Interest-Rate Smoothing and Optimal Monetary Policy: A Review of Recent Empirical Evidence

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Abstract

The Federal Reserve and other central banks tend to change short-term interest rates in sequences of small steps in the same direction and reverse the direction of interest rate movements only infrequently. These characteristics, often referred to as interest-rate smoothing, have led to criticism that policy responds too little and too late to macroeconomic developments, suggesting to some observers that the Federal Reserve has an objective of minimizing interest-rate volatility. This paper, however, argues that interest-rate smoothing may well represent optimal behavior on the part of central banks whose only objectives are to stabilize output and inflation. We present empirical results from several recent papers that offer three explanations of interest-rate smoothing: forward-looking behavior by market participants, measurement error associated with key macroeconomic variables, and uncertainty regarding relevant structural parameters.

I. Introduction

The conduct of monetary policy by central banks is of considerable interest to both academic researchers and to financial market participants. This interest has generated a large literature that attempts to describe and evaluate the interest rate policies of central banks. One characteristic that has been widely noted in this literature is that many central banks, including the Federal Reserve, adjust short-term interest rates in a smooth manner. In fact, some researchers have argued that observed interest rate movements are too sluggish, and that a less timid interest rate policy would be more effective at stabilizing output and inflation. Furthermore, the observed smoothness of interest rates has been considered evidence that central banks have a separate objective of minimizing interest rate volatility in addition to the goals of stabilizing output and inflation.

This paper, instead, argues that the observed smoothing of the interest rate may indeed be optimal, even if the central bank is not explicitly concerned with interest rate volatility. In particular, the paper considers three characteristics of the policymaking environment that may render some degree of interest-rate smoothing optimal: forward-looking behavior by market participants, measurement error associated with key macroeconomic variables, and uncertainty regarding relevant structural parameters. The paper is organized as follows. This introductory section presents some evidence on the smoothness of the interest rate and clarifies the definition of interest-rate smoothing that is used throughout the paper. Sections 2 through 4 describe each of the three arguments in detail and present supporting empirical results from recent research on the U.S. economy. Section 5 offers a brief conclusion.

A Definition of Interest Rate Smoothing

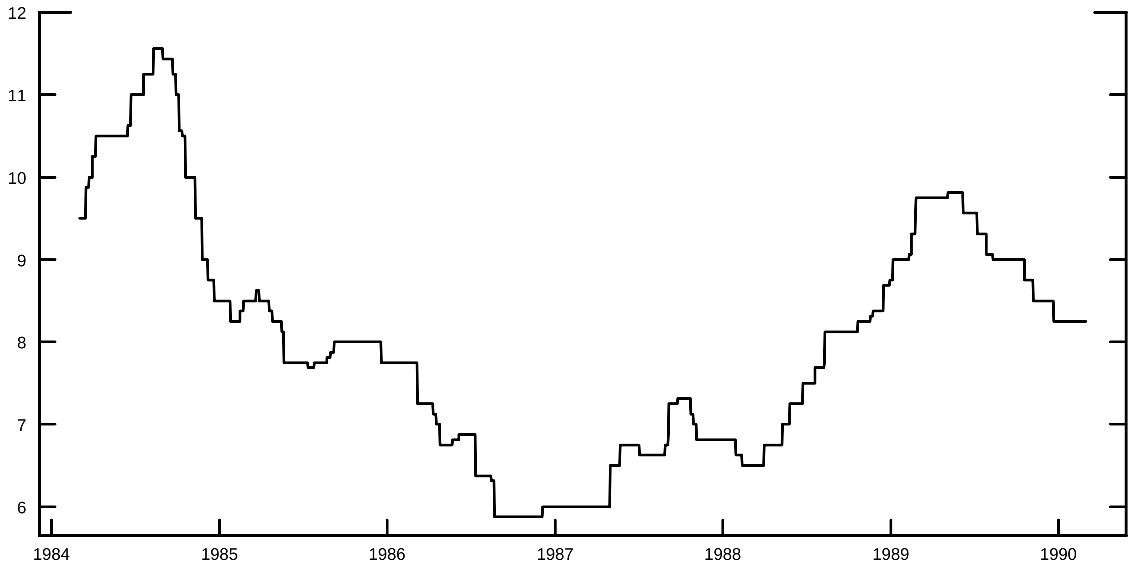
The belief that the Federal Reserve, like most other central banks, deliberately chooses a smooth path for the short-term interest rate may stem from the dual observations that the federal funds rate tends to move in sequences of small steps in the same direction and that reversals in its direction are relatively infrequent. As apparent in Figure 1, which displays the intended federal funds rate from 1984 through 1998, changes in the funds rate are frequently followed by further changes of the same sign. Indeed, in this sample 85 percent of funds rate

Figure 1

Intended Federal Funds Rate

March 1990 to December 1998

March 1984 to March 1990



changes represent “continuations” in the direction of policy. Furthermore, such continuations often occur in fairly rapid succession, with an average of 34 days separating changes when there is a continuation compared to an average of 97 days for a reversal, suggesting that these changes constitute steps within a single policy movement. The magnitude of these steps is modest, typically a quarter of a percentage point, as only 13 percent of funds rate changes in this sample have been by half a percentage point or larger.[2] Similar patterns are observed in official interest rates in many other countries. Lowe and Ellis (1997) have presented evidence for Australia, the U.S., the U.K., Japan, and Germany, and Goodhart (1998) has, in addition, looked at interest rates in France, Italy, Canada, Spain, the Netherlands, Belgium, Sweden, and Austria.

Of course, if monetary policy systematically reacts to macroeconomic variables such as inflation and output, these patterns in interest-rate behavior may simply reflect the persistence in the movements of those variables. This possibility becomes evident when central bank behavior is characterized by an interest rate reaction function--that is, a rule for setting the federal funds rate that responds systematically to variables such as output, inflation and past interest rates. A common specification of such a rule is

$$\mathbf{r}_t = \rho\, \mathbf{r}_{t-1} + (1 - \rho)\,(\,\mathbf{rr}^* + \pi_t\,) + \alpha\,(\pi_t - \pi^*) + \beta\, y_t\,. \tag{1}$$

According to this rule, the current federal funds rate $\mathbf{r}_t$ is determined by the lagged funds rate, the equilibrium real interest rate, $\mathbf{rr}^*$, the inflation rate, π_t, the inflation target, π^*, and the output gap, $\mathbf{y}_t$, which is the difference between real current and potential output. The coefficients α and β capture the response to output and inflation, while ρ measures the weight put on the past funds rate setting. Note that the well-known Taylor rule is a special case of (1) that sets ρ equal to zero (see Taylor (1993)).

Clearly, if output and inflation fluctuations are persistent, the systematic policy response will impart some smoothness to the federal funds rate. However, the degree of smoothness of the observed funds rate will be influenced importantly by two characteristics of interest rate reaction functions such as (1). First, a value of the coefficient on the lagged funds rate ρ that is positive

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[2] Rudebusch (1995), who was among the first to study this smoothness, presents more formal statistical evidence of this behavior for the U.S. economy.

but below one induces *partial adjustment* of interest rates to changes in the other macroeconomic variables. In particular, it implies that a deviation of output from potential or inflation from target will trigger a sequence of policy moves in the same direction until output and inflation have been restored to their desired paths. Second, the *overall responsiveness* of the interest rate rule is determined by the response coefficients α and β. For a given value of ρ, smaller coefficients on output and inflation imply more timidity in the responsiveness of the interest rate, which results in lower interest rate volatility. We use these two characteristics of interest rate reaction functions to define interest-rate smoothing. In the remainder of the paper, interest-rate smoothing refers to a high degree of partial adjustment and limited overall responsiveness of the interest rate.

As to the observed degree of partial adjustment and responsiveness, there exists a large literature on estimating interest rate rules that has produced estimation results for many different countries and time periods (see Clarida, Gali, and Gertler (1998), Judd and Rudebusch (1998), and Orphanides (1997), among others). Rather than providing a detailed survey of the many different reaction functions that can be found in the literature on policy rules, we present an example taken from Orphanides and Wieland (1998) estimated by means of instrumental variables techniques using quarterly U.S. data from 1980:Q1 to 1996:Q4:

$$\mathbf{r}_t = \underset{(0.0036)}{-0.0042} + \underset{(0.07)}{0.795}\,\mathbf{r}_{t-1} + \underset{(0.13)}{0.625}\,\pi_t + \underset{(0.26)}{1.171}\,y_t - \underset{(0.23)}{0.967}\,y_{t-1} + \mathbf{u}_t\,. \tag{2}$$

$$\bar{R}^2 = 0.925;\ \text{SER} = 0.010;\ \text{DW} = 2.50$$

The variables are defined as in (1), and unexplained residuals are denoted by **u**.[3] The results indicate that federal funds rate behavior during the 1980s and 1990s can be largely described by a systematic response to the lagged funds rate, the inflation rate, and the current and lagged output gap. Furthermore, while the lagged output gap is important in the early part of the 1980s, it could be dropped without any loss in fit if the rule were estimated from 1987 onwards.[4]

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[3] Inflation is measured by the rate of change in the chain-weighted GDP deflator over the previous four quarters. The output gap measure is based on chain-weighted GDP and is constructed using estimates of potential output from the Congressional Budget Office (1997).

[4] The pattern of coefficients on the output gap and its lag suggest that policy not only responded to the level of output but also its recent growth, at least during the early 1980s.

Two findings that are common to much of the literature are of particular interest. First, the size and significance of the partial adjustment coefficient, which is about 0.8, provides direct evidence that the observed degree of persistence in federal funds rates is greater than can be attributed to systematic policy responses to persistent output and inflation fluctuations.[5] Second, the federal funds rate responds significantly to output and inflation. In particular, a favorable property of (2) is that the federal funds rate responds sufficiently aggressively to an increase in inflation to induce an increase in real rates and an effective tightening of monetary policy. Thus, the criticism leveled against monetary policy in the 1970s, namely that it did not respond sufficiently to keep inflation under control, does not apply to policy estimated over the 1980s and 1990s.[6] Nevertheless, interest rate rules estimated over the latter period have been subjected to a different criticism.

Criticism of Federal Reserve Policy

In the context of interest rate reaction functions such as (1) and (2), asking whether the observed degree of interest rate smoothing is optimal is equivalent to asking whether the observed degree of partial adjustment and the overall responsiveness of interest rates are optimal. Some analysts who have evaluated the performance of policy rules in terms of stabilizing output and inflation fluctuations have argued that an optimal policy rule would not exhibit as high a degree of partial adjustment and that estimated interest-rate reaction functions such as (2) are too timid. Of course, forming such a judgement requires a specific macroeconomic model that describes the determination of output and inflation when interest rates are set according to a specific rule. Quantitative studies that have come to the conclusion that policy rules which fit interest rate behavior in the 1980s and 1990s are too inertial and timid have typically relied on models that assume adaptive expectations and ignore important sources of uncertainty (see for example Ball (1999), Rudebusch (1998), Rudebusch and Svensson (1998) and Williams (1999)). Because these models assume that the short-run relationship between interest rates and output and

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[5] As a comparison of the estimation results in the literature shows, this finding is robust across alternative specifications and sample periods. Among numerous other specifications, the finding of a substantial degree of partial adjustment extends to rules that respond to forecasts and to real-time data.

[6] Clarida, Gali and Gertler (1998), for example, show that if the long-run response to an increase in inflation, $\alpha/(1-\rho)$, is less than one, inflation may spin out of control due to self-fulling expectations of an increase in inflation. The estimated long-run response in (2) is about 3.

inflation is known with certainty and invariant to policy, output and inflation can be stabilized more effectively by making interest rates more responsive to macroeconomic variables than observed historically. That is, the policymaker can achieve greater macroeconomic stability in these models by accepting higher volatility of the interest rate.

As a result, the Federal Reserve has been criticized for responding too little and too late to macroeconomic developments. Furthermore, it has been suggested that the Federal Reserve's practice of smoothing interest rates reflects an objective of lowering interest rate volatility, in addition to the policy goals mandated in the Federal Reserve Act.[7] In fact, many empirical studies of optimal monetary policy assume that policymakers have a three-fold objective of minimizing deviations of output from its potential level, deviations of inflation from its target, and the variability of the level or the change in the short-term interest rate. Some researchers, using backward-looking models, have found that a large weight on interest-rate variability in the policymakers' loss function is required to obtain an optimal rule that matches historical estimates.

In contrast, this paper argues that the observed degree of interest-rate smoothing reflects to a large extent optimal behavior on the part of central banks that are concerned only with output and inflation stability. Three arguments help to explain why the observed degree of interest rate smoothing may be optimal: the *forward-looking behavior of market participants*, *data uncertainty* or measurement error regarding key macroeconomic variables, and *uncertainty regarding relevant parameters* of the economic structure.

Three Motives for Interest-Rate Smoothing

1. Forward-looking expectations. In models with forward-looking expectations, estimated policy rules such as (2) are more effective in stabilizing output and inflation for a given level of interest rate volatility than rules without partial adjustment. If policy exhibits a high degree of partial adjustment, forward-looking market participants will expect a small initial policy move to be followed by additional moves in the same direction, which increases the impact of policy on current output and inflation without requiring large interest rate changes.

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[7] The three objectives mandated for the Federal Reserve are maximum employment, stable prices, and moderate long-term interest rates. These objectives would be attained through stabilizing output and inflation, since a stable, low inflation environment would allow the economy to achieve maximum employment and would lower long-term interest rates.

2. Data uncertainty. Model-based evaluations of simple policy rules typically assume that policymakers observe key macroeconomic variables without error. In practice, however, some measures of output and inflation tend to be revised several times following the initial data release, while estimates of potential output or the natural unemployment rate may even be revised years later. Recent research has shown that under simple policy rules such as (1) the central bank should moderate the responsiveness of the interest rate to initial data releases when that data is measured with error, since an aggressive policy response would induce unnecessary fluctuations in the interest rate resulting in unintended movements in output and inflation.

3. Uncertainty about parameters. Policymakers are not only uncertain about the exact state of the economy, but also about key parameters of the economic structure that affect the transmission of monetary policy. When parameters are uncertain, aggressive policy moves which might otherwise be expected to offset inflation and output deviations fairly quickly are more likely to have unpredicted consequences on output and inflation. It may instead be optimal to implement a gradual response of the interest rate that would return output and inflation more slowly to the targeted values.

Other explanations of interest-rate smoothing have been offered in the literature, including concern about the soundness of the financial sector, maintaining the reputation of the central bank, issues regarding consensus decision-making, and adverse reactions of financial markets to frequent changes in the direction of interest rates. Although these arguments may have merit, empirical evidence is yet to be provided, and several of the arguments still have to be modeled rigorously. As a result, this paper focuses on the three arguments outlined above. In the following sections we discuss empirical evidence for each of these arguments. While for each argument we refer to several supporting recent studies, we limit the more detailed review of empirical methodology and results to one study per argument. In particular, this paper reviews the results of Levin, Wieland, and Williams (1998) regarding efficient simple interest-rate rules under forward-looking expectations, Orphanides (1998b) regarding the impact of data uncertainty on optimal Taylor rules, and Sack (1998a) regarding optimal policy under parameter uncertainty. The three studies have in common that they apply to the U.S. economy and were conducted at the Federal Reserve Board. While we have not extended our review to cover the experience of other countries and central banks, we again note that choosing a smooth path for short-term interest rates is a strategy common to many central banks.

II. Interest-Rate Smoothing in Forward-Looking Models

Empirical Evidence

Recent research showing that the presence of forward-looking market participants may motivate some degree of interest-rate smoothing includes Williams (1999), Rotemberg and Woodford (1998), Woodford (1998), and Levin, Wieland, and Williams (1998). The latter paper is perhaps of special interest since the authors use the Federal Reserve's own FRB/US macroeconomic model with forward-looking expectations. Levin, Wieland and Williams (LWW) conduct two different experiments to assess the benefits from interest-rate smoothing in terms of output and inflation stabilization. The first experiment focuses on the benefit of increasing the inertia of the interest rate through a *higher degree of partial adjustment*, without changing interest rate volatility. The second experiment examines the potential for further improvements in output and inflation performance by raising the *overall responsiveness* of the interest rate and allowing higher interest rate volatility.

As a benchmark for comparison, LWW compute the standard deviation of output, inflation, and interest rates that would result from following the estimated rule (2) in an economy described by the FRB/US model that is subjected to shocks similar to those experienced historically. The performance is then compared to the outcomes that could be achieved with an optimal choice of the response coefficients for the class of policy rules defined by (1).

In the course of the first experiment, LWW compute the best attainable outcomes in terms of inflation and output variability from following rules with and without partial adjustment subject to the constraint that interest rate volatility is no greater than under the estimated policy rule. In the case of no partial adjustment they set ρ in equation (1) equal to zero and then search for the values of α and β that minimize a weighted average of the unconditional variances of inflation and output. Repeated application of this minimization procedure for alternative weights on inflation and output volatility traces out a policy frontier that can be thought of as the best attainable set of outcomes for policy rules such as equation (1), but without partial adjustment.

Figure 2 shows the trade-off between output and inflation variability that results from these computations. In general, points in the southwest portion of the chart represent better outcomes, in terms of lower inflation and output volatilities, than do points in the northeast. The figure shows the outcome from the estimated rule (2), which yields standard deviations of output, inflation and the change in interest rates of 2.66 percent, 1.52 percent, and 1.22 percent, respectively. The solid line corresponds to the minimum inflation volatility attainable for a given amount of output volatility in the absence of partial adjustment. A point on the northwest part of the frontier would be chosen by a policymaker who puts a relatively high weight on reducing inflation volatility, while a point on the southeast part of the frontier would be chosen if avoiding output volatility is given a high weight. The tradeoff between inflation and output volatility along the frontier stems largely from supply or price shocks.[8] The key result is that the point representing the outcome under the estimated policy, which incorporates partial adjustment, lies to the southwest of this frontier. Thus, the estimated policy rule is more effective in reducing inflation and output volatility than rules without partial adjustment, even when the response coefficients on output and inflation for the latter rules are chosen optimally.

The next step is to determine whether the estimated degree partial adjustment, as reflected by a value of the partial adjustment coefficient ρ of about 0.8 in equation (2), is optimal in terms of stabilizing output and inflation in the FRB/US model. To answer this question, LWW repeat the above computations, but in doing so choose a value of ρ that helps lower the attained weighted average of inflation and output variability. Again, the minimization is subject to the constraint that the degree of interest-rate volatility under the estimated rule is not exceeded.

The outcomes for rules with an optimal degree of partial adjustment are shown by the dashed line. Rules on this policy frontier perform better than the estimated rule and substantially better than rules without partial adjustment in terms of reducing inflation and output volatility. These results indicate that inertia in interest rates induced by partial adjustment is a desirable property of a policy directed towards stabilizing output and inflation. The optimal value of the partial adjustment coefficient ρ in the FRB/US model tends to be close to 1, which implies that these rules are essentially setting the change in the funds rate. LWW also find that such change rules are close to optimal in two alternative estimated macroeconomic models of the U.S. economy with rational expectations, a smaller model from Orphanides and Wieland (1998) and the multi-country model of Taylor (1993). In a fourth model, the small macroeconomic model

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[8] The policy response to a demand shock will help stabilize both output and inflation, so that there is less of a trade-off between inflation and output variability arising from these shocks.

Figure 2

Forward-Looking Expectations and Interest Rate Smoothing

Levin, Wieland, Williams (1998)

Evaluating Policy Rules

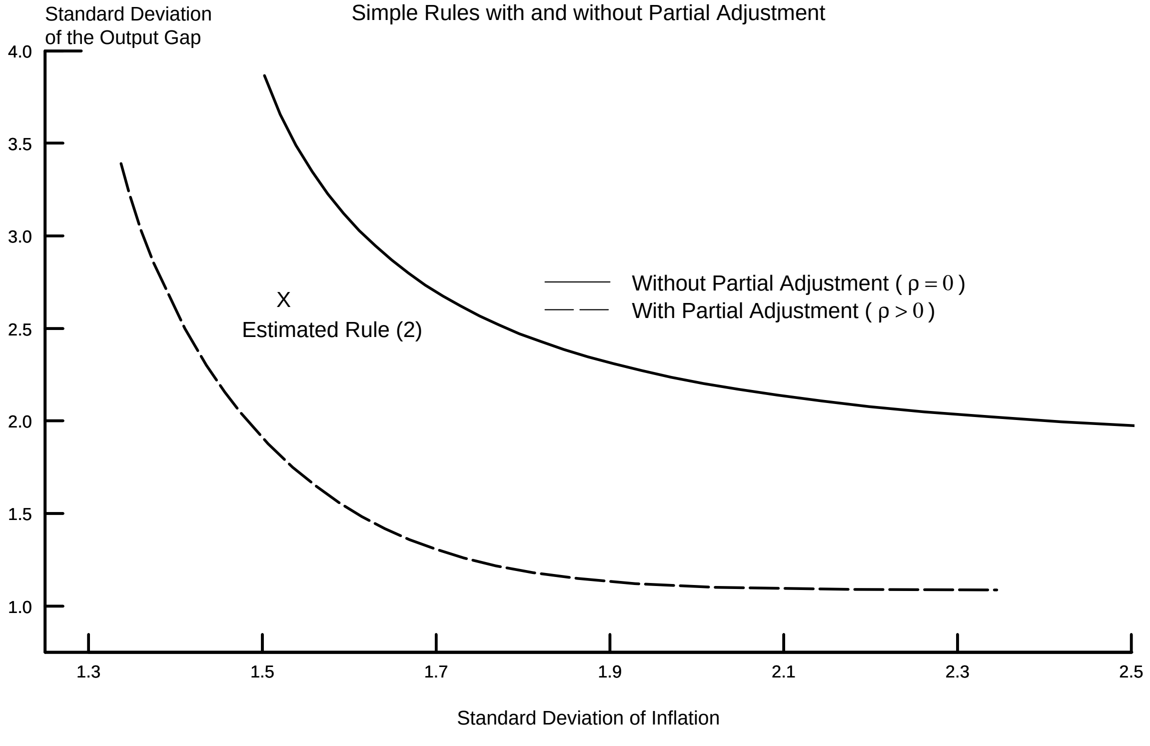
- Compute output, inflation, and interest rate variability for the estimated rule (2).
- Compute inflation and output variability for policy rules such as

$$r_t = \rho r_{t-1} + (1-\rho)(rr^* + \pi_t) + \alpha(\pi_t - \pi^*) + \beta y_t$$

constraining interest volatility to the value observed under the estimated rule.

Policy Frontiers in the FRB/US Model

Simple Rules with and without Partial Adjustment



by Fuhrer and Moore (1995), they find optimal values for the partial adjustment coefficient ρ that are closer to the estimated value in (2), between 0.8 and 0.9.[9]

In the second experiment, LWW explore whether output and inflation volatility could be reduced further by increasing the overall responsiveness of the policy rules and allowing interest rates to be more volatile. They do so by repeating the preceding minimization exercise while allowing interest-rate volatility to be twice and three times as large as under the estimated rule. Figure 3 shows that the policy frontier shifts towards the origin as the constraint on interest-rate volatility is relaxed, but only by a very small amount. Thus even a substantially more aggressive policy that accepts a very large increase in interest-rate volatility generates little benefit in terms of inflation and output stability. Compared to results using backward-looking models, the tradeoff between interest-rate volatility and output and inflation volatility is much less pronounced. While efficient simple rules still induce higher interest volatility than historical policy, the difference in terms of output and inflation performance is not as large as might have been expected based on studies with backward-looking models.

As to the partial adjustment coefficient ρ, relaxing the constraint on interest rate volatility results in only a slight reduction in its optimal value. For example, doubling the standard deviation of the change of the federal funds rate reduces the optimal value of ρ only by about 0.07, on average, from a range of [.96, 1.02] to [.93, .96]. LWW obtain similar results in the three other models they consider, Taylor's multi-country model, the model by Orphanides and Wieland, and the Fuhrer-Moore model. They conclude that even with relatively high interest rate volatility, a high degree of partial adjustment is preferred in these models. While all the results reported by LWW still incorporate some constraint on interest rate volatility, optimal rules without such a constraint have been reported by Fuhrer (1997) for a version of the last model considered by LWW. He finds optimal values of the partial adjustment coefficient between 0.76 and 1 depending on the weight on output versus inflation volatility. These results indicate that the smooth interest rate changes induced by a high degree of partial adjustment are optimal even when no constraint on interest rate volatility is imposed.

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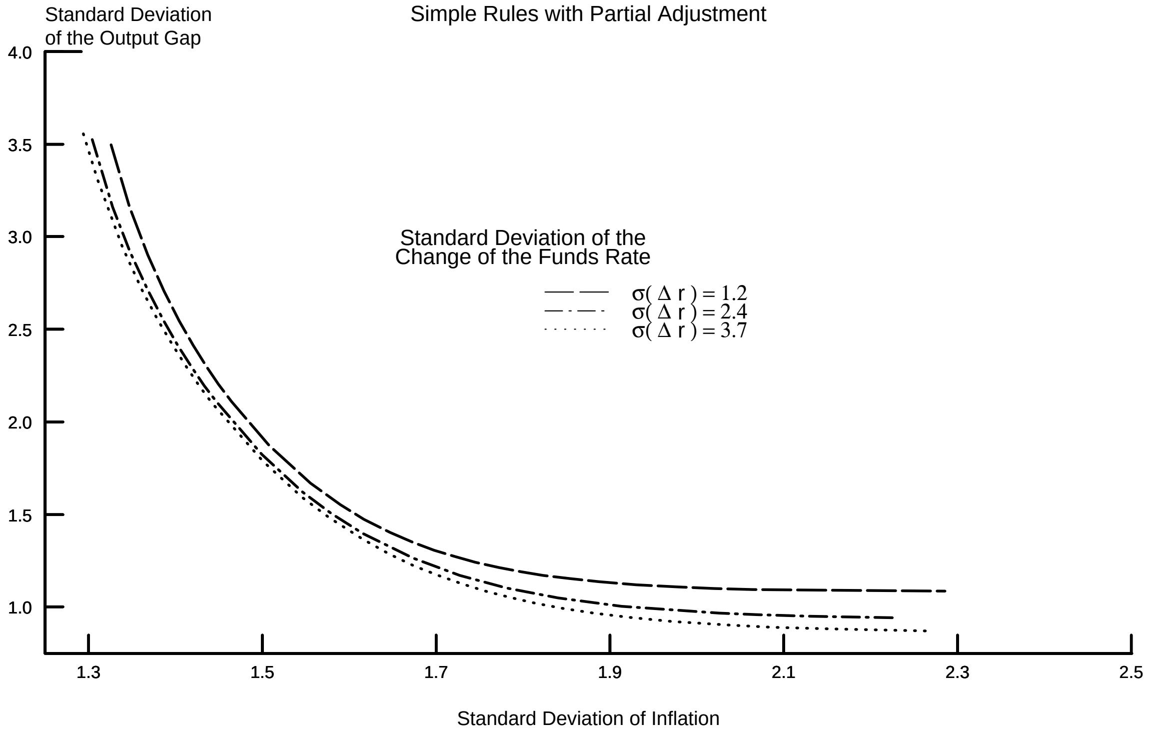
[9] This finding is consistent with Fuhrer's (1997) evaluation of optimal rules with a later version of that same model.

Figure 3

Forward-Looking Expectations and Interest Rate Smoothing

Levin, Wieland, Williams (1998)

Policy Frontiers under Alternative Constraints on Interest Volatility



An Explanation

The key difference in models with forward-looking instead of adaptive expectations is that the effect of actual changes in short-term interest rates on output and inflation is no longer invariant to the anticipated path of policy.[10] Forward-looking market participants in financial, goods and labor markets form expectations about the conduct and effects of future monetary policy, which influence their decisions. As a result, output and inflation may be more effectively stabilized by inducing expectations of future policy actions that adjust in an appropriate manner to macroeconomic shocks. Interest rate rules with partial adjustment, which generate sequences of policy moves in the same direction with few reversals, are particularly effective in exploiting this expectations channel of monetary policy transmission.

This result is perhaps best understood in the context of a point made by Goodfriend (1991). Noting that output and prices primarily respond to movements in longer-term rates, which in turn depend on expectations of future short rates, he argued that policy rules that communicate a changed path of future short rates to the public can be quite effective. Once the policymaker has established a reputation of conducting a policy of small steps in the same direction with infrequent reversals, a changed path of future rates can be communicated effectively by means of a small initial move. Woodford (1998) provides a formal analysis of this argument and concludes that such a policy of interest-rate smoothing, if it is credible to the private sector, offers the prospect of significant effects of monetary policy upon aggregate demand without requiring excessively volatile short-term interest rates.[11] This explanation is consistent with remarks by various policymakers. For example, the Bundesbank's former chief economist and current member of the ECB's Executive Board, Otmar Issing (1997), stated "If changes in official rates in a certain direction that are confirmed by repetition and not expected to be reversed soon have most influence on longer-term rates, it would seem appropriate for the Bundesbank to adjust its official rates in the smoothest manner."

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[10] Forward-looking or model-consistent expectations are not simply a fixed function of past information but take into account the economic structure and the policy pursued by the central bank.

[11] In fact, the results from Rotemberg and Woodford(1998) and Woodford(1998) indicate that the optimal policy rule may have a coefficient ρ that is greater than 1. Although such a rule appears "explosive," it actually induces a smooth interest rate path because the forward-looking behavior of economic agents keeps inflation and output from deviating far from their targeted levels.

Summary

By inducing expectations of additional interest-rate movements, a policy rule that moves the interest rate gradually can have a substantial impact on output and inflation while maintaining a low level of volatility of the short-term interest rate. As a consequence, simple policy rules that involve considerable partial adjustment of the interest rate, as found in historical interest-rate rules estimated over the 1980s and 1990s, may be quite effective. Moreover, because of the forward-looking behavior of market participants, the benefit of increasing the volatility of the interest rate above that observed is found to be quite limited, which is different from the results found using backward-looking models.

III. Interest-Rate Smoothing and Data Uncertainty

Due to their simplicity, policy rules such as equation (1) which respond only to a few macroeconomic variables such as the current output or unemployment gap, current inflation, and the lagged federal funds rate may be particularly useful as a benchmark or guide for actual policy. In that role, policy decisions can be compared to the interest rate prescriptions that would follow from such simple rules. Model-based evaluations of simple policy rules such as the studies discussed in the previous section indicate that simple rules may be very effective in stabilizing output and inflation if the response coefficients are chosen efficiently. However, these studies typically assume that the variables which enter the policy rule are observed without error. In practice, initial readings of these variables may be very imprecise, so that policymakers face considerable uncertainty about the true state of the economy at the time of the policy decision. For example, output and inflation data tend to be revised for several quarters following the initial release. In addition, unobservable variables such as potential output and the natural rate of unemployment must be updated from experience and model-based estimates, a process that could result in more persistent measurement error. In the presence of such data uncertainty, it may be optimal for simple policy rules such as (1) to moderate the response of the interest rate to measured levels of the output gap and inflation. Implementing an aggressive policy reaction to the data would induce unnecessary fluctuations in the interest rate from its reaction to movements in these variables driven simply by measurement error, which in turn would result in unintended movements in output and inflation.

Empirical Evidence

Recent research showing that the presence of such data uncertainty may motivate some degree of interest-rate smoothing includes Orphanides (1998b), Rudebusch (1998), and Smets (1998). All three of these papers estimate models of the U.S. economy with adaptive expectations that typically consist only of three equations: a Phillips curve relationship relating output gaps to inflation, an aggregate demand equation relating output gaps to the interest rate, and a policy rule. Smets (1998) focuses exclusively on the implications of random measurement error associated with unobservable potential output, while Orphanides (1998b) and Rudebusch (1998) consider the possibility of serially correlated errors associated with early readings of inflation and the output gap.[12] In the remainder of this section we focus on the empirical results from Orphanides (1998b) over the period 1980 to 1992.

Orphanides first shows that policy evaluations that disregard data uncertainty may severely overstate how effective monetary policy can be in stabilizing output and inflation. As a benchmark for comparison, he calculates the policy that would be optimal in the absence of measurement error. The potential outcomes under this policy are characterized by a frontier describing the tradeoff between inflation and output variability, as in section 2. This frontier is obtained by varying the policymaker's relative concern about inflation and output variability, assuming that he faces the distribution of supply and demand shocks obtained from the estimated model.[13] In contrast to the results in section 2, no constraint was imposed on interest-rate variability. The solid line in Figure 4 shows the policy frontier that could have been achieved if in fact there was no measurement error. The actual performance of inflation and the output gap over the sample is also shown in the figure. The optimal policy rule that disregards data uncertainty responds more aggressively to output and inflation than the observed policy and as

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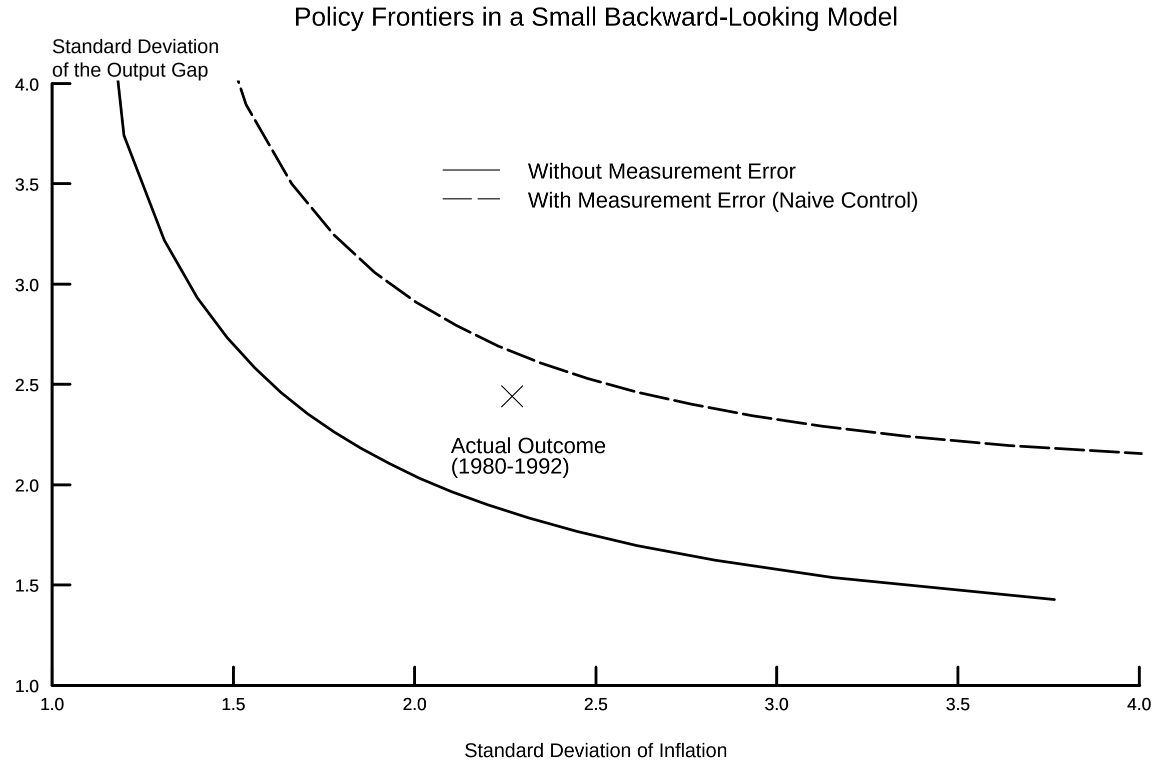
[12] The dynamic properties of the data noise used by the latter two authors has been estimated by Orphanides (1998a) based on the differences between real time data on inflation and output gaps collected from the Federal Reserve's Greenbooks and final data for the period from 1980 to 1992.

[13] As discussed in section 2, macroeconomic models typically involve a tradeoff between output and inflation variability stemming largely from supply shocks.

Figure 4

Data Uncertainty and Interest Rate Smoothing

Orphanides (1998b)



Policy Frontiers in a Small Backward-Looking Model a result promises considerably less variability than the actual outcomes. This is precisely the result that underlies the "too little, too late" criticism of Federal Reserve policy. It appears that a more active policy would have resulted in much better stabilization performance.

Once measurement error is taken into account, however, the performance of this policy rule changes dramatically. The dashed line in Figure 4 traces out the results that would arise if policy were to respond in the same aggressive way to the noisy initial observations of inflation and the output gap that were available at the time of the policy decisions. This strategy, which Orphanides terms "naive control," results in substantially worse outcomes than the observed policy. Of course, such naive policy is unlikely to appropriately reflect the actual practice of policymakers who are aware of the imperfections associated with economic data.

Orphanides proceeds to investigate how policy can appropriately account for the existence of data uncertainty. A policymaker that is aware of the imprecision of the data will use all available data, an appropriate structural model, and any prior assessment in an attempt to filter out the measurement error and form estimates of the true underlying values of the macroeconomic variables. In particular, the policymaker will put less weight on recently released data on the output or inflation gap in updating estimates of these variables because of the measurement error in the releases. The policymaker will then determine the optimal policy choice based on those estimates. Perhaps surprisingly, the optimal policy response to the estimated variables turns out to be exactly the same as the response that would have been implemented in the absence of data uncertainty. Even though the policymaker's estimates may be fairly imprecise, policy responds as if the state of the economy were observed without any measurement error--a property that is often referred to as "certainty equivalence."[14] The ball-and-chain line in Figure 5 constitutes the policy frontier achieved under the optimal control approach. It is found to improve output and inflation performance substantially compared to the naive control policy which disregards the existence of data uncertainty. Moreover, the optimal control policy is found to improve upon actual policy, but by much less than was suggested by the

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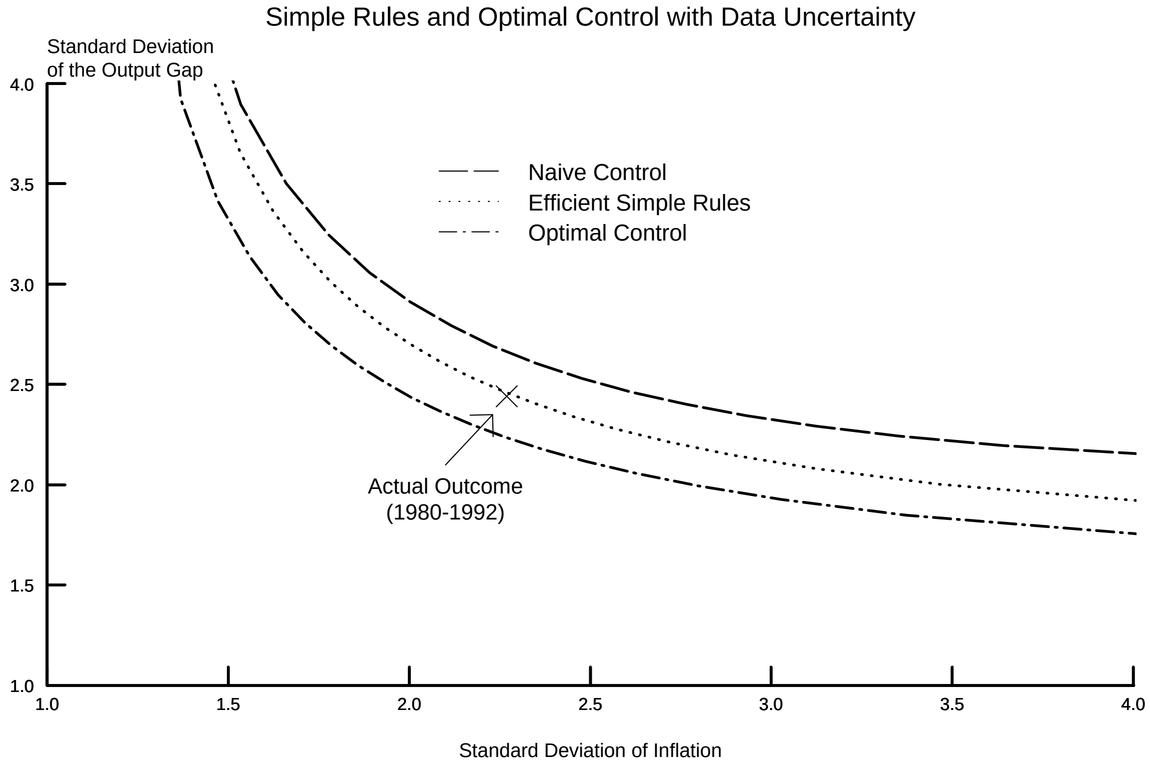
[14] This certainty equivalence result holds in the linear-quadratic class of models, in which the policymaker's objectives are quadratic and the dynamic structure of the economy is linear. It is because of this certainty equivalence property that the optimal policy can proceed in the two steps described, first forming optimal estimates and then deciding the policy choice, a result also known as the "separation principle."

Figure 5

Data Uncertainty and Interest Rate Smoothing

Orphanides (1998b)



preceding analysis in Figure 4, which disregarded data uncertainty.

However, following the optimal strategy described above is rather complicated, as it requires taking into account all available information in the estimation and responding to estimates of all relevant state variables. As a less complicated alternative, Orphanides considers the performance of efficient simple policy rules that are restricted to respond directly to measured levels of output and inflation. This is of particular interest because such rules are often used as a benchmark for comparison to the actual policy. Certainty equivalence will not hold in this case because of the constraints that are imposed on the problem, namely that the policymaker is limited to respond to the measured levels of the variables rather than the optimally filtered estimates. In this class of policy rules, the optimal response coefficients to output and inflation are found to be substantially reduced in comparison to a policy rule that ignores data uncertainty. The policy frontier associated with efficient simple rules corresponds to the dotted line in Figure 5. By reducing the responsiveness to the noisy data releases, efficient simple rules perform better than the naive control policy that disregards the existence of data uncertainty. Furthermore, the historical performance of the U.S. economy over this period turns out to be right on the efficient simple rule frontier, leaving little room for the claim that much improvement in output and inflation stabilization would have been possible in this class of policy rules by a more active policy, one with higher response coefficients. As a result, comparisons between actual monetary policy and simple policy rules that disregard data uncertainty, which form the basis for much the criticism of policy found in backward-looking models, may be quite misleading. The observed policy response to movements in output and inflation may appear to be too timid, but in fact this timid response may be optimal in the presence of data uncertainty.

Summary

The presence of data uncertainty moderates the response of the interest-rate to measured levels of the output gap and inflation. This attenuation is immediately apparent under simple policy rules in terms of reduced response coefficients, but it also takes place under optimal policy rules. In particular, even though the interest rate is responding in the same manner to the filtered estimates under the optimal policy rule, data uncertainty reduces the impact of the data releases on those estimates. Overall, the results from Orphanides (1998) suggest that efficient simple policy rules for stabilizing output and inflation imply a degree of activism that is quite similar to actual policy in the 1980s and 1990s. However, that paper does not demonstrate that data uncertainty provides a rationale for the high coefficient on the lagged interest rate in estimated interest-rate rules. This partial adjustment could potentially reflect slowly evolving beliefs about the true state of the economy, but this remains to be shown by future research.

IV. Interest-Rate Smoothing and Parameter Uncertainty

Up to this point, the models discussed assume that policymakers have the luxury of knowing the structure of the economy with certainty. In fact, parameters from economic models are estimated imprecisely and typically vary unpredictably through time. Moreover, policymakers may not even know the correct structure of the model. As a result, monetary policy must be implemented in the presence of a considerable amount of uncertainty, without full confidence about the effect of interest-rate choices on macroeconomic variables such as the output gap or inflation. Although the exact impact of parameter uncertainty on the optimal policy choice can depend on specific modeling assumptions, a general result tends to emerge: Parameter uncertainty adds caution to the optimal policy rule. By responding more tentatively to macroeconomic developments, policymakers can limit the undesired impact that their policy may have on output and inflation due to incorrect estimates of the model's parameters.

Some Background

Theoretical analysis of optimal policy under parameter uncertainty dates back to Brainard (1967). More recent papers include Wieland (1998), who analyzes optimal policy under uncertainty about the natural rate of unemployment and the slope of the short-run Phillips curve, and Sack (1998b), who investigates the impact of uncertainty about the policy multiplier. Both types of uncertainty lead to interest-rate movements that often are not large enough to correct the entirety of the expected output gap or the deviation of inflation from its target. In the words of Alan Blinder (1995), optimal policy involves "a little stodginess" in which "the central bank should calculate the change in policy required to get it right and then do less." The reason is that aggressive interest-rate changes typically increase the uncertainty in the response of output and inflation when parameters are unknown.[15]

To see this, consider the optimal policy response in a situation where output is currently above the level consistent with the policymaker's objectives. If the negative response of output to the interest rate were known with certainty, as shown in the top panel of Figure 6, the optimal policy decision would be trivial: increase the interest rate by the amount required to reach the desired level of output, shown in the figure by the interest rate i_1.

The presence of uncertainty need not materially complicate this decision. If uncertainty enters additively--say through unpredictable variation in the level of household spending--the aggregate demand relationship would shift about in a parallel fashion, as in the middle panel of the figure. The expected level of output is indicated by the solid line, but the actual output level may be above or below the expected level, as shown by the dashed lines. If the policymaker implements the same interest rate change to i_1, output will reach the desired level on average, but the actual outcome could lie anywhere in the range indicated by the thick line segment at i_1. This uncertainty leaves the policymaker worse off than in the case with no uncertainty, as the realized level of output will most likely differ from the level consistent with the policymaker's objectives. However, the policymaker cannot reduce the magnitude of the potential output deviation by moving less, for example to the interest rate i_2. Additive uncertainty does not affect the optimal policy decision because the uncertainty about the response of output is independent of the policy choice. This is the certainty equivalence result that was discussed in the context of data uncertainty.

Unfortunately, the uncertainty confronting policymakers is more pervasive than assumed in the case of additive uncertainty, considerably complicating the policy choice. In particular, the policymaker may also be uncertain about the slope of the aggregate demand relationship, as shown in the bottom panel of Figure 6. The expected shape of the curve given the policymaker's estimates of the parameters is again shown by the solid line, but because of the imprecision in those parameter estimates, the level of output observed at the current interest rate could have instead resulted from an alternative set of parameter values, such as those generating the two schedules shown by the dashed lines in the figure. The important difference from the case of

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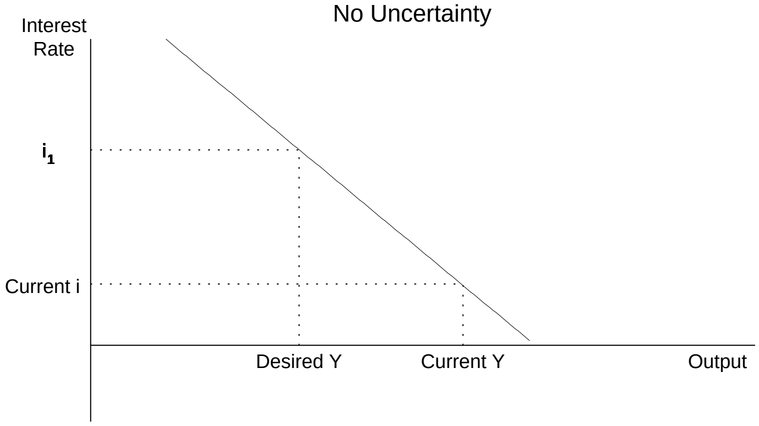
[15] As pointed out by Brainard, whether parameter uncertainty results in a less aggressive policy response depends critically on the covariances between unknown parameters. The empirical results presented below impose no restrictions on the covariance matrix of the parameter estimates.

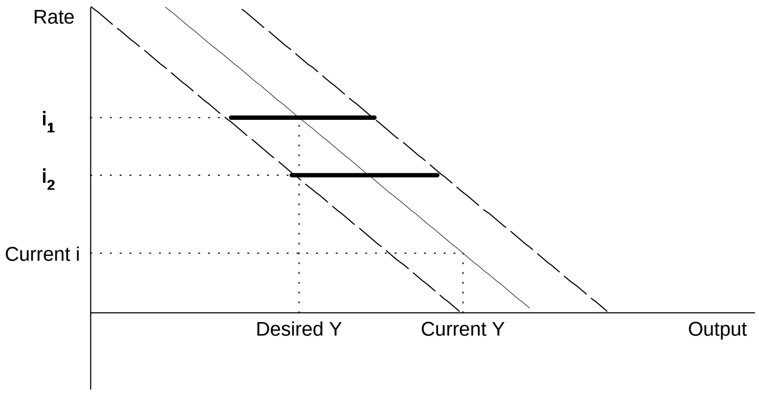
Figure 6

Parameter Uncertainty and Interest Rate Smoothing



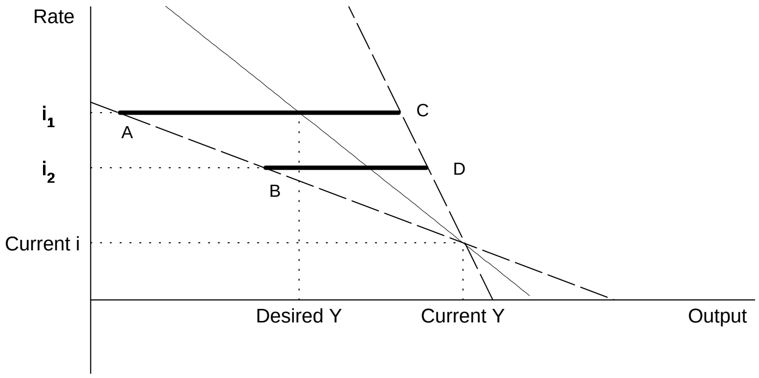
No Uncertainty

- **Policy decision is trivial: increase the interest rate enough to reach the desired level of output.**



Additive Uncertainty

- **Uncertainty about the response of output is independent of the interest rate change.**



Parameter Uncertainty

- **Uncertainty about the response of output increases with the interest rate change.**

additive uncertainty is that the uncertainty in the response of output now *increases* with the magnitude of the interest rate change. An aggressive interest rate movement, for example to $i_{1,}$ could leave output far away from the desired level if the sensitivity of output to interest rate changes turned out to be much different than believed. Reducing the size of the interest rate response to i_2 significantly reduces the size of the output deviation if output turns out to be more sensitive to the interest rate than believed (point B instead of point A) and only leaves a slightly larger output deviation if output is instead less sensitive to the interest rate (point D instead of point C). As a result, implementing a more moderate interest rate change reduces the amount of uncertainty in the response of output, as indicated by the narrower band of potential outcomes. Parameter uncertainty therefore creates a trade-off to be considered in the optimal policy decision: More aggressive interest rate changes will move output closer to the desired level on average but will generate more uncertainty in those outcomes. This is analogous to the problem facing an investor choosing between a safe and a risky asset. The investor may be willing to hold some of the safe asset even though it has a lower expected return in order to reduce the uncertainty of the payout. Similarly, the optimal policy may damp interest rate changes, deciding not to move the full extent required to reach the desired level of output in expected terms so as to reduce the range of potential deviations in output.

Of course, the degree of uncertainty that policymakers face will likely change over time. Figure 7 extends the static results to a dynamic setting, showing that parameter uncertainty may result in gradual and persistent movements in the interest rate. The initial response of the interest rate to macroeconomic developments will be damped for the reasons discussed above, reaching only i_2 for example, but the degree of uncertainty may subsequently decline as the policymaker learns about the impact of interest rate changes.[16] That is, the fan-shaped region of uncertainty shifts up and narrows around the current interest rate as information about the transmission of policy begins to accumulate, as shown in the top panel of the figure. Having observed the reaction to the initial policy move to i_2, the policymaker faces a narrower range of potential outcomes around the desired level of output from reaching i_1 in a second policy step, compared to implementing a single, large policy move as shown in the bottom panel. Even if the

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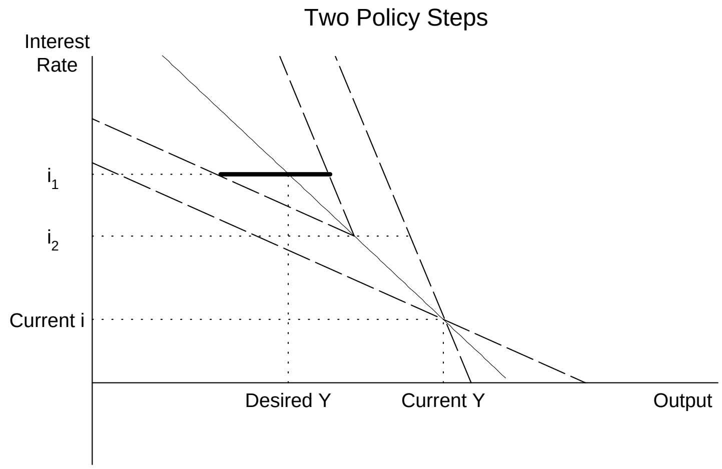
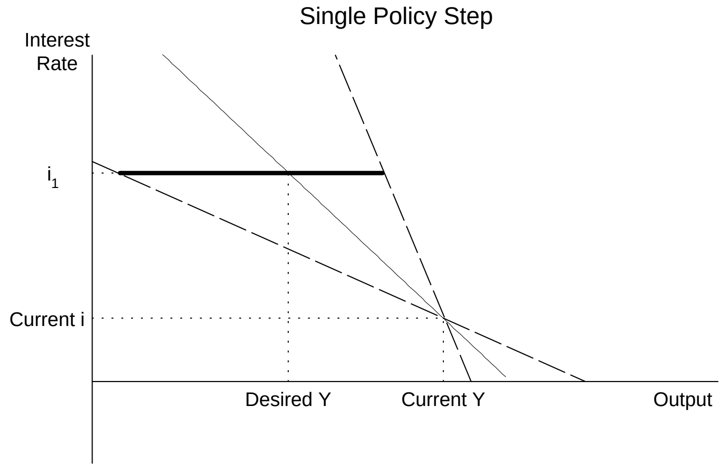
[16] In addition, the uncertainty may also be reduced if the initial policy change pushes the economy into a region where the effect of additional policy moves has been estimated more precisely.

Figure 7

Parameter Uncertainty in a Dynamic Context





uncertainty does not decline much after the initial policy move, the optimal interest rate response may still be very smooth and persistent. In particular, the policymaker may optimally choose not to push the interest rate as high as i_1 because of the uncertainty in the response of output at that interest rate level, but may instead implement a more limited but persistent increase in the interest rate, one that moves inflation more slowly towards its desired level by sustaining the output gap for a longer period of time.

Some Results

Recent empirical evidence regarding the importance of parameter uncertainty as a rationale for interest-rate smoothing has been provided by Estrella and Mishkin (1998), Rudebusch (1998), and Sack (1998a). By taking as given a specific model of the economy and specifying a set of goals for the central bank, these papers calculate the optimal path for the federal funds rate. In the following we present results taken from Sack (1998a), who calculates the optimal funds rate policy that minimizes a weighted sum of deviations of the unemployment rate from an equilibrium level and inflation from a target, given the dynamic behavior of these variables as summarized in a vector autoregression (VAR). The optimal policy that is calculated is not a simple policy rule as equation (1), but instead determines the interest rate in response to all current and lagged variables in the VAR. This policy will depend on lagged values of the interest rate because previous policy choices continue to affect the targeted variables due to the substantial lags in the impact of monetary policy.

This optimal policy is compared to the actual setting of the federal funds rate, which is estimated by one of the equations in the VAR. The monthly interest rate changes implemented under this estimated policy rule over the period 1984 to 1998 are shown in the top panel of Figure 8. Many of the characteristics of interest-rate smoothing described in the introduction are evident: Interest rate changes tend to be limited in size, and successive changes often have the same sign. As indicated to the right of the graph, the standard deviation of monthly interest rate changes is 15 basis points, and 79 percent of these changes were continuations in the direction of policy.[17]

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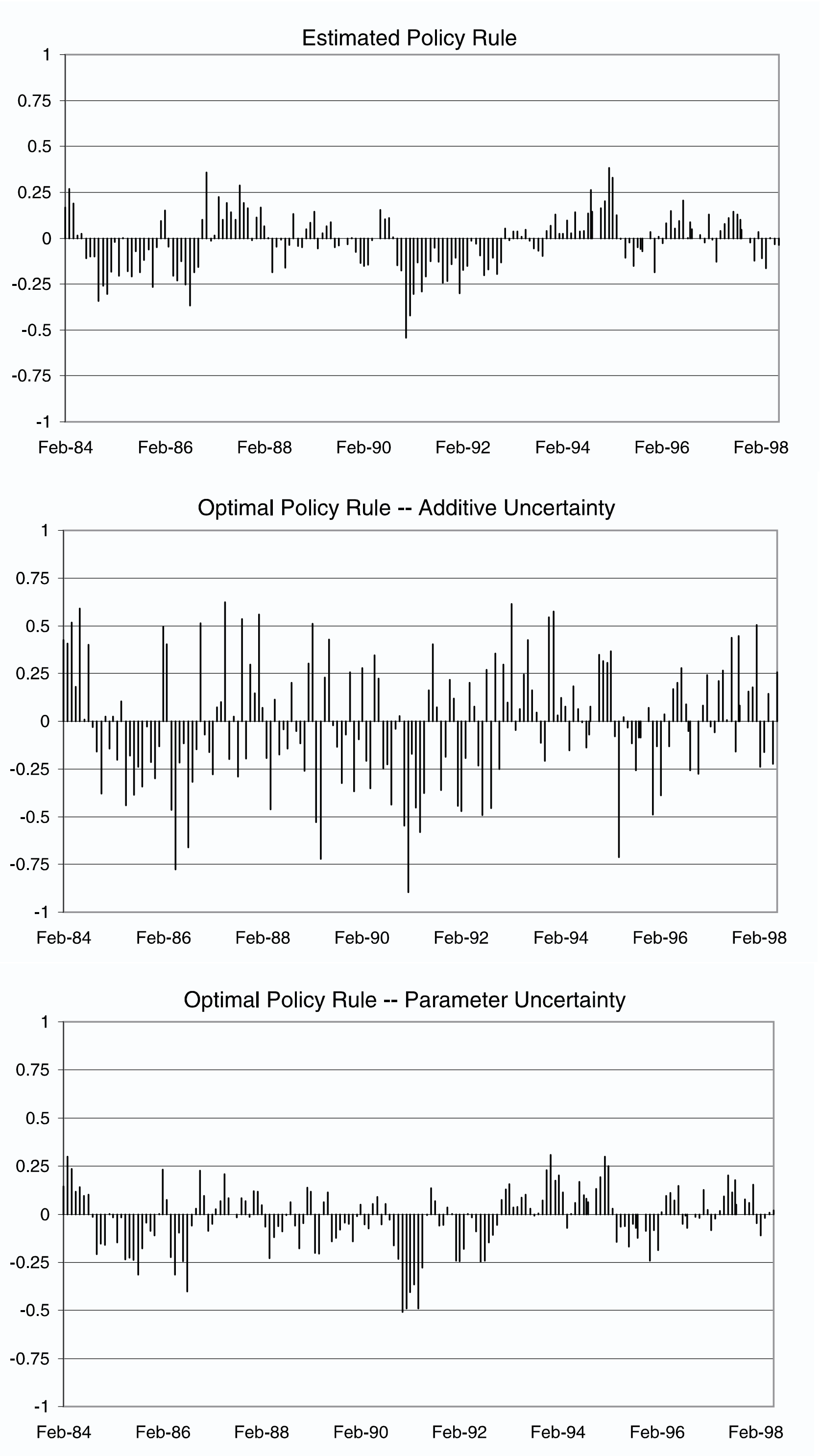
[17] To calculate the percentage of continuations, this paper follows Goodhart(1998) and categorizes the interest rate changes predicted by the various policy rules into 25 basis point increments.

Figure 8

Parameter Uncertainty and Interest Rate Smoothing

Sack(1998a)

Monthly Interest Rate Changes



Continuations

79%

Std. Dev. of Rate Changes

15 b.p.

Continuations

60%

Std. Dev. of Rate Changes

31 b.p.

Continuations

80%

Std. Dev. of Rate Changes

15 b.p.

The estimated policy can be compared to the optimal policy to determine whether the observed degree of smoothing is appropriate. To do so, the analysis calculates the interest rate changes that would have been realized had the optimal policy rule been implemented over this period, assuming that the economy was subjected to the same set of shocks. The second panel shows the results from this exercise under the assumption of *additive uncertainty*, in which the policymaker takes the estimated VAR coefficients to represent the true values of the parameters and assumes that uncertainty enters only through an additive disturbance--the error terms in the VAR equations. In this case, the optimal policy adjusts the interest rate sharply in response to macroeconomic developments, which more than doubles the volatility of interest rate changes and limits the tendency for the interest rate to move in a sequential steps in a particular direction. These results indicate that when the relationship between the interest rate and the targeted variables is fixed and perfectly known, the optimal policy can more effectively stabilize the targeted variables by implementing more aggressive interest rate changes than observed historically.[18]

Once the policymaker considers the full scope of the uncertainty surrounding the estimated dynamics of the economy, the policy choice must be adjusted for the fact that the coefficients of the VAR are estimated imprecisely. In particular, the uncertainty surrounding the response of unemployment and inflation increases the further that the actual interest rate deviates from the level predicted by the historical sample. Intuitively, the policymaker has the most precise estimates about the effect of the interest rate on the economy when the contemplated policy action is similar to those in the sample over which all the coefficients were estimated. An outsized policy move by that standard implies that many of the observations used to estimate the coefficients are not relevant, so that the response of the targeted variables is more uncertain. Thus, the high degree of activism found to be optimal under additive uncertainty has to be tempered in the presence of parameter uncertainty.

To account for parameter uncertainty, Sack calculates the policy that is optimal once the policymaker considers the imprecision of the parameter estimates as measured by the variance-covariance matrix of the VAR coefficients. The optimal policy under *parameter uncertainty*

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[18] This is exactly the result discussed in section 2 of researchers who work with backward-looking models, as in the VAR.

implements the interest rate changes shown in the third panel. As evident in the figure, parameter uncertainty dampens the responsiveness of the interest rate, substantially reducing the volatility of interest rate changes and leading to more continuations in the direction of policy movements. The optimal policy under parameter uncertainty therefore captures several of the prominent characteristics of interest-rate smoothing.[19]

Recent empirical work by Rudebusch (1998) and Estrella and Mishkin (1998) differs somewhat from the results reported here. These authors conclude that the extent of parameter uncertainty that they have identified would not account for the observed degree of timidity in the Federal Reserve's response to output and inflation, finding a smaller effect of parameter uncertainty and less inertia in the interest rate under the optimal policy. Several factors may account for the discrepancy from the above results. First, these papers focus on quarterly and annual movements in the interest rate and are estimated across much longer samples. Second, these papers evaluate the effect of parameter uncertainty on simple policy rules in models with more limited dynamics, whereas the above results consider optimal policy rules that account for the rich dynamics of the VAR. Finally, these studies consider uncertainty about fewer parameters, which limits some of the covariance between parameters that may be driving the interest-rate smoothing.

Extensions

Empirical papers using estimated models such as Sack (1998a), Rudebusch (1998), and Estrella and Mishkin (1998) have measured uncertainty by the estimated variance of model parameters for a given sample period; that is, they have treated the degree of uncertainty as fixed. In practice, however, policymakers' beliefs about relevant structural parameters as well as the precision of available estimates will vary over time, particularly if the unknown parameters themselves are changing. This has been recognized in recent work using theoretical and calibrated models that incorporate learning by the policymaker (see Sack (1998b) and Wieland (1996) and (1998)). Although the impact of learning and time-varying parameters on the optimal degree of interest-rate smoothing has not yet been investigated empirically, several important considerations

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[19] Even though it involves very persistent interest rate movements, the optimal policy is still found to be somewhat more aggressive than the observed policy. See Sack(1998a) for more details.

emerge from these models. First, because the degree of uncertainty about relevant parameters varies over time, the incentive for cautious policymaking is not constant. Furthermore, if the true underlying parameters are in fact time-varying, past observations should be discounted relative to more recent observations, which may increase the importance of the lagged interest rate in a simple policy rule. In particular, uncertainty about the effects of policy will tend to be minimized near the lagged interest rate, since the most relevant information is provided by recent outcomes near this level. More generally, even though the structure of the parameter uncertainty may be rather complicated, the lagged interest rate may capture much of its effect in a simple policy rule, because it represents the optimal decision implemented under a similar degree of uncertainty in the previous period.

One should also note that there are circumstances when parameter uncertainty may justify some activism. For example, policymakers may wish to implement larger interest-rate movements to more effectively learn about relevant parameters, an effect referred to as experimentation. Hence, in models that incorporate learning, the policymaker typically faces a tradeoff between caution and experimentation. Yet even with experimentation, the optimal policy is still found to be less aggressive in most situations than a policy that disregards parameter uncertainty.

Finally, it would also be interesting to consider the impact of uncertainty over the structure of the model itself, as opposed to the parameters in a given model. Policymakers may face greater uncertainty than captured in the above empirical studies because of uncertainty about the specification of structural relationships and the possibility of structural changes in those relationships. To address this issue, Levin, Wieland, and Williams (1998) have analyzed the performance of simple policy rules across four different models. In general, they find that a rule with interest-rate smoothing performs well in all four models considered, so that such a rule may be robust to model uncertainty in addition to parameter uncertainty.

An alternative approach to studying efficient policy under model uncertainty is pursued by Sargent (1998), Onatski and Stock (1998), and Tetlow and von zur Muehlen (1999). These papers apply robust control techniques to design interest rate policies that not only perform well if the reference model turns out to be close to the true economy, but that are also reasonably robust to model misspecification. One particularly interesting finding from this research is that a more aggressive policy stance may be called for in the presence of model uncertainty when policymakers are guarding against worst-case alternatives.

Summary

Parameter uncertainty may provide an incentive to implement gradual interest-rate movements in order to limit any undesired impact on the economy arising from incorrect parameter estimates. Recent empirical evidence shows mixed results about the importance of this effect, but at least in some cases parameter uncertainty has been shown to have a significant effect on the optimal policy. In particular, Sack's analysis based on a VAR model shows that a substantial degree of interest-rate smoothing at a monthly frequency can be attributed to an optimal policy response in the presence of parameter uncertainty. Moreover, models that involve stochastic parameters and learning by the policymaker are likely to attribute a more important role to partial adjustment of the interest rate under simple policy rules than has been suggested by existing empirical studies on the impact of parameter uncertainty.

V. Conclusion

This paper has offered several explanations for why interest-rate smoothing by central banks may be an optimal approach for stabilizing inflation and output, without assuming an interest-rate smoothing objective for the central bank. In particular, some degree of interest-rate smoothing is optimal when the policymaker is faced with forward-looking behavior by market participants, measurement error associated with key macroeconomic variables, and uncertainty regarding relevant structural parameters. Supporting empirical evidence for this contention appears in three recent studies: Levin, Wieland, and Williams (1998), Orphanides (1998b), and Sack (1998a).

Based on this research, we find plausible reasons for the inertial response of U.S. monetary policy in the 1980s and 1990s to fluctuations in key macroeconomic variables such as output and inflation. The three factors considered--forward-looking expectations, parameter uncertainty, and data uncertainty--would each rationalize a substantial degree of interest-rate smoothing in U.S. monetary policy. Of course, the results presented also indicate that engaging in too much interest-rate smoothing can have a detrimental impact on macroeconomic performance. For example, it has been argued that in the 1970s, policy did not respond sufficiently aggressively to increases in inflation to induce a tightening. In the 1980s and 1990s, however, interest rates clearly responded sufficiently aggressively to inflation, and the degree of interest-rate smoothing observed has not been far from the optimal level found under the three factors considered in this paper. While none of the three factors, as far as existing empirical results are concerned, is able to account completely for the observed degree of interest-rate smoothing, taken together they may be more than sufficient. Furthermore, in each case we suggest extensions that might further enhance the empirical support for interest-rate smoothing as optimal policy. A useful avenue for future research would seem to be an empirical evaluation of all three factors in a single model that would make it possible to test the relative importance of the factors and the interaction between them.

References

Ball, Laurence, (1998), Policy Rules for Open Economies, forthcoming in, John B. Taylor, ed., Monetary Policy Rules, NBER and Chicago Press.

Ball, Laurence, (1999), Efficient Rules for Monetary Policy, International Finance, Vol 2, 63-83.

Blinder, Alan, (1995), Central Banking in Theory and Practice, Lecture 1: Targets, Instruments and Stabilization, Marshall Lecture presented at the University of Cambridge.

Brainard, William, (1967), Uncertainty and the Effectiveness of Policy, American Economic Review, Vol. 57, 411-425.

Clarida, Richard, Jordi Gali, and Mark Gertler, (1998), Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory, NBER Working Paper No. 6442.

Clarida, Richard and Mark Gertler, (1998), The Science of Monetary Policy, forthcoming in, Journal of Economic Literature.

Congressional Budget Office, (1997), The Economic and Budget Outlook, United States Government Printing Office.

Estrella, Arturo and Frederic Mishkin, (1998), Rethinking the Role of NAIRU in Monetary Policy: Implications of Model Formulation and Uncertainty, NBER Working Paper #6518.

Fuhrer, Jeffrey C., (1997), Inflation/Output Variance Trade-Offs and Optimal Monetary Policy, Journal of Money, Credit, and Banking 29, 214-234.

Goodfriend, Marvin, (1991), Interest Rates and the Conduct of Monetary Policy, Carnegie-Rochester Conference Series on Public Policy 34, 7-30.

Goodhart, Charles, (1997), Why do the Monetary Authorities Smooth Interest Rates?, Chapter 8, in, S. Collignon, ed., European Monetary Policy, (Pinter: London), 119-174.

Goodhart, Charles, (1998), Central Bankers and Uncertainty, Keynes Lecture to the British Academy, October 29, 1998.

Issing, Otmar, (1997), Comment on Chapter 8, in, S. Collignon, ed., European Monetary Policy, (Pinter: London), 175-178.

Levin, Andrew, Volker Wieland, and John Williams, (1998), The Robustness of Simple Monetary Policy Rules under Model Uncertainty, forthcoming in John B. Taylor, ed., Monetary Policy Rules, NBER and Chicago Press.

Lindsey, David, (1997), Discussion of The Smoothing of Official Interest Rates, in Philip Lowe, ed., Monetary Policy and Inflation Targeting: Proceedings of a Conference, (Sydney: Reserve Bank of Australia), 313-318.

Lowe, Philip and Luci Ellis, (1998), The Smoothing of Official Interest Rates, in, Philip Lowe, ed., Monetary Policy and Inflation Targeting: Proceedings of a Conference, (Sydney: Reserve Bank of Australia), 286-312.

Onatski, Alexei and James Stock, (1998), Robust Monetary Policy under Model Uncertainty in a Small Model of the U.S. Economy, Manuscript, Harvard University.

Orphanides, Athanasios, (1998a), Monetary Policy Rules based on Real-Time Data, Finance and Economics Discussion Series, 1998-3, Board of Governors of the Federal Reserve System.

Orphanides, Athanasios, (1998b), Monetary Policy Evaluation with Noisy Information, Finance and Economics Discussion Series, 1998-50, Board of Governors of the Federal Reserve System.

Orphanides, Athanasios and Volker Wieland, (1998), Price Stability and Monetary Policy Effectiveness when Nominal Interest Rates are Bounded at Zero, Finance and Economics Discussion Series, 1998-35, Board of Governors of the Federal Reserve System.

Rotemberg, Julio and Michael Woodford, (1998), Interest Rate Rules in an Estimated Sticky-Price Model, forthcoming in, John B. Taylor, ed., Monetary Policy Rules, NBER and Chicago Press.

Rudebusch, Glenn, (1995), Federal Reserve Interest Rate Targeting, Rational Expectations and the Term Structure, Journal of Monetary Economics 35, 245-274.

Rudebusch, Glenn and Lars Svensson, (1998), Policy Rules for Inflation Targeting, forthcoming in, John B. Taylor, ed., Monetary Policy Rules, NBER and Chicago Press.

Rudebusch, Glenn, (1998), Is the Fed too Timid? Monetary Policy in an Uncertain World, Mimeo, Federal Reserve Bank of San Francisco.

Sack, Brian, (1998a), Does the Fed Act Gradually? A VAR Analysis, Finance and Economics Discussion Series, 1998-17, Board of Governors of the Federal Reserve System.

Sack, Brian, (1998b), Uncertainty, Learning and Gradual Monetary Policy, Finance and Economics Discussion Series, 1998-34, Board of Governors of the Federal Reserve System.

Sargent, Thomas, (1998), Discussion of ‘Policy Rules for Open Economies’ by Laurence Ball, forthcoming in, John B. Taylor, ed., Monetary Policy Rules, NBER and Chicago Press.

Svensson, Lars E.O., (1997), Open-Economy Inflation Targeting, Manuscript, Stockholm University.

Smets, Frank, (1998), Output Gap Uncertainty: Does it Matter for the Taylor rule?, forthcoming in, Monetary Policy under Uncertainty, Reserve Bank of New Zealand.

Taylor, John. B., (1993), Discretion versus Policy Rules in Practice, Carnegie-Rochester Conference Series on Public Policy 39, 195-214.

Tetlow, Robert J. and Peter von zur Muehlen, (1999), Can Model Structure Uncertainty Imply Policy Attenuation?, Mimeo, Federal Reserve Board.

Wieland, Volker, (1998), Monetary Policy and Uncertainty about the Natural Unemployment Rate, Finance and Economics Discussion Series, 1998-22, Board of Governors of the Federal Reserve System.

Wieland, Volker, (1996), Monetary Policy, Parameter Uncertainty, and Optimal Learning, Mimeo, Board of Governors of the Federal Reserve System.

Williams, John, (1999), Simple Rules for Monetary Policy, Finance and Economics Discussion Series, 1999-12, Board of Governors of the Federal Reserve System.

Woodford, Michael, (1998), Optimal Monetary Policy Inertia, Mimeo, Princeton University.