010)
# obs.	106	106	106	74	74	74
$H_0 : g_\pi = 1$?	Reject*, $g_\pi > 1$	Reject*, $g_\pi > 1$	Reject*, $g_\pi > 1$	Reject**, $g_\pi < 1$	Do not reject	Reject*, $g_\pi < 1$
Prob J-test.	0.301	0.165	0.372	0.976	0.969	0.891

(*),(**),(***) significant at 1%, 5%, and 10%, respectively. Standard deviations are in brackets.

Estimated by GMM: $i_t = g_i i_{t-1} + (1 - g_i)\left[(r^* - (g_\pi - 1)\pi^*) + g_\pi \pi_{t,k} + g_x x_{t,q}\right] + \varepsilon_t$

. The set of instruments includes lags 1 to 4 of federal funds rate, inflation, output gap, constant, M2, and the short-long spread.

The results in previous table are consistent with Jondeau, Bihan and Gallès (2004), who find exactly the same conclusion, but use many less instruments.[3]

Since the inflation coefficient decreases in the restricted sample, we may conjecture that it is the interest rate pushing up in the early 1980s that drives it towards being greater than one. Moreover, both the variability of intercept and of inflation coefficient indicate traces of a discretionary conduct of the monetary policy.

If it is true that under Greenspan's chairmanship the Fed policy was characterized by the exercise of period-by-period discretion, the picture here should not be a surprise at all. As a matter of fact, Blinder and Reis (2005) have detected some subsample instability during Greenspan's tenure. Thus, by proxying the output gap dissimilarly, such instability emerges mostly in π^* and in g_π.

The contradiction with the Taylor's principle might be a surprise. The principle posits that an interest rate response to inflation greater than one-to-one characterizes an active monetary policy, which translates into price determinacy or stable inflation. The reverse also holds, an accommodative monetary policy responds to inflation in a magnitude smaller than one-to-one, characterizing an unstable inflation. Nevertheless, we see an inflation parameter g_π inferior to one in Table 3 and in Table 2, combined with extremely low inflation volatility and output, which seems to be counterintuitive. Nevertheless, there are empirical and theoretical arguments consistent with what we have seen. Theoretically, Cochrane (2007) provides conditions for having a passive monetary policy associated with stable inflation and an active monetary policy associated with unstable inflation. Bueno (2008) provides an example confirming his claim by using Brazilian data. He shows that with inflation instability, policymakers responded to it in a fashion greater than one-to-one but

[3] In fact, a better procedure would be to estimate the model by continuous updating. However, my point is to make a direct comparison with CGG. Thus, I keep their specification very closely.

were unable to stabilize prices. And, after stabilizing inflation, the monetary policy became passive. Therefore, I shall explore this issue further for the U.S.

The fact that the inflation coefficients are in general high and very significant using the entire post-Volcker sample makes it more difficult to disrupt the figures by using a narrower sample. But if we observe such disruption, we can ask whether the numbers would change had I taken the output gap at which the Fomc *really* looked when they set the interest rate. They may have looked at the expected unemployment rate, as registered in the Greenbook; however, that is not the output gap. Hence, if they followed a rule, they must have estimated some kind of output not necessarily equal to what is written there. Besides, each member of the Fomc makes his own expectations about the future, which is not necessarily equal to what is read of the Greenbook. Moreover, the Fomc may have looked at other information unavailable to the econometrician that may be driving the inflation coefficient and the intercept someway. Finally, the rule or the model used by the Fomc may be changing, in a way hardly captured in the GMM framework, even if in fact the monetary policy is active. In view of these arguments, the next section estimates the rule jointly with the output gap and a time-varying intercept in order to account for these issues.

5 The Kalman Filter

A crucial novelty here is the simultaneous estimation of the output gap and the time-varying intercept with the other usual coefficients of the rule using the Kalman filter method. To the best of my knowledge, this strategy has not been done yet and it is substantially different from the approach in Orphanides and Williams (2002), for they take output individually to estimate potential output. Thus, under this framework, the section analyzes two issues in sequence. The first is the effect, mainly on the fixed inflation parameter g_π, of estimating the output gap jointly with the Taylor rule. Then, the model allows the coefficient to vary and analyzes the discoveries.

To adapt the Taylor rule to the Kalman filter, we might take the original Taylor (1993) rule that uses lagged inflation and output rather than current values in the reaction function. However, Taylor (1999, p. 12) claims that current and lagged one-quarter variables are practically equivalent models. Thus, I consider the reaction function with current inflation and output[4], which amounts to setting $(k, q) = (0, 0)$:

$$i_t = g_i i_{t-1} + (1 - g_i)(\mu + g_\pi \pi_t + g_x x_t) + \varepsilon_t, \tag{3}$$

where $\mu \equiv [r^* - (g_\pi - 1)\pi^*]$.

Since $(k, q) = (0, 0)$, then the term reduces to $\varepsilon_t = \upsilon_t$. I make one additional assumption by defining $\upsilon_t \sim i.i.N(0, \sigma^2)$. Rudebusch and Svensson (1999, p. 221) defend the use of current gap by arguing that it would help proxying for the set of information available to the members of the Fomc. As a matter of fact, not only does the Fed have much more information about the actual state of the economy compared with the information embodied in the variables of the rule, but it also watches the market continuously and makes decisions more often than at a quarterly basis.[5]

The output gap x_t is unobservable. Thus based on the signals of the interest rate

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[4] I remind the reader that had I set the forward-looking model in the previous section as $(k, q) = (0, 0)$, the conclusions would not have changed at all. Moreover, in previous versions of this paper, I have estimated the rule with contemporaneous variables by maximum likelihood and nonlinear least squares instead of GMM. The conclusions once again hold unchanged.

[5] This is a behavioral reaction function, but of course it does have theoretical foundations. It results from a forward-looking macroeconomic model in which the central bank maximizes a quadratic loss function in deviations of inflation and output from their respective targets. That is, the rule is consistent with a forward-looking model *à la* Woodford (2003, p. 246).

and output with the information in $t-1$, the filter optimally predicts the hidden variable in t. Hamilton (1994) gives a complete explanation about how the filter works. Moreover, the previous section showed some instability in π^*, which translates into making the intercept fluctuate. However, since the main point is on the inflation parameter g_π and for the sake of simplicity, I present μ instead of π^*. Finally, the model permits making g_π time-varying as it will be specified later. Thus, given these considerations, one needs to impose some structure on the potential output, the output gap and the intercept of the model before estimating it.

5.1 Potential Output and Output Gap

Consider the output q_t as the sum of potential output and output gap:

$$q_t = q_t^n + x_t.$$

The goal here is to model the hidden potential output q_t^n and the hidden output gap x_t. The simplest way of modeling potential output is to define it as a linear or quadratic trend model. However, one cannot disregard the possibility that output contains a unit root.[6] Under this assumption, potential output must follow the same logic and possess the same order of integration. Ehrman and Smets (2001) and Kuttner (1994) thus propose a random walk model:

$$q_t^n = q_{t-1}^n + \varepsilon_{q,t},$$

where $\varepsilon_{q,t} \sim i.i.N.\left(0, \sigma_q^2\right)$

I add a stochastic drift to their model to account for persistent shocks on the

[6] See Orphanides and Norden (2002) for a survey on output gap models.

potential output growth, *e.g.*, changes in productivity:

$$
\begin{aligned}
q_t^n &= q_{t-1}^n + \lambda_t + \varepsilon_{q,t}; \\
\lambda_t &= \lambda_{t-1} + \varepsilon_{\lambda,t},
\end{aligned}
$$

where $\varepsilon_{\lambda,t} \sim i.i.N.\left(0, \sigma_\lambda^2\right)$

If the variance σ_λ^2 turns out to be null, then potential output growth features only short-run shocks. Otherwise, the growth features a stochastic trend, λ_t, and a short-run shock, $\varepsilon_{q,t}$.

Regarding the output gap, I follow Kuttner (1994) and Orphanides and Norden (2002) among others, and I assume an AR (2) specification:

$$
x_t = \phi_1 x_{t-1} + \phi_2 x_{t-2} + \varepsilon_{x,t},
$$

where

x_t is stationary, meaning that its characteristic roots are outside the unit circle;

$\varepsilon_{x,t} \sim i.i.N.\left(0, \sigma_x^2\right)$.

5.2 Time-varying Intercept

The Fomc looks at variables unobserved by the econometrician and has its expectations with respect to latent variables which enter the decision-making process. Besides noise information, exogenous disturbances, shocks from tastes (see Woodford, 2003, p. 50), and some uncontrollable imperfection in dealing with open market operations, all of them influence the actual interest rate actually observed. A time-varying intercept helps to account for such characteristics and also to indicate possible shifts over time in the monetary policy. Thus, in order to admit a time-varying intercept, I modify equation (3) and specify:

$$i_t = g_i i_{t-1} + (1 - g_i)(a_t + g_\pi \pi_t + g_x x_t) + \varepsilon_t \tag{4}$$

where a_t denotes the time-varying intercept that can take several specifications. In particular, as Rotemberg and Woodford (1998) suggest, consider an AR (1) model:

$$a_t = \mu + \psi a_{t-1} + \varepsilon_{a,t},$$

where

$|\psi| < 1;$

$\varepsilon_{a,t} \sim i.i.N.\left(0, \sigma_a^2\right).$

Implicitly, we have been assuming that i_t is stationary, as well as π_t. Accordingly, x_t and a_t must be stationary. Of course, if $\psi = 0$, then the Taylor rule precludes the intercept from being time-varying and $\varepsilon_{a,t}$ may be merged with u_t for practical purposes.

5.3 Model with Fixed Coefficients

Of course the estimation by GMM differs from the Kalman filter approach in a number of aspects. Here in particular, I include the entire sample to estimate the output gap and the rule with the Kalman filter. Thus, it is convenient to make the coefficients of both approaches as comparable as possible. With that purpose in mind, I introduce a dummy variable that appropriately separates data into two parts and permits us to estimate all coefficients and state variables at once. Therefore, let d_t be a dummy variable that takes the value 1 before some breaking point, *i.e.*, $t < 79:3$ (pre-Volcker) or $t < 87:3$ (pre-Greenspan) and 0, otherwise. Then, equation (4) may be rewritten as:

$$
\begin{aligned}
i_t &= d_t \left[g_{i,f} i_{t-1} + (1 - g_{i,f}) \left(a_t + g_{\pi,f} \pi_t + g_{x,f} x_t \right) \right] + \\
&\quad (1 - d_t) \left[g_{i,s} i_{t-1} + (1 - g_{i,s}) \left(a_t + g_{\pi,s} \pi_t + g_{x,s} x_t \right) \right] + \varepsilon_t,
\end{aligned}
$$

where f indicates the first sample, and s indicates the second sample.

To make things clear, I write down a quick summary of what we have seen so far. There are four observable variables, i_t, π_t, 1, and q_t and four unobservable variables q_t^n, x_t, λ_t, and a_t in the model. Thus the Kalman filter will estimate the following system of equations, in which the first two are the measurement and the other are the state equations:

$$
\begin{cases}
i_t = d_t \left[g_{i,f} i_{t-1} + (1 - g_{i,f}) \left(a_t + g_{\pi,f} \pi_t + g_{x,f} x_t \right) \right] + \\
(1 - d_t) \left[g_{i,s} i_{t-1} + (1 - g_{i,s}) \left(a_t + g_{\pi,s} \pi_t + g_{x,s} x_t \right) \right] + \varepsilon_t; \\
q_t = q_t^n + x_t;
\end{cases}
$$

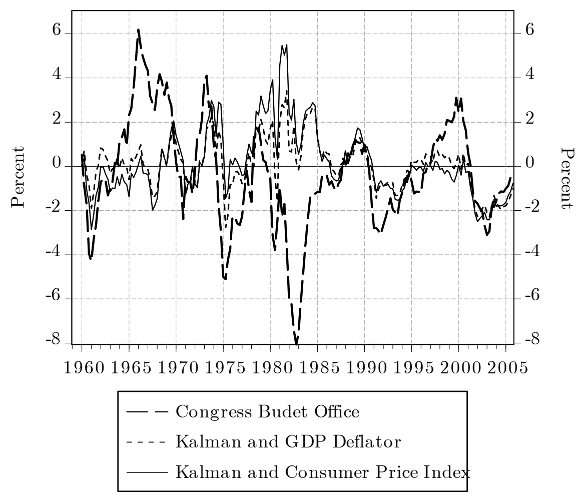
$$
\begin{cases}
x_t = \phi_1 x_{t-1} + \phi_2 x_{t-2} + \varepsilon_{x,t}, \ \varepsilon_{x,t} \sim i.i.N. \left(0, \sigma_x^2\right); \\
q_t^n = q_{t-1}^n + \lambda_t + \varepsilon_{q,t}, \ \varepsilon_{q,t} \sim i.i.N. \left(0, \sigma_q^2\right); \\
a_t = \mu + \psi a_{t-1} + \varepsilon_{a,t}, \ \varepsilon_{a,t} \sim i.i.N. \left(0, \sigma_a^2\right); \\
\lambda_t = \lambda_{t-1} + \varepsilon_{\lambda,t}, \ \varepsilon_{\lambda,t} \sim i.i.N. \left(0, \sigma_\lambda^2\right).
\end{cases}
\tag{5}
$$

5.4 Fixed Coefficients: Empirics

In order to get some feeling about how the output gap estimated by the Kalman filter differs from other methodologies and determines the coefficients of the reaction function, consider Figure 3, whose series are obtained by setting $d_t = 1$ if $t < 79:3$. For purposes of comparison, the picture is constructed with the output gap generated by the CBO potential output and outcomes from the Kalman filter, depending on whether the inflation proxy is the GDP Deflator or CPI. I rule out the output gap generated by the Kalman filter and PCE from the analysis because it coincides with the Kalman and GDP Deflator series.

The Kalman gaps represent the best one-step-ahead prediction using past information. That is not true regarding the one resulting from the CBO, which may have been constructed with *ex-post* information.

Figure 3: Alternative Estimation Methods of Output Gap: Kalman Filter - one-step-ahead prediction and Congress Budget Office



Output gap from CBO is much more volatile than the others. It has an amplitude of 14% versus amplitudes of 5% and 8% of the GDP Deflator and CPI, respectively. In general, all gaps follow the same tendency but not the same intensity, therefore policy recommendations diverge sometimes. I set apart two periods to comment on. The first is between 1965 and 1970. Even following the same tendency, CBO prescribes expansion at 6% followed by a reduction in activity. By contrast, Kalman stipulates recession at -2% followed by an increase in activity. Then, both methods close the 1960s indicating a 2% expansion. The second period begins in 1980 and ends in 1985. Now the opposite movement occurs. The Kalman method indicates expansion but with diminishing activity and CBO indicates recession. I interpret such behavior as resulting from a decrease in productivity[7], probably due to the oil price shock at the end of the 1970s. Such an event and the growing inflation at the time pushed the potential GDP down relatively to GDP and may have caused the behavior evidenced in the figure. Furthermore, there was a huge increase in the interest rate at the beginning of the 1980s, indicating measures for holding prices from going up. Therefore, the Kalman approach interpreted the movement as an excess of demand. Also, Figure 3 resembles Ang and Piazzesi's (2003) estimate of real activity. In particular, their amplitude is as big as mine.

Table 4 merges the results of two separate estimations, exactly as the GMM estimation does[8]. The first makes the breakpoint in the third quarter of 1979; the second makes the breakpoint in the third quarter of 1987, when Greenspan becomes the chairman. The table does not show the coefficients corresponding to the pre-Greenspan period obtained from the second estimation, but they are shown in Appendix D. For the sake of robustness, I present the results considering the three proxies for inflation.

A vertical analysis reveals that g_i parameters seem to be slightly smaller in the post-Volcker period compared with the pre-Volcker one. Then, the new breakpoint leads them to surge significantly from 0.75 to 0.95, approximately. Regarding the analysis across inflations, the parameters are roughly identical.

[7] The conclusion comes from looking at the picture of λ_t over time, reported in the Appendix.

[8] Inference here should be cautious, since the Kalman Filter produces the best estimates conditional on knowing the true parameters. However, the econometrician does not know them, and so has to estimate them. As such, a correction on the standard deviation of the Kalman prediction should be done. I skip from doing that as the majority of literature on Kalman Filter. Notwithstanding, the central tendency of the coefficients is anyway preserved, and thus the conclusions are reliable.

All inflation parameters g_π without exception are less than one in Table 4.[9] Evidently, there was an increase in magnitude from the pre-Volcker to the post-Volcker period, however it was insufficient to exceed one. In the post-Greenspan time, the significance vanishes as happened in the estimation with GMM, and even the sign may become negative. Interestingly, although PCE and the GDP deflator have a low correlation between each other, the magnitude of their coefficients is similar in the first two subsamples. On the other hand, notwithstanding the high correlation between PCE and CPI, the size of their coefficients becomes similar only in the post-Greenspan period.

Table 4: Coefficient Estimates of System (5) - Taylor rule and Potential Output Jointly Estimated

Coef./Inflation Proxy		GDP Deflator	PCE	CPI
g_i	pre-Volcker	0.772* (0.061)	0.786* (0.046)	0.789* (0.065)
	post-Volcker	0.711* (0.071)	0.730* (0.057)	0.722* (0.077)
	post-Greenspan	0.946* (0.020)	0.949* (0.016)	0.964* (0.014)
g_π	pre-Volcker	0.503* (0.165)	0.588* (0.177)	−0.065 (0.179)
	post-Volcker	0.934* (0.221)	0.854* (0.221)	0.061 (0.168)
	post-Greenspan	−0.497 (0.764)	0.414 (0.745)	0.301 (0.966)
g_x	pre-Volcker	0.368* (0.141)	0.362* (0.130)	0.390** (0.162)
	post-Volcker	0.386* (0.141)	0.412* (0.106)	0.472* (0.133)
	post-Greenspan	2.169** (1.010)	2.296** (0.983)	3.278** (1.551)

(*),(**),(***) significant at 1%, 5%, and 10%, respectively. Standard deviations are in brackets. Kalman filter procedure with maximum likelihood. GDP: Gross domestic product; PCE: Personal consumption expenditures; CPI: Consumer price index.

The interest rate response to the output gap increases across samples. It was roughly around 0.4 before and after Volcker, but it became much higher in the post-

[9] See the coefficients of the pre-Greenspan time in Appendix D. The figures are the same as in this section.

Greenspan time, indicating greater concern about the output. The figures are similar across inflations, and again the sizes of the parameter are more similar between the GDP deflator and PCE, but not with PCE and CPI.

In general terms, the coefficients of g_i and g_x are close across samples if we split them into pre- and post-Volcker, however they disrupt when one breaks the series between pre- and post-Greenspan. On the other hand, the inflation coefficient increases if I break the series in the former case and disrupts otherwise. Since the break in the third quarter of 1979 favors the estimation of g_π towards a number greater than one and keeps the other parameters close across samples, let that be the split date in the remaining of the paper.

If I make the variance of the stochastic trend arbitrarily small, that is, $\sigma_\lambda^2 \to 0$, then the inflation coefficient becomes slightly greater than 1, becoming 1.18, however it is not statistically different from the estimation with free variance for the stochastic trend. The magnitude of the other coefficients (not reported) are similar to those in Table 13 with only one main difference. Now, the ones of the output gap autoregression are greater. However, that does not change the output gap perspective; it resembles almost perfectly the Kalman filter gap in Figure 3, hence it is unnecessary to display it here.

The analysis so far makes it clear that the inflation coefficient depends crucially on the output gap. In general, the inflation coefficient is consistently below one, regardless of the inflation proxy, sample break and even estimation method considered after Greenspan. It is 1.18 when $\sigma_\lambda^2 \to 0$, but not statistically different from one in Table 4. According to Clarida, Galí and Gertler's (2000) interpretation then, either the Greenspan's time was unstable or an inflation coefficient less than one may be associated with stable inflation or the inflation coefficient is time-varying. That hypothesis is the subject of the next section.

5.5 Time-Varying Coefficient

If one conjectures that $g_\pi \leq 1$ in both subsamples for large periods, then when one finds $g_\pi > 1$, it is only because of a few and very active responses to inflation coupled with using output gaps that the Fed might not really be looking at. Then, by estimating the output gap observed by the Fed, which is much less volatile than others, we find how the Fed is worried about the economic activity and that the inflation parameter is smaller than it is conventionally believed. Those findings should have been expected had we trusted in Greenspan's (2004) speech. In particular, it is very likely that the Fomc's decision takes into account a number of other variables *not* observed in the rule. Therefore, other facts rather than inflation and gap must be driving the interest rate. Thus, this section follows Greenspan's suggestion and provides evidence that the inflation parameter must be varying through time.

In fact, Greenspan (2004, p. 38) explicitly says:

> *"The economic world in which we function is best described by a structure whose parameters are continuously changing. The channels of monetary policy, consequently, are changing in tandem. An ongoing challenge for the Federal Reserve - indeed, for any central bank - is to operate in a way that does not depend on a fixed economic structure based on historically average coefficients."*

Thus, as in Boivin (2006), I assume the inflation coefficient follows a random walk process:

$$g_{\pi,t} = g_{\pi,t-1} + \varepsilon_{\pi,t}, \ \varepsilon_{\pi,t} \sim i.i.d. \left(0, \sigma_\pi^2\right).$$

By defining this new state variable, it is possible to assess the behavior of the response to inflation over time. Moreover, by arbitrarily fixing its variance σ_π^2, it is possible to analyze how sensitive the inflation parameter is to changes in its variance.

The other coefficients lose their relative importance in both subsamples in terms of magnitude by letting the inflation parameter vary over time. Now the inflation coefficient is time-varying, so its importance should naturally increase and, if pertinent, become even greater than one.

Table 5 shows the complete set of estimates, depending on the inflation proxy. It reveals that the smooth parameter g_i is less important after Volcker than before in terms of size, but the response to output is more important recently, consistent with what we had already detected in previous analyses. The parameters with the CPI proxy are considerably diverse from the others in three aspects. First, the response to output gap is almost twice as much as when other inflations are used. Second, for the first time, we see the possibility of a time-varying intercept, since ψ is statistically different from zero. Third, because ψ varies, then μ is likely to be low compared to other inflations.

Figure 4 shows the output gaps resulting from fixed and time-varying inflation parameters. The time-varying parameter makes the output gap more volatile. However, both series conserve the same tendency and rarely diverge with respect to policy recommendation. However, the intensity of the gap is not always similar as in years 1961 to 1963, 1968, 1975, and between 1981 and 1985. For the last time interval, the explanation rests on the interpretation of the stochastic drift λ_t, which decreases sharply in the early 1980s and makes the output gap positive.

Figure 5 depicts the behavior of the inflation parameter over time considering GDP deflator as proxy for inflation. It also shows its two standard deviations. Thus, we can realize the inflation parameter fluctuating around zero practically during the entire time that Greenspan headed the Fed. Between 1980 and 1985 the parameter was greater than one, although with high volatility consistent with Sims and Zha

Table 5: Coefficient Estimates - Taylor rule, Inflation Coefficient and Potential Output Jointly Estimated

Coef./Output Proxy		GDP deflator	PCE	CPI
g_i	pre-Volcker	0.578*	0.516*	0.624*
		(0.071)	(0.063)	(0.065)
	post-Volcker	0.465*	0.406*	0.559*
		(0.085)	(0.066)	(0.067)
g_x	pre-Volcker	0.163*	0.154*	0.327*
		(0.056)	(0.062)	(0.119)
	post-Volcker	0.216**	0.267*	0.430*
		(0.088)	(0.065)	(0.127)
μ		6.036*	2.809	0.157
		(1.853)	(5.480)	(0.179)
ψ		-0.229	0.224	0.975*
		(0.406)	(0.079)	(0.025)
ϕ_1		1.542*	1.511*	1.527*
		(0.156)	(0.134)	(0.116)
ϕ_2		-0.579*	-0.529*	-0.644*
		(0.152)	(0.134)	(0.120)
Log-lik.		1,549.0	1,531.4	1,509.4
Schwarz		-16.47	-16.28	-16.04

(*),(**),(***) significant at 1%, 5%, and 10%, respectively. Standard deviations are in brackets. Kalman filter procedure with maximum likelihood. GDP: Gross domestic product; PCE: Personal consumption expenditures; CPI: Consumer price index.

(2006) achievements.

The picture permits us to see that an inflation parameter greater than one occurred during the Volcker's time as Fed's chairman and 1971. It was less than -1 once during Greenspan's chairmanship. Conceptually, we can have price determinacy if $g_\pi < -1$ (see Cochrane, 2007). For the rest of the periods, it was not superior to one, and since 1992 it has been often negative.[10]

I do not present the inflation coefficient with the other proxies for inflation, because the qualitative conclusions hold unchanged as discussed here and they would look like Figure 5.

What really varies with different inflation proxies is the magnitude of the variance.

[10] In other econometric environment, Sims and Zha (2006) find an interest rate response to inflation with a mean of 1.99 and a 68% probability interval between -0.09 and 2.48.

Figure 4: Kalman Filter Estimates of: Predicted Output Gaps - GDP Deflator

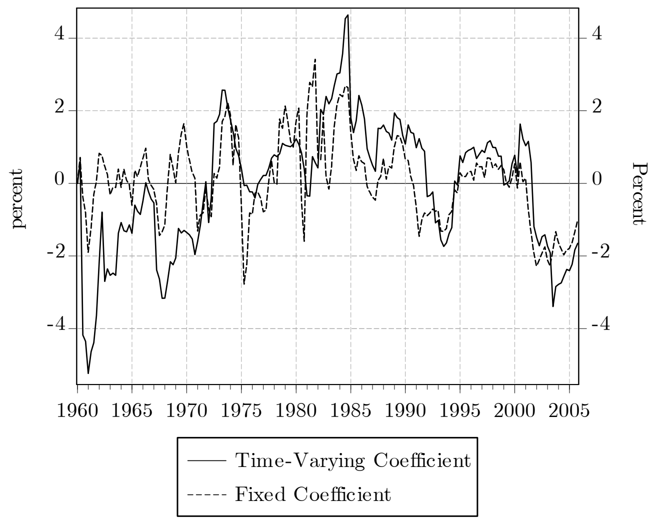
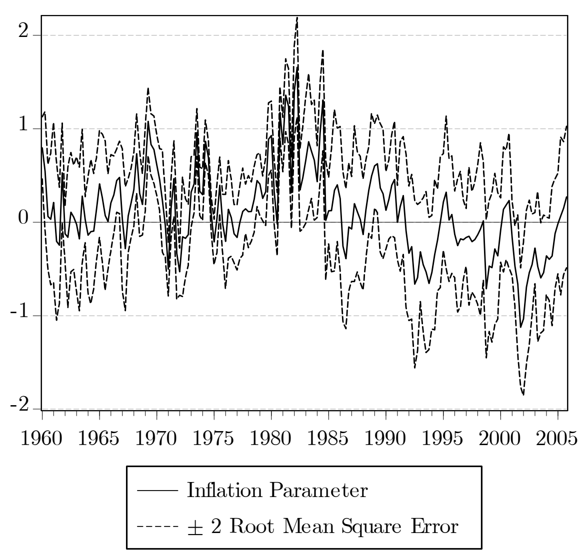


Figure 5: Smoothed Inflation Estimate

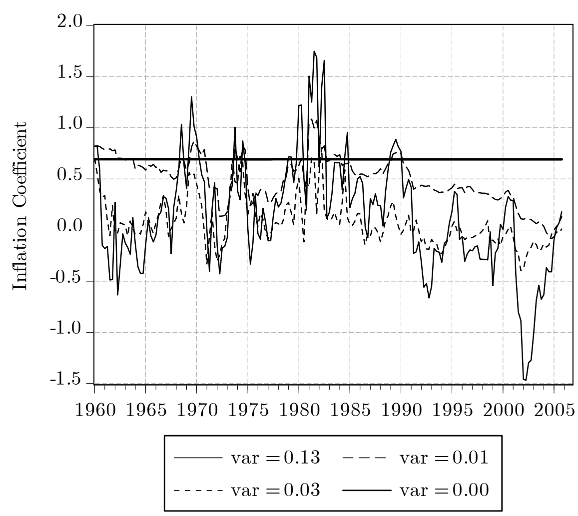


The other proxies have a smaller magnitude, which makes them almost always less than one. Bueno (2006) estimates the Taylor rule using Markov Switching regimes and his results are roughly consistent with the previous picture.

By fixing the variance of the inflation coefficient, one can perceive what pushes it towards one. Figure 6 shows the average inflation parameter $g_\pi \to 0.63$ when $\sigma_\pi^2 \to 0$. Then, by letting the variance increase, we see it growing up between 1980 and 1985 towards a number greater than one, but decreasing, even to negative numbers, as we go farther to the center of the picture.

It is difficult to explain why g_π would be negative (with high variance), but it is conceivable if the Fed does not follow a predetermined rule and look at other variables. In any case, the main point that should be stressed is that g_π is hardly above 1. I thus conjecture that estimates of $g_\pi > 1$ by GMM happen because of the few influential observations occurred in the early the 1980s (see Davidson and MacKinnon, 1993, p. 32 for a discussion).

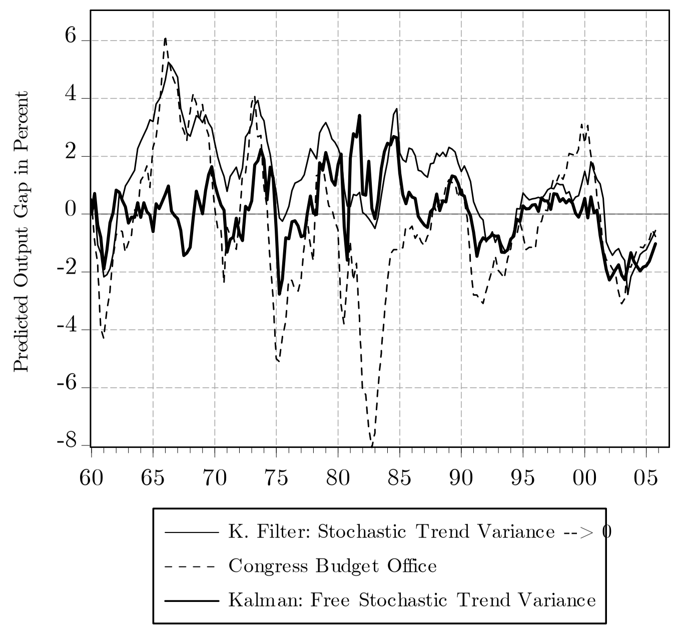
Figure 6: GDPP: Smoothed Time-Varying Inflation Parameter - Predetermined Variance

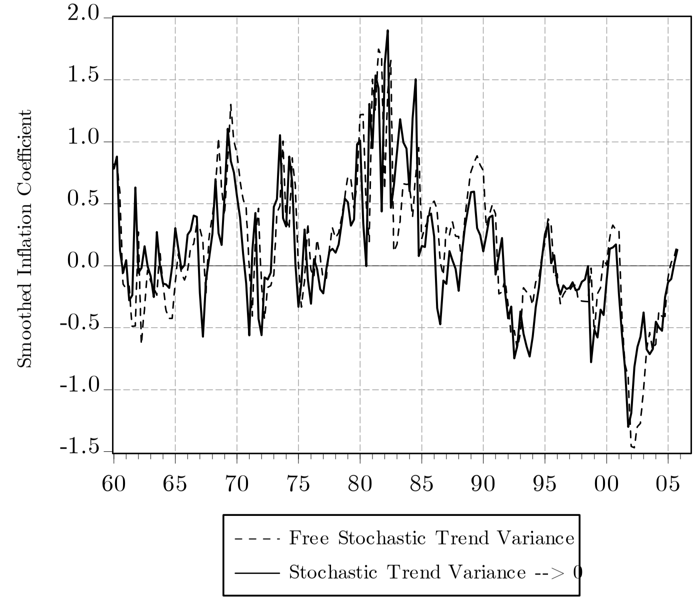


The preceding analysis enables us to claim that the inflation parameter is time-varying and, hence, consistent with Greenspan's (2004) speech. Therefore, the sample break choice of CGG was fundamental to drive the parameter post-Volcker to be greater than one. Moreover, if the inflation parameter is less than one during long periods of time, then a response to inflation greater than one-to-one may not be necessary for monetary stability.

What happens to the output gap and the inflation coefficient if I make the variance of the stochastic trend arbitrarily small? In that case, the qualitative conclusions with respect to the inflation coefficient still hold. Yet it becomes more volatile. The magnitude of the other coefficients (not reported) are similar to those in Table 5 with only one main difference. Now, there is room for having a time-varying intercept. On the other hand, the output gap generated under these circumstances is slightly different, particularly between 1965 and 1970, because it approximates the CBO estimate. All these observations are better grasped from Figure 7.

Figure 7: Effects on the Output Gap and Inflation Coefficient of Making the Stochastic Trend Variance Arbitrarily Small





6 Conclusions

This paper has empirically characterized the monetary policy in the U.S. through a forward-looking Taylor-rule-type reaction function before and after Volcker's and before and after Greenspan's chairmanships. It has shown that changing the sample break disrupts CGG's findings because the inflation parameter during Greenspan's tenure is considerably smaller than otherwise using the entire sample, and sometimes it is even nonsignificant or significantly less than one. Several robustness checks, varying the proxy for inflation and the output gap scheme, confirm the results. Table 6 summarizes the main findings of the first step. Essentially, it shows that the inflation parameter in the Greenspan's time was about 1 or less. It also shows you can find a greater-than-one coefficient in the pre-Volcker period, with linear detrending.

Table 6: Wald Test for $g_\pi = 1$

Inflation Proxy	**Gap/Period**	**Pre-Volcker**	**Post-Volcker**	**Greenspan**
GDP deflator	CBO	NR	$> 1^{*}$	NR
	L. T.	$> 1^{**}$	$> 1^{**}$	NS
	Q. T.	$< 1^{**}$	$> 1^{*}$	NR
PCE	CBO	NR	$> 1^{*}$	NR
	L. T.	$> 1^{***}$	$> 1^{*}$	NS
	Q. T.	NR	$> 1^{***}$	NR
CPI	CBO	$< 1^{*}$	$> 1^{*}$	$< 1^{*}$
	L. T.	NR	$> 1^{*}$	NR
	Q. T.	NS	$> 1^{*}$	$< 1^{*}$

(*),(**),(***) significant at 1%, 5%, and 10%, respectively.

GDP: gross domestic product; L. T.: Linear detrend; Q. T.: Quadratic detrend; NR: not rejected; NS: not rejected and nonsignificant

Given the strong finding that the coefficients in the Greenspan's time might not be greater than one, and since it depends crucially on the output gap, the paper innovates by estimating the rule jointly with the output gap by Kalman filter. The approach permits us to get a feeling about the effect of the output gap on the inflation parameter and estimate which gap the policymakers might be looking at when they set the interest rate. Moreover, the approach helps test whether the rule intercept varies over time. The conclusion leads us to believe the inflation parameter is less than one and, possibly, time-varying, in accordance with Greenspan's (2004) speech.

Then, the paper takes the possibility of a time-varying response to inflation in his speech and enables it in the Kalman filter model. Indeed, we have seen an inflation coefficient that fluctuates over time, but which is rarely greater than one. An explanation for that finding is mentioned in Greenspan's speech, which says the Fed does not follow the Taylor rule in the conventional sense and the rule is not even a description of how the Fomc makes decisions either.

In view of the results, a question is to explain why Clarida, Galí and Gertler (2000) obtained $g_\pi > 1$ in the post-Volcker period instead of less than 1. We have seen that the issue must be due to a few influential observations that have led the inflation coefficient to rise between 1980 and 1985.

Consequently, we were able to see a monetary policy in which an inflation coefficient less than one is associated with stable inflation. The claim thus disrupts conventional wisdom regarding the Taylor's principle.

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Appendix A: Data Description

This section provides the basic statistics of the data used in this paper. They were downloaded from the Fed of Saint Louis. All data are originally seasonally adjusted, when pertinent. Description here refers to quarterly data between 1960:1 and 2005:4, and all data are log-linearized and annualized. Table 7 summarizes the numbers.

Table 7: Data Description - Quarterly Basis (in log)

Series	**EFFR**	**GDPP**	**CPI**	**PCE**
Units	%	%	%	%
Mean	6.10	3.70	4.16	3.70
Std. Dev.	3.30	2.42	3.15	2.52
Series	**M2**	**Spread**	**GDP**	**Pot. GDP**
Units	%	%	log	log
Mean	6.76	1.38	8.62	8.62
Std. Dev.	3.52	1.15	0.42	0.43

All data are downloaded from the Fed of Saint Louis. Variations are taken between t and $t-1$. EFFR: Effective federal funds rate; GDPP: Gross domestic product deflator; CPI: Consumer price index; PCE: Personal consumption expenditures; Spread: spread between the 10-year bond rate and the 3-month Treasury bill rate; CBO: Potential Output from the Congress Budget Office.

Appendix B: Robustness Checks

Appendix B.1: Consumer Price Index: Other Samples

Table 8 presents numbers close to what CGG found in their paper, when one looks at the CBO column, since the sample is identical to theirs.

Table 8: Inflation Proxy: Consumer Price Index $(k, q) = (1, 1)$

Sample	**Volcker and Greenspan (1979:3-1996:4)**			**Pre-Volcker**		
Gap Proxy	CBO	L. Trend	Q. Trend	CBO	L. Trend	Q. Trend
π^*	3.276* (0.241)	3.986* (0.812)	3.759* (0.222)	3.598* (0.346)	5.812** (2.887)	4.811* (0.548)
g_π	2.481* (0.056)	2.361* (0.423)	3.027* (0.251)	0.669* (0.043)	0.919* (0.056)	0.006 (0.614)
g_x	0.305* (0.025)	0.015 (0.076)	0.044 (0.046)	0.066* (0.015)	0.193* (0.034)	0.311 (0.291)
g_i	0.825* (0.007)	0.892* (0.024)	0.884* (0.014)	0.474* (0.061)	0.829* (0.028)	0.851* (0.108)
# obs.	70	70	70	77	72	71
$H_0 : g_\pi = 1$?	Reject*, $g_\pi > 1$	Reject*, $g_\pi > 1$	Reject*, $g_\pi > 1$	Reject*, $g_\pi < 1$	Do not Reject	Do not reject
Prob J-test.	0.803	0.432	0.870	0.590	0.869	0.666

(*),(**),(***) significant at 1%, 5%, and 10%, respectively. Standard deviations are in brackets.
Estimated by GMM: $i_t = g_i i_{t-1} + (1 - g_i)\left[(r^* - (g_\pi - 1)\,\pi^*) + g_\pi \pi_{t,k} + g_x x_{t,q}\right] + \varepsilon_t$

. The set of instruments includes lags 1 to 4 of federal funds rate, inflation, output gap, constant, M2, and the short-long spread.

Appendix B.2: GDP Deflator and Other Samples

This section shows the GMM estimations using the GDP deflator as proxy for inflation. Table 9 presents the coefficients using the entire post-Volcker sample and the post-Greenspan sample.

Table 9: Inflation Proxy: GDP Deflator $(k, q) = (1, 1)$

Sample	**Volcker and Greenspan (1979:3-2005:4)**			**Greenspan**		
Gap Proxy	CBO	L. Trend	Q. Trend	CBO	L. Trend	Q. Trend
π^*	2.525* (0.228)	2.436* (0.459)	2.898* (0.456)	2.014*** (0.686)	2.303** (1.076)	6.106*** (3.356)
g_π	5.315* (1.149)	4.992* (1.564)	5.706* (1.737)	2.243** (1.248)	5.739 (11.036)	2.233** (1.217)
g_x	0.295** (0.128)	0.124 (0.158)	0.063 (0.154)	0.421* (0.111)	0.109 (0.568)	0.408* (0.122)
g_i	0.938* (0.020)	0.954* (0.020)	0.943* (0.026)	0.912* (0.033)	0.974* (0.040)	0.905* (0.038)
# obs.	106	106	106	74	74	74
$H_0 : g_\pi = 1$?	Reject*, $g_\pi > 1$	Reject**, $g_\pi > 1$	Reject*, $g_\pi > 1$	Do not reject	Do not reject	Do not reject
Prob J-test.	0.550	0.380	0.538	0.751	0.973	0.716

(*),(**),(***) significant at 1%, 5%, and 10%, respectively. Standard-deviations are in brackets.
Estimated by GMM: $i_t = g_i i_{t-1} + (1 - g_i) [(r^* - (g_\pi - 1) \pi^*) + g_\pi \pi_{t,k} + g_x x_{t,q}] + \varepsilon_t$
. The set of instruments include lags 1 to 4 of federal funds rate, inflation, output gap, constant, M2, and the short-long spread.

The results show that the inflation coefficients fall significantly in size and the variance may increase in the Greenspan's sample.

Table 10 permits one *to* compare my coefficients with CGG's results, reinforcing my final findings. In general, I get coefficients greater than theirs. In the pre-Volcker period, I find an inflation coefficient even greater than one, indicating the parameter depends heavily on the choice of output gap.

Table 10: Inflation Proxy: GDP Deflator $(k,q) = (1,1)$

Sample	**Volcker and Greenspan (1979:3-1996:4)**			**Pre-Volcker**		
Gap Proxy	CBO	L. Trend	Q. Trend	CBO	L. Trend	Q. Trend
π^*	2.777*	2.618*	3.636*	40.138	1.950*	5.528*
	(0.284)	(0.339)	(0.308)	(334.465)	(0.375)	(0.911)
g_π	3.500*	3.190*	2.872*	0.987*	1.928*	0.456*
	(0.642)	(0.482)	(0.362)	(0.120)	(0.448)	(0.247)
g_x	0.177***	0.107***	0.074	0.109*	0.280*	0.122
	(0.100)	(0.056)	(0.046)	(0.028)	(0.105)	(0.096)
g_i	0.871*	0.841*	0.813*	0.776*	0.802*	0.822*
	(0.041)	(0.046)	(0.050)	(0.052)	(0.059)	(0.062)
# obs.	70	70	70	77	72	71
$H_0: g_\pi = 1$?	Reject*, $g_\pi > 1$	Reject*, $g_\pi > 1$	Reject*, $g_\pi > 1$	Do not Reject	Reject**, $g_\pi > 1$	Reject**, $g_\pi < 1$
Prob J-test.	0.628	0.584	0.767	0.567	0.899	0.803

(*),(**),(***) significant at 1%, 5%, and 10%, respectively. Standard-deviations are in brackets.

Estimated by GMM: $i_t = g_i i_{t-1} + (1 - g_i)\left[(r^* - (g_\pi - 1)\,\pi^*) + g_\pi \pi_{t,k} + g_x x_{t,q}\right] + \varepsilon_t$

. The set of instruments include lags 1 to 4 of federal funds rate, inflation, output gap, constant, M2, and the short-long spread.

Appendix B.3: Personal Consumption Expenditures

Table 11 presents the same conclusions the previous section did. The magnitude of the inflation coefficients decrease sharply from the entire sample to the restricted sample during the Greenspan's chairmanship. However, the response to output gap increases.

Table 11: Inflation Proxy: Personal Consumption Expenditures $(k, q) = (1, 1)$

Sample	**Volcker and Greenspan (1979:3-2005:4)**			**Greenspan**		
Gap Proxy	CBO	L. Trend	Q. Trend	CBO	L. Trend	Q. Trend
π^*	2.935* (0.295)	2.927* (0.525)	2.171* (0.672)	1.344 (10.641)	7.338 (14.784)	5.663* (1.911)
g_π	3.388* (0.569)	3.319* (0.670)	5.406** (2.343)	1.094*** (0.630)	0.653 (1.059)	1.951* (0.623)
g_x	0.118 (0.095)	0.013 (0.102)	−0.265 (0.301)	0.364* (0.078)	0.356** (0.148)	0.203* (0.064)
g_i	0.912* (0.024)	0.927* (0.022)	0.951* (0.029)	0.881* (0.038)	0.923* (0.032)	0.824* (0.053)
# obs.	106	106	106	74	74	74
$H_0 : g_\pi = 1$?	Reject*, $g_\pi > 1$	Reject*, $g_\pi > 1$	Reject***, $g_\pi > 1$	Do not reject	Do not reject	Do not reject
Prob J-test.	0.841	0.640	0.834	0.889	0.902	0.987

(*),(**),(***) significant at 1%, 5%, and 10%, respectively. Standard deviations are in brackets.
Estimated by GMM: $i_t = g_i i_{t-1} + (1 - g_i)\left[(r^* - (g_\pi - 1)\,\pi^*) + g_\pi \pi_{t,k} + g_x x_{t,q}\right] + \varepsilon_t$
. The set of instruments includes lags 1 to 4 of federal funds rate, inflation, output gap, constant, M2, and the short-long spread.

Table 12 makes CGG comparable to this work. Since the PCE and CPI are highly correlated, the results are similar.

Table 12: Inflation Proxy: Personal Consumption Expenditures $(k, q) = (1, 1)$

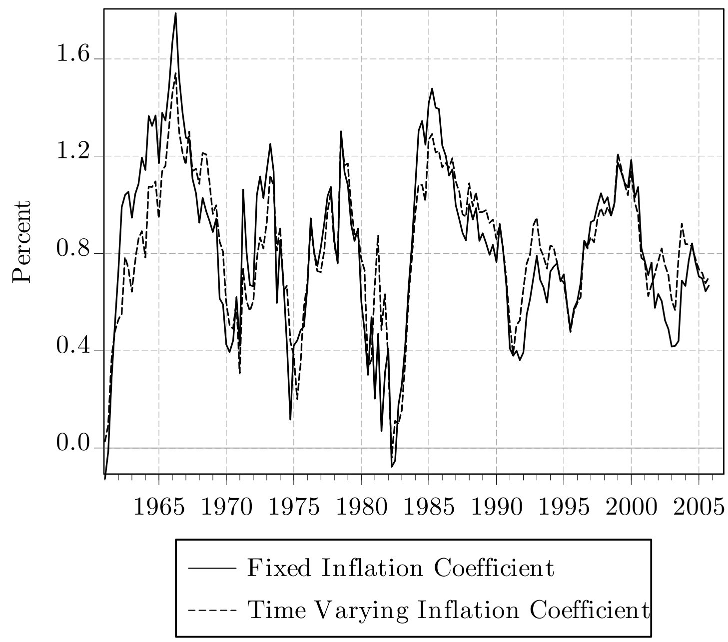
Sample	**Volcker and Greenspan (1979:3-1996:4)**			**Pre-Volcker**		
Gap Proxy	CBO	L. Trend	Q. Trend	CBO	L. Trend	Q. Trend
π^*	3.768*	4.072*	2.640*	6.432***	1.604*	4.784*
	(0.535)	(0.674)	(0.635)	(3.745)	(0.505)	(0.544)
g_π	2.828*	2.688*	3.461*	0.910*	1.975*	−0.688
	(0.461)	(0.423)	(0.834)	(0.082)	(0.576)	(2.312)
g_x	−0.070	−0.062	−0.147	0.098*	0.279*	0.705
	(0.131)	(0.081)	(0.109)	(0.027)	(0.129)	(1.121)
g_i	0.893*	0.884*	0.907*	0.669*	0.832*	0.920*
	(0.030)	(0.032)	(0.035)	(0.061)	(0.067)	(0.109)
# obs.	70	70	70	77	72	71
$H_0 : g_\pi = 1$?	Reject*, $g_\pi > 1$	Reject*, $g_\pi > 1$	Reject*, $g_\pi > 1$	Do not Reject	Reject***, $g_\pi > 1$	Do not reject
Prob J-Test.	0.908	0.812	0.867	0.740	0.911	0.738

(*),(**),(***) significant at 1%, 5%, and 10%, respectively. Standard deviations are in brackets.
Estimated by GMM: $i_t = g_i i_{t-1} + (1 - g_i)\left[(r^* - (g_\pi - 1)\,\pi^*) + g_\pi \pi_{t,k} + g_x x_{t,q}\right] + \varepsilon_t$
. The set of instruments includes lags 1 to 4 of federal funds rate, inflation, output gap, constant, M2, and the short-long spread.

Appendix C: Stochsatic Drift

This appendix shows the picture of the stochastic drift with and without time-varying inflation coefficient, where the inflation proxy is the GDP deflator.

Figure 8: Filtered Stochastic Drift from GDP Deflator



The series follow closely the same path, regardless of the model used for estimating the inflation parameter. The series with fixed coefficient seems to be slightly more volatile.

Appendix D: Kalman Filter Estimates

Appendix D.1: Fixed Coefficients

Table 13 contains all parameter estimates of the model with fixed coefficients. It shows that the parameters of the state equations are rather similar. The goodness-of-fit, measured by the likelihood function, indicates practically the same values across inflations with PCE being slightly the best model.

Table 13: Coefficient Estimates of System (5) - Taylor rule and Potential Output Jointly Estimated - pre and post-Volcker

Coef./Inflation Proxy		**GDP Deflator**	**PCE**	**CPI**
g_i	$60-79$	0.772* (0.061)	0.786* (0.046)	0.789* (0.065)
	$79-05$	0.711* (0.071)	0.730* (0.057)	0.722* (0.077)
g_π	$60-79$	0.503* (0.165)	0.588* (0.177)	-0.065 (0.179)
	$79-05$	0.934* (0.221)	0.854* (0.221)	0.061 (0.168)
g_x	$60-79$	0.368* (0.141)	0.362* (0.130)	0.390** (0.162)
	$79-05$	0.386* (0.141)	0.412* (0.106)	0.472* (0.133)
μ		3.255** (1.335)	3.260** (1.285)	5.365* (1.687)
ψ		0.041 (0.089)	0.017 (0.079)	0.087 (0.104)
ϕ_1		1.081* (0.122)	1.073* (0.093)	1.117* (0.114)
ϕ_2		-0.204*** (0.107)	-0.205* (0.075)	-0.202** (0.102)
Log-lik.		1,494.7	1,494.8	1,489.7
Schwarz		-15.85	-15.85	-15.80

(*),(**),(***) significant at 1%, 5%, and 10%, respectively. Standard-deviations are in brackets. Kalman Filter procedure with maximum likelihood. GDP: Gross domestic product; PCE: Personal consumption expenditures; CPI: Consumer price index.

Table 14 shows the results using the break before and after Greenspan. The parameters in the state equations are similar across inflation proxies. The inflation coefficients are always less than one. Blinder and Reis (2005), restricting the sample to the Volcker's chairmanship, found an inflation coefficient less than one as well.

Table 14: Coefficient Estimates of System (5) - Taylor rule and Potential Output Jointly Estimated - pre- and post-Greenspan

Coef./Inflation Proxy		**GDP Deflator**	**PCE**	**CPI**
g_i	$60-87$	0.774^* (0.067)	0.786^* (0.055)	0.844^* (0.053)
	$87-05$	0.946^* (0.020)	0.949^* (0.016)	0.964^* (0.014)
g_π	$60-87$	0.734^* (0.236)	0.878^* (0.261)	0.328 (0.264)
	$87-05$	-0.497 (0.764)	0.414 (0.745)	0.301 (0.966)
g_x	$60-87$	0.568^* (0.210)	0.563^* (0.191)	0.729^{**} (0.312)
	$87-05$	2.169^{**} (1.010)	2.296^{**} (0.983)	3.278^{**} (1.551)
μ		3.534^{**} (1.660)	2.955^{***} (1.788)	5.025^{**} (2.014)
ψ		0.098 (0.104)	0.064 (0.099)	0.085 (0.108)
ϕ_1		1.392^* (0.133)	1.406^* (0.130)	1.438^* (0.130)
ϕ_2		-0.555^* (0.127)	-0.583^* (0.125)	-0.602^* (0.125)
Log-lik.		1515.2	1516.3	1511.4
Schwarz		-16.25	-16.26	-16.21

(*),(**),(***) significant at 1%, 5%, and 10%, respectively. Standard-deviations are in brackets. Kalman Filter procedure with maximum likelihood. GDP: Gross domestic product; PCE: Personal consumption expenditures; CPI: Consumer price index.