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Estimating the Inflation-Output Variability Frontier with Inflation Targeting: A VAR Approach

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Abstract: This paper (i) illustrates how a VAR model can be used to evaluate inflation targeting, (ii) derives the policy frontier available to the central bank using counterfactual experiments with real time data, and (iii) estimates how this frontier has changed over time in terms of the position and slope of the available tradeoff between output gap variability and inflation variability under inflation targeting. Various inflation targets are considered as are tolerance bands of varying width around these targets. The results indicate that over time (i) a given reduction in inflation variability is associated with a smaller rise in output variability and that (ii) a given inflation variability is achieved with smaller interest rate volatility. Consistent with the data, our results require federal funds rate persistence, though no instrument instability was observed.

I. Introduction

Over the past decade and a half, most major central banks around the world have adopted monetary policy frameworks that include either explicit or implicit inflation targets. As implemented, many central banks have aimed at average inflation rates over periods of two years or so rather than at the monthly inflation rate, consistent with Svensson (1997), who has shown that inflation targeting is optimally characterized as inflation *forecast* targeting over the policy horizon.

At roughly the outset of the inflation targeting period, Taylor (1994) argued that policy makers should focus on the tradeoff between inflation variability and output variability. Recently, Nessén and Vestin (2005) demonstrated how inflation targeting could be employed in a model focusing on this tradeoff. They derived analytically the inflation variability-output variability frontier for the case of average inflation targeting. However, their analytical results are only for a setting of average inflation targets for a two-period horizon. For longer horizons, they employ a numerical approach in a small conceptual model.

We show how a VAR model that comprises the variables in a small representative New Keynesian model of the U.S. economy can be used to implement and evaluate a variant of inflation targeting in which the policy authority targets forecast-average inflation over a two-year horizon, roughly consistent with recent practice.[1] We also investigate the actual inflation variability-output variability tradeoffs in counterfactual experiments that employ real-time data constructed for three different sample periods. In the end, we are able to show how the policy frontier has changed through time, both in terms of position and slope of the available tradeoff. Although we use a small VAR that allows us to illustrate how inflation targeting may be evaluated using inflation forecasts that reflect all information in the model, the technique can be applied to larger structural models as well.

As just noted, we conduct three experiments. The first begins in 1983:10, using a model estimated over the period 1962:1-1983:9. Though not part of the inflation targeting period, an experiment beginning in 1983:10 is a useful comparison for the second and third experiments described below. Specifically, we view this period as one with a relatively high weight on inflation control in the underlying policy maker preference function after the accelerating inflation that culminated with double-digit inflation as the decade began. Furthermore, as punctuated by the unusual Saturday evening FOMC meeting in October 1979,

[1]Our maintained assumption is that during the 1990s, the Fed was in implicit inflation targeter, a case persuasively made by Goodfriend (2005).

substantial concern existed with regard to inflation expectations. In broad terms, then, the objectives during this initial period of focus were much the same as in inflation targeting regimes: a relatively high weight on inflation control and conditioning of expected inflation. The inflation output variability tradeoff constructed for this period is a benchmark against which to compare the tradeoff in the second and third experiments. The second experiment begins in 1993:1 using a model estimated over 1980:1-1992:12, and the third begins in 2001:1 using a model estimated over 1980:1-2000:12.

In our model, monetary policy is conducted using the federal funds rate to target a forecast of average inflation. Consistent with Svensson (1997), we implement this assumption by allowing the funds rate to respond to all variables in the model. That is, in contrast to a simple Taylor rule, we assume the Federal Reserve adjusts the funds rate in response to all information in the model relevant to the forecast path of inflation. Support for this approach comes from Bernanke (2004), who, in comparing and contrasting use of "simple feedback policies" (instrument rules) and "forecast-based policies," indicates that the forecast-based approach "… has become increasingly dominant in the monetary policymaking of leading central banks…. [T]he Fed relies primarily on the forecast-based approach for making policy."

We compute the policy innovation needed to maintain inflation within a specified (possibly zero-width) inflation band, so our approach can be characterized as one of policy commitment. Our motivation is provided in part by Clarida, Gali and Gertler (1999), who show that policy commitment produces gains to welfare compared with discretionary policy, even when there is no inflationary bias of the type in the classic presentations of Kydland and Prescott (1977) or Barro and Gordon (1983).

As our procedure always selects the policy innovation needed to attain the inflation goal, there is a risk of instrument instability. In contrast, Woodford (1999) shows that policy inertia, the observed "sluggish" movements of the target interest rate compared with what might be suggested in a standard optimal control solution, can represent optimal policy. So, while our approach may produce instrument instability, it is also possible that inertia in the interest rate will result. It turns out that there is substantial smoothing of the interest rate in our counterfactual simulations, even though we have not imposed any features that would explicitly limit the magnitude of interest rate movements.[2]

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[2]Specifically, Woodford argues that building and maintaining credibility requires that central bank optimization take into account not only current conditions and the bank's forecast of economic conditions,

In recent theoretical literature, a common way to analyze monetary policy is to write down a loss function subject to the constraints imposed by the economic system. We stop short of attempting an empirical implementation of this approach. Central bankers do not usually announce the loss function or the relative weights on output and inflation variabilities.[3] Our more modest goal is to construct the policy variance frontier implied by our empirical VAR model. Note that this frontier is a natural focal point since the expected value of the output gap is zero and in a credible inflation targeting regime, the inflation rate on average is equal to the (explicit or implicit) inflation target.[4] What policymakers can influence is the variability around these values. Technically, our empirical derivation of the policy variance frontier shows the marginal rate of technical substitution, the rate at which policymakers can tradeoff inflation vs. output variability. Since we do not attempt to specify or estimate the loss function and its parameters, we do not present an estimate of the marginal rate of substitution, the rate at which policymakers want to make this tradeoff.[5]

In Section II, we present an intuitive explanation for the experiments, with technical detail relegated to an appendix. In Section III, we specify the empirical model, discuss data and its transformations, and examine the plausibility of the estimated model through a presentation of the impulse responses to a policy shock. We include in Section IV the main statistical results, culminating in presentation of the inflation-output volatility tradeoff. Finally, in Section V, we summarize the results and discuss possible explanations for the results.

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but also requires validating expectations formed in the past with policy actions that produce current conditions consistent with these expectations. He concludes (p. 8) that such an approach "… if understood by the private sector, offers the prospect of significant effects of central bank policy upon aggregate demand, without requiring excessively volatile short-term interest rates." That is, a credible, successful central bank, to paraphrase Woodford, induces the bond market to do its work for it.

[3] Svensson (2003, p. 451) argues that "In practice, the loss function is not specified in this detail…The decisionmaking body of the central bank selects the combination of forecasts that 'looks best' in the sense of achieving the best compromise between the inflation gap and stabilizing the output gap, that is, that implicitly minimizes the loss function."

[4] Thus, we assume that there is no attempt to maintain output above the natural level, which eliminates inflation bias, as in Barro and Gordon (1983). Their analysis is in a model in which the central bank is not able to credibily commit today to particular policy actions in the future. So, while the bank can talk tough today about future policy, it has an incentive to cheat today to raise output above its target level. The equilibirium is where the loss due to the long-run inflation associated with cheating offsets any gains from stimulating output above target. Of course, a criticism of this analysis is that a rational central bank would understand that there is no long-run gain to output from cheating today and hence would not cheat in the first place. For a further discussion of this literature, see section 4 of Clarida, Gali and Gertler (1999).

[5] Cecchetti and Ehrmann (2002) provide evidence on the marginal rate of substitution across central banks by estimating an economic model, combining it with the actual path of interest rates, and solving for the parameters of a simple loss function consistent with the model and the interest rate actions.

II. Methodology

In this section, we present the basic intuition behind the methodology used to estimate the policy frontier for alternative inflation targets and associated bandwidths. Technical details are contained in the appendix.

We organize our discussion around a recent characterization of the policy process presented by Blinder (1997, p. 9):

> "First, you must plan an entire hypothetical path for your policy instrument, from now until the end of the planning horizon, even though you know you will activate only the first step of the plan. It is simply illogical to make your current decision in splendid isolation from what you expect to do in subsequent periods. Second, when next period actually comes, you must appraise the new information that has arrived and make an entirely new multiperiod plan. If the surprises were trivial, that is, if the stochastic errors were approximately zero, step one of your new plan will mimic the hypothetical step two of your old plan. But if significant new information has arrived, the new plan will differ notably from the old one. Third, you must repeat this reappraisal process each and every period."

We interpret this as follows. When the FOMC meets, it evaluates, *inter alia*, the green book forecasts for the next several years, and the various policy options contained in the blue book. This is the 'first step of the plan' by which 'an entire hypothetical path for the policy instrument, from now until the end of the planning horizon' is considered. The second step of the plan comes at the next FOMC meeting, when 'new information' has arrived and 'an entirely new multiperiod plan' is implemented. Note that the forecasts and assesments of the policy alternatives in the planning horizon extend well beyond the next FOMC meeting.

In our analysis below, it is this 'first step' of the two step procedure outlined by Blinder that we are modeling. At this step in our analysis, policy makers specify a numerical inflation target plus or minus some (possibly zero) tolerance range or "inflation band," over the next h periods.[6] We then construct a path for the policy instrument that will achieve the inflation goals over the h-period horizon. Since in our empirical application we use monthly data and set h = 24, we will discuss our analysis in terms of a monthly data frequency.

[6] Svensson (1997) suggests that non-zero bandwidths may reflect allowance for 'unavoidable' variability in inflation. In addition, he also suggests that the bandwidth may be wider the higher the weight on output stabilization in the loss function.

We specify the inflation goal in terms of a 24-month average inflation forecast.[7,8] That is, policy makers are forward-looking, planning interest rate policy to maintain what we will call the forecast average inflation rate (FAIR) to be on or within the specified inflation band.[9] Aiming for inflation on or within such a band is consistent with current practice by inflation-targeting central banks. That is, if the forecast for inflation over the next 24 months is on or within the band, no policy intervention is undertaken. If the FAIR is outside the band, then an intervention is used to return this measure of inflation to the band. [10]

Since a forecast of the inflation process is needed, we need to specify the source of these forecasts in our analysis. We begin with a structural model

$$y_t = A_0 y_t + A_1 y_{t-1} + \ldots + A_p y_{t-p} + \varepsilon_t \tag{1}$$

In equation (1), y_t is an (Nx1) vector of variables, including the inflation rate and the federal funds interest rate. The elements of the A_i matrices represent the structural coefficients and the elements of ε_t are structural shocks. We assume that $E(\varepsilon\varepsilon') = \Omega$ is diagonal. The reduced form of (1) is $\Pi(L)y_t = e_t$, where $\Pi(L) = I - \Pi_1 L^1 - \ldots - \Pi_p L^p$, with the reduced form coefficient matrices given by $\Pi_i = (I - A_0)^{-1} A_i$ and reduced form shocks by $e_t = (I - A_0)^{-1}\varepsilon_t$. The moving average matrix is defined as $C(L) = [\Pi(L)]^{-1}$, with $C_0 = I$. Define $D_s = C_s(I - A_0)^{-1}$. The moving average representation (MAR) of equation (1), expressed in terms of the structural shocks, is

$$y_t = \sum_{s=0}^{\infty} D_s \varepsilon_{t-s} \; . \tag{2}$$

[7] Svensson (2003) notes that both the Bank of England and the Svierges Riksbank have used a two-year inflation forecast horizon for conducting monetary policy.

[8] Note that there is no necessary reason the ‘planning horizon’ need be equal to the time frame over which the average inflation rate targeted by the policy authority. We use both equal to 24 months to roughly mimic reality. Specifically, the green book forecasts are for a period of about two years. And, as in the previous footnote, some inflation-targeting central banks employ two year forecasts for inflation as the inflation objective. There is no reason, for example, that the forecasts evaluated at a policy meeting could not extend to, say, three years while announcing and maintaining a goal for a two-year average inflation rate over this planning horizon.

[9] The policy authority in our analysis can be either an explicit or implicit inflation targeter.

[10] While we do not do so in our simulations, it would be straightforward in practice to allow for judgment in the forecast by including an adjustment for factors that are outside the model but deemed by policymakers to be important for the immediate policy exercise.

Fundamental to our analysis is the historical decomposition, which in its basic form is found by advancing equation (2) by n periods and then decomposing the resulting expression into two terms:

$$y_{t+n} = \sum_{s=0}^{n-1} D_s \varepsilon_{t+n-s} + \sum_{s=n}^{\infty} D_s \varepsilon_{t+n-s} \tag{3}$$

The second term on the right hand side of equation (3) is the dynamic forecast or base projection (BP) of y_{t+n} conditional on information at time t. The first term on the right hand side shows the influence on y_{t+n} of the shocks to the variables in the system between periods t+1and t+n. Even though the expected values of these shocks are zero, policy makers know that the realizations of these shocks over any particular period are likely to be nonzero. These shocks represent the source of variability around the base projection. Given a set of shocks to the system, we obtain monthly inflation rates from the relevant equation in system (3), which are then averaged to obtain the FAIR.

The rule we employ in our empirical work is that if the FAIR is outside the band, the policy maker will undertake a policy action that returns the FAIR to the closest edge of the band. There are at least three reasons to return to the edge of the band rather than the midpoint. First, although we don't model the loss function explicitly, if it depends on the variance of output as well as the variance of inflation, then the more aggressive policy action needed to return the FAIR to the midpoint could induce additional variability in output, raising the overall loss.[11] In light of the "dual mandate" for the Federal Reserve, it does not seem unreasonable to us to moderate the policy response to inflation in light of concerns for output (and/or employment) stability. Second, if there is multiplicative uncertainty about the economy, in the sense of Brainard (1967), then the policy authority may not necessarily aim at the midpoint of the range. That is, if there is not certainty equivalence, then aiming at the midpoint no longer necessarily is optimal.[12] Given uncertainty about economic parameters, aiming for an inflation rate other than the midpoint of the inflation band can be justified. Third, if policy makers want to minimize their impact on financial markets, returning to the edge of the inflation band requires a smaller interest rate innovation, and thus helps minimize interest rate movements. That is, our rule implies that we undertake the smallest policy action needed to attain the

[11] This is essentially the point of opportunistic policy described in Orphanides, Small, Wieland and Wilcox (1997). For additional discussion, see also Result 12 in Clarida, Gali, and Gertler (1999).

[12] See Result 11 in Clarida, Gali, Gertler (1999). Specifically, they argue that "parameter uncertainty may reduce the response of the policy instrument to disturbances in the economy." That is, the reduction in the response may lead to aiming for the edge of the band rather than the midpoint.

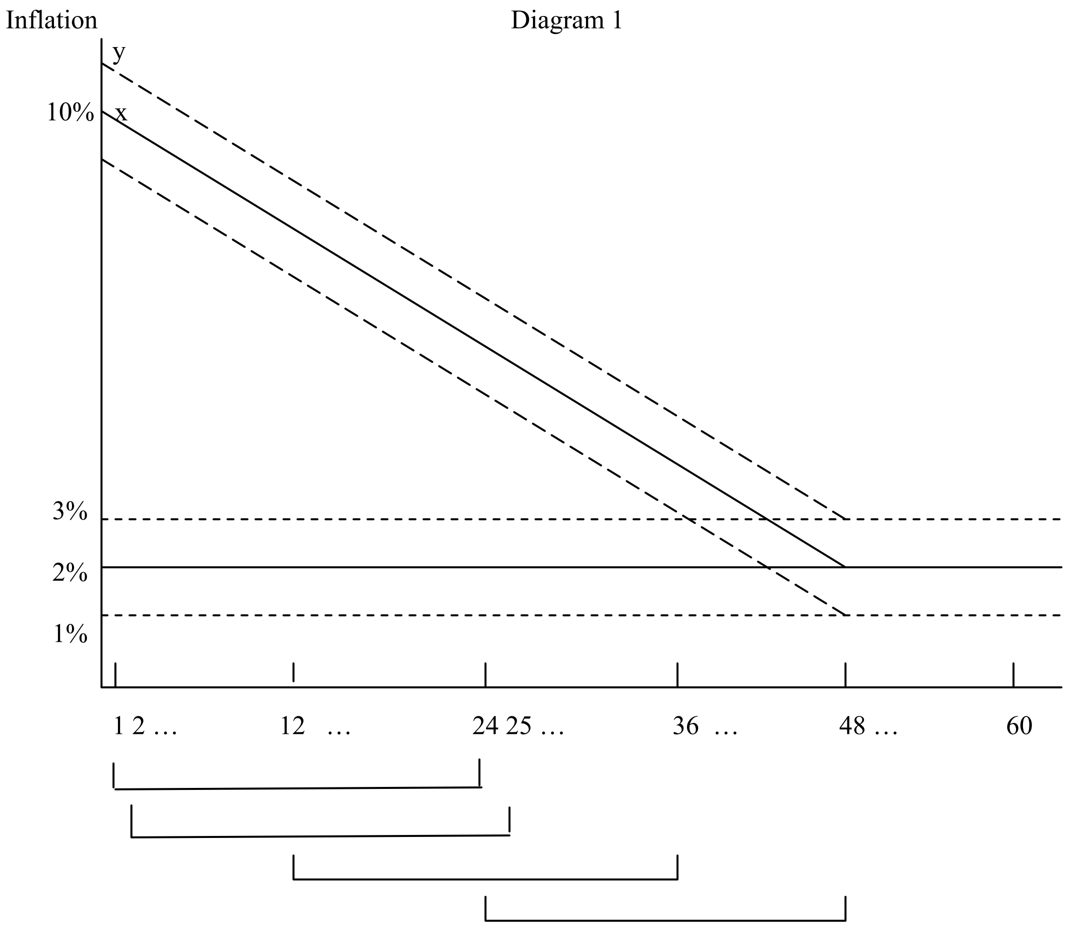
objective. Of course, the tradeoff is that our smaller financial market inverventions may be more frequent than relatively aggressive actions aimed at returning to the midpoint of the band.

We emphasize that the objective is the FAIR over this period rather than either the current or any particular future monthly inflation rate. Current inflation is the result of past decisions by both policy makers and private agents in the economy and is presumably not directly affected by current policy actions. Reported inflation, or a forecast of a particular monthly inflation rate, may lie outside the acceptable inflation band without necessarily calling for a policy action as long as the FAIR suggests that the longer-run objective will be satisfied. However, if the FAIR lies outside the band, then a current policy action is called for. In our application, we will use the federal funds rate as the policy instrument to control the inflation rate, and a policy action in a particular month is defined as an intervention in the funds rate equation in that month. [13] Due to interaction with other system variables via system dynamics, a policy action in a particular month will affect inflation over the remainder of the horizon. That is, even if the funds rate has a relatively small contemporaneous effect on inflation, marginal changes in this rate can still have substantial effects on long-run inflation.

Diagram 1 gives a schematic presentation of the ‘first stage’ of our model of the Blinder process described above. Period 1 on the horizontal axis is the first period of the planning horizon, which in practice would be the date of an FOMC meeting. The vertical axis is the inflation rate.

Two alternative inflation bands are sketched on Diagram 1. The band centered at 2%, with ±1% bands around this midpoint, represents the long-run goal for policy. Of course, it is possible that at the time an inflation target is adopted, actual inflation will be above this long run target range; after all, inflation targets are adopted to try to control an inflation problem. In Diagram 1, the negatively sloped lines represent a transitional inflation band in which inflation is to be gradually lowered, so that after some (possibly publicly announced) period of time inflation will be brought into the long-run range. In Diagram 1, a policy of gradualism over 48 months is depicted. This period could be shorter or longer, of course, depending on policy maker preferences.

[13] As is shown in the technical discussion in the appendix, the desired change in the funds rate is implemented by replacing the residual term in the funds rate expression with an appropriately-sized shock that brings the funds rate to the desired level. Below, however, we argue that our policy action is not a variant of the constant interest rate rule discussed in detail by Leitemo (2003) and that our identification scheme for the policy action is less restrictive than that in constant interest rate rules.



Consider period 1 in Diagram 1, and recall Svensson's (1997) result that inflation targeting is optimally characterized as inflation forecast targeting. The policy maker has data through the prior period (period 0) and is interested in policy simulations conditional on data through period 0, a procedure roughly similar to that undertaken at a given FOMC meeting. Assume that the inflation rate is about 10%, such as at point "x" or point "y" in the diagram. Then at period 1, the policy maker makes a forecast of inflation over the next 24 months and computes the average of the monthly inflation forecasts. The period 1-24 is "underlined" beneath the horizontal axis. If the average inflation forecast is within the inflation band, such as point "x", then no policy intervention is undertaken. Alternatively, if the average inflation forecast is at a point like "y" a policy intervention is needed that will bring the current forecast to the upper edge of the band.[14] Conditional on the policy taken in period 1, in period 2 a new forecast is made conditional on what was done in period 1 – intervention or not. If, for example, an intervention was needed in period 1, the magnitude of this intervention must be incorporated into the analysis to properly forecast inflation over the next 24 month period in which average inflation is to be inside the band. That is, forecast inflation over periods 2-25 is computed, as indicated by the second "underline" beneath Diagram 1. If the forecast is within the band, as at "x" in period 1, then no intervention is needed; if it is above the band, as at "y" in period 1, an appropriate intervention is conducted to bring the 24 month average inflation forecast within the band. If, at a given policy meeting in period 0, Blinder's "planning horizon' is 2 years ('even though you know you will only activate the first step of the plan') then inflation forecasts are conducted through the end of this horizon, so a forecast is needed at month 24, which extends over months 25-48, the last underlined period in Diagram 1.

Below, we present the results of three experiments, each representing a different time period. Each experiment roughly corresponds to the 'first step' in the policy process – i.e., to the planning process described by Blinder.

For each experiment, we estimate a VAR model using real-time data that ends in the period before the start of the simulation and compute the base projection at time t. This forecast of y_{t+24} is represented by the second right-hand-side term in equation (3) and is estimated from the lagged historical residuals from the VAR. Since the base projection is based on historical residuals, it does not change across the trials of a given experiment.

Each experiment is conducted with four bandwidths. Each experiment starts with the actual inflation rate in the period prior to the experiment and gradually lowers the inflation target to 2% over a 48 month period (as in Diagram 1), subject to the bandwidth. The alternative bandwidths are 0, 1, 2, and ∞. So, in Diagram 1, given the negatively sloped transition path, the dashed lines assume one of the indicated bandwidth values.

[14] If the forecast inflation rate is below the band, then in a transitional period such as that characterized by the negatively sloped inflation band in Diagram 1, the policy maker may choose to conduct policy consistent with opportunistic disinflation. This could entail the policy maker lowering the transitional range of the inflation target (our band) so that the period over which the gradualist policy need be conducted is shortened.

Each experiment with a given bandwidth consists of 1000 trials. We determine the variances of inflation (around the trial mean) and the output gap (also around the trial mean). For a given inflation target, we use these variances of inflation and output from the four bandwidths in each experiment to construct the inflation-output variability frontier and ask, among other things, how the frontier has changed over time and how it is affected by choice of the long-run inflation target.

For each trial, we draw (with replacement) from the estimated residuals for each equation in the system a vector of residuals of length 48, the sum of the two-year planning horizon and the 24-month horizon over which average inflation is to be attained.[15] The initial 24 terms of this vector of shocks are used to compute the first term on the right-hand-side of (3). When combined with the base projection, equation (3) gives the path the economy, as represented by the system of equations, would follow under this draw.

Combining the base projection and the initial 24 elements of the vector of draws from the residuals gives the policy maker a forecast of inflation for each of the next 24 months. The policy maker averages these 24 individual monthly inflation rates to compute the FAIR. If this rate is inside the band, no policy intervention is needed. On the other hand, if this inflation rate is outside the band, a "preemptive" policy action of sufficient magnitude to return the 24 month average forecast inflation rate to the closest edge of the band is calculated.[16] That is, if a policy intervention is needed to attain the band, the drawn residual from the interest rate equation is replaced with one that is computed to assure that the FAIR attains the policy objective. Furthermore, this policy intervention is carried along for the remainder of the trial, affecting all the system variables in later time periods. Also, as is shown in the technical appendix, the computation by which the needed intervention is done is conditional on the shocks drawn for later time periods; the needed current policy action is "identified" using the remaining residuals from the draw.

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[15] We need 48 residuals since during the last month of the two year planning horizon, policy makers want to know the FAIR for the subsequent 24 months.

[16] We note that attempting to use the funds rate to control the inflation rate at very short horizons may lead to instrument instability. The intuition behind this statement is that the interest rate is not an important component of measured prices and that the contemporaneous effect of a change in the interest rate on aggregate demand is very small. Consequently, an interest rate change would have a relatively small near-term impact on the inflation process, requiring large interest rate movements to affect short-term inflation. With a longer-term inflation objective, say one of several years as we employ here, a current interest rate change has lagged effects on the inflation rate, consistent with system dynamics. This point is recognized by central bankers, who generally implement policy via interest rate innovations which are allowed to work their way through the dynamics of the economy.

Finally, note that since the residuals in equation (3) are structural, the residual drawn for the policy equation can be replaced with the needed policy action without implications for the random shocks to the other equations since it was assumed there is no contemporaneous correlation among the structural shocks.[17,18]

This procedure is done for each month in the policy planning horizon (t+1 through t+24). For example, whether or not an intervention is undertaken in period t+1, the next step is to compute the average 24-month forecast for the period beginning in period t+2, using the individual 24-monthly inflation rates to compute the FAIR. In period t+2, a policy action is either needed or not. Either way, the dynamic path of the economy is computed, and so on. After passing through the planning horizon, we obtain at the end a path for the system of variables in which policy is used to attain the inflation objective of maintaining the FAIR on the edge of or inside the band. By construction, this counterfactual path over the planning horizon is consistent with the inflation objective of the policy authorities. For each bandwidth of each experiment, we repeat this process for 1000 draws and obtain 1000 such counterfactual paths, from which we compute the variance of each element of the vector of variables.

In the first step of Blinder's process, the policy maker takes into account the results of the entire 24-month planning horizon since (in his words) 'It is illogical to make your current decision in splendid isolation from what you expect to do in subsequent periods.' This longer range planning process, analogous to the evaluation of the green and blue books at the FOMC meeting, may be aimed at issues such as whether there is instrument instability for a given policy which might not show up at shorter horizons, whether there are undesirable characteristics of the implied interest rate interventions (are they too

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[17] An alternative approach for obtaining a desired average inflation rate would be to employ a "constant interest rate" approach, which would take the base projection and adjust it by imposing a constant interest rate over the 24-month horizon that brings about the desired average inflation rate. This approach thus implicitly imposes an entire path for the shocks to the interest rate equation. In our analysis, we identify the current policy shock needed to attain the objective (given the rest of the draw) while the constant interest rate approach implicitly identifies a vector of shocks, current and for the remainder of the horizon, needed to maintain a constant interest rate and simultaneously attain the inflation objective. The constant interest rate approach thus imposes more policy action than needed to attain the policy objective. It imposes interest rate smoothness while our approach allows the path of rates to be determined by the response of the policy maker to the forces that may drive the FAIR outside the band.

[18] It is possible to model correlations among the structural shocks, as in Bernanke and Mihov (1998). If such modeling included contemporaneous correlation between the policy innovation and other variables, then other structural shocks would be affected when a policy shock needed to attain the FAIR is imposed. We do not model such contemporaneous correlations here.

frequent? do they impart too much variability into the financial market?), and so on. At the same time, the policy maker also knows that it is likely to 'activate only the first [portion] of the plan.'

In the second step of Blinder's procedure, 'new information that has arrived,' is assessed, and an 'entirely new multiperiod plan' is made. In real time, this would include additional economic data, incorporating information contained in the shocks to these data. In our model of Blinder's approach, this second step would occur annually, and include re-estimation of the model; in reality, this may be the next FOMC meeting. If we were to proceed to this second step in our analysis, we would collect a new real-time data set a year after the first, and then re-do the experiments described above. In any case, at the outset of this second step, we would ignore the results beyond the first 12 months of the planning horizon, which were generated knowing we would 'activate only the first step[s] of the plan.'

III. Empirical Model

As noted earlier, the variables in the VAR model we estimate include those in the typical New Keynesian model--the output gap, the inflation rate, and the federal funds rate. Additionally, we include the rate of change in a commodity price index for two reasons. First, we add commodity prices following earlier literature that addresses the "price puzzle" often found in VAR models (see, for example, Boivin and Giannoni (2002)). Second, since commodity price volatility is often used to represent supply shocks, as a first (and likely crude) approximation, we use this variable to help control for changes in output and inflation volatility emanating from sources outside the policy process. In order to establish the usefulness of the model for monetary policy evaluation, the macroeconomic effects of monetary policy are estimated by computing impulse response functions (IRFs) for shocks to the federal funds rate.

The model is estimated using monthly real time data over three time periods: 1962:1-1983:9, 1980:1-1992:12, and 1980:1-2000:12. Our first counterfactual inflation targeting simulation begins in 1983:10, a year after the end of reserve targeting that characterized the October 1979-October 1982 period, thus allowing for the adjustment process to the new operating procedure to be basically completed before initiating the experiments. The second counterfactual experiment begins in 1993:1, which roughly corresponds to the initial implementation of inflation targeting at central banks around the world. The third counterfactual begins in 2001:1. This starting point was chosen for two reasons. One is that there was considerable uncertainty about the macroeconomic effects of the decline in stock prices that began in 2000.

The second is that it allows a year's transition from the Y2K preparations of the Federal Reserve and the subsequent volatility in the growth rate of the monetary base.[19] In estimating the VAR, twelve lags of all variables are employed.

The transformations of the variables in the model follow the transformations of the variables in the typical New Keynesian model.[20] The output gap is the log of real GDP minus the log of Hodrick-Prescott filtered real GDP.[21] Since real GDP is not available monthly, a quarterly output gap was first constructed and was then interpolated to monthly values using the random walk option of the distrib.src procedure from WinRATS 6.02b.[22]

Since central banks tend to focus on longer-term inflation, the inflation rate is measured by the year-over-year rate of the change in the personal consumption expenditure deflator, a key series in the Fed's evaluation of inflation.[23] This avoids filtering out longer-run inflation information as would occur, for example, if we had used the annualized monthly rate of change in the price level. The federal funds rate is the monthly average of the daily rate. The rate of change in commodity prices is calculated as the annual difference of the log of this series. A description of the real time data and sources of the data is provided in the data appendix.

Monetary policy, represented as shocks in the federal funds rate equation, is identified using a Choleski decomposition. The ordering of the variables is: the rate of change in commodity prices, the

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[19]There was a big spike in total reserves in the system at the end of 1999, and the growth rate of the monetary base jumped sharply. Reserves quickly returned to the pre-Y2K level, and monetary base growth fell sharply over 2000 and even became negative toward the end of 2000, although it had begun to rise by the end of the year.

[20]Given the considerable debate about the power of unit root and cointegration tests, we chose to employ the transformations of the variables used in the typical New Keynesian model.

[21]A commonly-used alternative measure of the output gap is the log of real gdp minus the log of potential output constructed by the Congressional Budget Office. However, since the CBO measure of potential output is not available on a real-time basis, we utilized the output gap based on the Hodrick-Prescott filtered real GDP. Although we recognize potential difficulties with the Hodrick-Prescott filter, such as the problem noted by Cogley and Nason (1995) of inducing business cycle dynamics when none exist if the filter is applied to difference stationary data, the Hodrick-Prescott filter is widely used in the the empirical monetary policy literature to construct output gap measures. Use of the Hodrick-Prescott filter to construct the output gap is thus consistent with previous literature.

[22]Although series available monthly such as industrial production and personal income could have been used to construct an output gap measure, we chose to use real GDP and interpolate our output gap measure to monthly frequency since the focus of policy is on broad economic activity and real GDP is better measure of broad economic activity than industrial production or personal income.

[23]Although core inflation is measured by the personal consumption expenditure deflator minus the effects of food and energy prices, the core series was not used in the model because it was not possible to construct a real-time version of this series for use in the simulations.

output gap, the inflation rate and then the federal funds rate. Placing the funds rate last is based on a suggestion by Bernanke and Blinder (1992), and allows a contemporaneous response by the Fed to movements in the other three variables while simultaneously imposing a lagged effect of monetary policy on these variables.[24]

The IRFs for a shock to the federal funds rate for all three estimation periods are presented in Figure 1. In each panel, the solid line is the point estimate and the dotted lines are one standard deviation confidence intervals computed using Monte Carlo simulations employing antithetical acceleration and 10,000 draws. The general pattern of results is similar for each sample period, but the timing and magnitude of effects differs across samples. The magnitude of the one standard deviation federal funds rate shock is comparable across the three samples: 0.57 for 1962:-1983:9, 0.50 for 1980:1-1992:12, and 0.49 for 1980:1-2000:12. A positive shock to the federal funds rate persists briefly, but the confidence interval for the funds rate spans zero within 6 months, which we interpret as a return to the initial value. There is a transitory negative effect on the rate of change in commodity prices, and the effect is stronger and more persistent for the 1962:1-1983:9 sample. The output gap becomes negative after several months, but returns to its initial value over time. The magnitude of the effect is greater for the 1962:1-1983:9 sample than the other samples, but the time required for output to return to its HP trend and stay there is comparable across all three samples. There is a transitory negative effect on the rate of change in the personal consumption expenditure price index but the magnitude of the effect, the time required before the effect becomes significant, and the time that lapses until the rate of inflation returns to its initial value differs across

[24] One concern about this ordering is that it does not allow monetary policy to have a contemporaneous effect on the commodity price index which is comprised of auction-market type variables that may well respond within the period to monetary policy shocks. Other concerns include (a) the assumption that the central bank responds contemporaneously to current period movements in output and the price level whereas data (even preliminary) on current period values of these variables is available only with a lag and (b) the constraint that output isn't allowed to respond contemporaneously to a shock to monetary policy. Imposing a lag in the effect of monetary policy on inflation is not controversial. Because of these concerns, we estimated a Bernanke (1986)-type structural VAR which differed from the Choleski described in the text by allowing a contemporaneous effect of monetary policy on commodity prices, by allowing a concurrent effect of monetary policy on output, and by imposing no contemporaneous response of the federal funds rate to output and inflation shocks. The federal funds rate was, however, allowed to respond contemporaneously to commodity price shocks. The point estimates for this structural VAR for a shock to the federal funds rate were plotted along with the confidence intervals for the Choleski decomposition. The point estimates for a monetary policy shock for all variables for all three samples were within the Choleski confidence intervals except for a few very minor departures in the very short-run for output (all three periods) and in the 1980:1-1992:12 period for the initial effect on commodity prices. Based on these results, we used the Choleski decomposition in all experiments.

samples. A significant negative effect is less evident in the 1980:1-1992:12 period than in the other samples.

Since the VAR models are used to assess the quantitative implications of inflation targeting, it is important that the VARs produce paths of the model variables for shocks to monetary policy that are consistent with the macro models in which monetary policy shocks can affect real variables. This appears to be the case for the VAR models used in this paper.

IV. Results

In this section, we present a variety of results from the inflation targeting experiments. The discussion in this section focuses on what policy makers would have seen had they employed our methodology. Specifically, we investigate the nature of the available tradeoffs between inflation and output variability and how these tradeoffs have changed in the two periods in which implicit inflation targeting is a reasonable working hypothesis. For comparison, we also investigate the period in the 1980s before implicit inflation targeting, which nonetheless was a time when disinflationary policy was at the forefront of policy discussion. In the section that follows, we discuss the economic interpretation of the results.

As detailed earlier, in each experiment we assume that a policy of gradualism to reduce inflation is employed. The benchmark policy is for the midpoint of each inflation band to approach 2% over a 48 month period with bandwidths varying between 0% and one that is arbitrarily large.

Our benchmark policy, including our choice of a 48 month transition, is based on both theoretical considerations and observation of central bank practices. Though not suggesting a specific length of the transition period, Svensson (1997) argues theoretically that a positive weight on the output gap in the loss function implies that optimal disinflationary policy will be one of gradualism. Given the "dual mandate," U.S. policymakers should then approach inflation targets gradually. In practice, according to Bernanke and Mishkin (1997), central bankers behave as suggested by Svensson. They note (p. 99): "Initial announcements of inflation targeting generally allow for a gradual transition from the current level of inflation to a desired steady state, usually the level deemed consistent with price stability." Furthermore, Bernanke and Mishkin later note that after the 1979 oil shock, the German Bundesbank "announced the 'unavoidable' inflation rate to be 4 percent, then moved its target gradually down to 2 percent over a six-year period." (p. 101). In the U.S., Goodfriend (2005) indicated that an "inflation scare" in 1987 due to the infusion of liquidity after the October 1987 stock market crash took the Greenspan Fed "… about five years to overcome" (p. 8). Our choice of 48 months as the transition period is a bit shorter than, but not at great odds with, these suggestions in the literature.

As noted in the previous section, the first experiment begins in 1983:10. Figure 2 shows the actual inflation rate through 1983:9 and the base projection of the inflation rate along with ±1% and ±2% bands in which inflation might be tolerated if the inflation rate is to move gradually toward 2% within 48 months. While this period is prior to the emergence of the modern literature on inflation targets, we include it not only for purposes of comparison but also due to the fact that, consistent with the abrupt change in the policy regime in October 1979 (including the unusual Saturday night meeting of the FOMC), the focus was clearly on disinflationary policy. As a result of this policy shift, along with the two recessions of the early 1980s, the inflation rate as measured by the personal consumption expenditures deflator at the outset of this experiment was approximately 3.8%. Note that while the actual inflation rate was relatively low, the base projection suggested that inflation would quickly move outside the ±1% or ±2% bands. Thus, for policy officials using real-time data in late 1983, the need for restrictive monetary policy looked highly likely. Such a policy would likely raise the specter of another recession following on the two at the outset of the decade, making empirical estimation of the inflation variability-output variability tradeoff an important consideration.

The second experiment begins in 1993:1. At the time, U.S. inflation was approximately 3%. Since other central banks were aiming at inflation targets in the 2% range, we take 2% as the midpoint of the longer-run inflation objective. Figure 3 shows the historical inflation rate policymakers would have observed, again in real time, at the outset of 1993. In addition, the plot shows the base projection of inflation from the model estimated with the then-available data, as well as the ±1% and ±2% inflation bands. Recall that the base projection is constructed under the assumption that shocks beginning in 1993:1 assume their expected values of zero. Even with this assumption, the inflation rate threatens to violate the narrower band within a year and a half and the wider band within about two and a half years. Of course, a central bank is aware that the actual path the economy follows is determined in part by the actual shocks the economy experiences, so there is a reasonable prospect for policy action of the type discussed here to the extent that one or a few "bad draws" from the distribution of shocks occurs.[25]

The third experiment begins in 2001:1. Even though inflation was reasonably well contained at approximately 2 1/2% when our third experiment begins and the base projection in Figure 4 puts inflation within the inflation bands, uncertainty about the macroeconomic effects of the decline in stock prices that began in 2000 suggests it is worth considering the implications of inflation targeting in 2001.

Summary statistics and basic results for the four bandwidths of each experiment for the three periods are presented in Table 1.[26] As detailed earlier, for each period and each bandwidth these results are from 1000 draws from the estimated residuals. Note that while the FAIR relative to the inflation band is used as the criterion of whether to intervene in a particular month, in order to be comparable to inflation data as commonly reported, the inflation statistics from our experiments reported in Table 1 are for the underlying inflation rates for each particular month rather than the FAIR.

Presented in Table 1, with each panel corresponding to a particular time period, are experimental results for four different bandwidths: 0%, 1%, 2% and an infinite band. [27] Part I of each panel presents summary statistics on the frequency of interventions aimed at maintaining the FAIR within the indicated bands. Part II provides data on the magnitude of the policy interventions. Parts I and II are based on our 24-month characterization of Blinder's 'planning horizon' since it is 'simply illogical to make your current decision in splendid isolation from what you expect to do in subsequent periods.' That is, the information in

[25] It is also evident that the general path of inflation in the U.S. is downward prior to 1993, as was the case for many countries that formally adopted inflation targeting. So, any claim that low inflation resulted from explicit or implicit inflation targeting in the early 1990s is problematic. We sidestep the difficult issue of how to test whether inflation targeting was the cause of the global disinflation during the late 1980s and early 1990s. Ball and Sheridan (2005) present a provocative analysis of this question. Our focus is on the inflation-output variability tradeoffs implied by our version of inflation targeting given the data at the outset of each experiment, which would have been of interest to policymakers over and above the question of whether the adoption of explicit or implicit targets in the early 1990s caused the contemporaneous fall in inflation.

[26] We have excluded from the statistics in Table 1 those trials in which a negative (nominal) interest rate would occur. Generally, the results that include trials in which negative interest rates occur are nearly identical to those reported below. Note that negative nominal rates do show up in real-world data on occasion. For example, Cecchetti (1988) discusses negative nominal interest rates on some Treasury securities in the 1930s and, more recently, Fleming and Garbade (2004) discuss repurchase agrements with negative interest rates. Casual analysis of our trials in which negative interest rates occur suggest that they were about the same order of magnitude as those appeared in Cecchetti and Fleming and Garbade.

[27] The 0% bandwidth is the case where the average inflation target is attained precisely each month. If a strict inflation nutter is one who aims for 0% inflation with a 0% band, this band might be characterized as reflecting that of a "modified inflation nutter," focused exclusively on attaining low but nonzero inflation rate.

parts I and II is analogous to the FOMC green book forecasts on the longer-run implications of the current or proposed policy path. Part III presents results on the variances of output, the inflation rate, and the interest rate. These part III data are only based on the first 12 months of the simulations since at this point in our characterization of Blinder's approach the annual evaluation of policy begins anew, with the policy maker making 'an entirely new multiperiod plan,' i.e., repeating the first step of the policy process.

Part I of each panel shows the number of interventions per trial, the average maximum number of interventions, and the number of trials with any policy intervention. The first row of part I shows not only the number of interventions per trial in each experiment, it also shows parenthetically the number of such interventions that are restrictive (i.e., interventions that raise the funds rate, the first number in the parentheses) and the number that are stimulative (i.e., interventions that lower the funds rate, the second number). The number of interventions per trial starts at the maximum of 24 months (the planning horizon) when the inflation objective is to be met precisely (i.e., with bandwidth of zero) and is zero when the band is arbitrarily wide (in which case it is not necessary to intervene). The number of interventions per trial declines as the bandwidth widens from ±1% to ±2%. Notice also that over time, as we move from Panel A to B and then from Panel B to C, the number of interventions per trial needed to maintain the ±1% (±2%) bandwidth falls. Furthermore, given the inflationary pressures suggested by the base projections in the first two periods, it is not surprising that for the ±1% and ±2% bands, the number of interventions needed to restrain inflation (positive policy shocks to the interest rate equation) outnumber the interventions needed to stimulate inflation in order to maintain inflation within the bands.

The second row of part I of each panel shows the average number of consecutive months per trial in which policy intervention is undertaken. Notice that the number of consecutive interventions, like the number of interventions in the first row of part I of each panel, declines within each experiment as the bandwidth widens from ±1% to ±2%. Also notice that the number of such interventions falls as we move from Panel A to B and then from B to C.

Our results on consecutive interventions per trial are due to our imposition of a "commitment" to the inflation target objective. That is, our analysis is designed to intervene, and by an appropriate magnitude, to maintain the FAIR within or on the edges of the bands, regardless of whatever else may happen within the economy. In our experiments, there is no option for the policymaker to deviate from this objective when computing the intervention.[28] The fact that the vast majority of interventions are in consecutive months again suggests the need for commitment since once the inflation rate breaches the edge of the inflation band, several policy shocks are needed to return average, long-run inflation to the specified level. Also note that while there is inertia in terms of a pattern of several consecutive interventions, given an initial intervention, it is less clear that there will necessarily be inertia in the interest rate itself, since (i) the interventions are partly a function of the random draws for all the variables, which can entail consecutive interventions but not necessarily of the same sign, and (ii) since there is an endogenous component to the funds rate equation over and above the intervention term. Additional clarification on the smoothness of interest rates will be provided below.

The third row of part I of each panel shows the number of trials for each bandwidth with any intervention. We again find that the number of such interventions falls as the band widens from ±1% to ±2%. Furthermore, the need for interventions declines across experiments as well.

Part II of each panel provides information on the magnitudes of the computed interventions needed to maintain inflation within the indicated bandwidths (the second and fourth rows of part II) as compared with the actual maximum and minimum of the estimated residuals from that equation (the first and third rows).

Some explanation is needed to put the computed interventions into a proper perspective. For the ±0% band, a policy intervention is required every period in order to obtain the objective, so the reported maximum intervention in each panel is six to ten times as large as the largest actual residual from the estimation. (Note that since pressures in the economy, especially in the early periods studied here, tend to be inflationary rather than disinflationary, interventions that lower the funds rate do not deviate substantially from the minimum estimated residual.) For the infinitely wide band, no intervention is undertaken, so the maximum and minimum interventions correspond to the estimated residuals. For the ±1% and ±2% bands, in each month of each trial we asked whether a policy intervention was needed. In some months an intervention was needed, in which case we replaced the residual drawn from the distribution of estimated residuals with the computed intervention.[29] If none was needed we retained the residual from the draw as we needed it for computation of the path of the system in later months. That is,

[28] Technical detail on these computations are included in appendix equations (A2) and (A3).
[29] Again, see equations such as (A2) or (A3) in the technical appendix for details.

for the ±1% and ±2% bands, not every trial required a policy intervention. For each 24-month trial, we retained the maximum and minimum values for the shock to the interest rate equation, the policy variable. Thus, sometimes these extreme values were from the random draws from the historical residuals and sometimes from the computed values if an intervention was needed. From these the extreme values across the trials, we chose to report the 95th (5th) percentile from the vector of maximum (minimum) shocks. We arbitrarily focused on the 95th (5th) percentile of the maximum (minimum) shock to the interest rate equation across the 1000 experiments to avoid placing too much weight on outliers.

In patterns similar to results in Part I, we again find that the magnitude of needed interventions declines the wider the band within a given experiment. We also again find that for a given bandwidth, as we move from Panel A to B and then from B to C, the maximum and minimum values of the needed interventions fall.

Part III of each panel shows the fundamental results – the variances of the key variables – for each bandwidth of each experiment. For clarity, these variances, plotted in Figures 5 and 6, show the basic results of the paper, the estimated tradeoffs between inflation and output variability and inflation and interest rate variability, respectively, over time.

The first notable feature of Figure 5 is that the tradeoff available to the Fed since its adoption of implicit inflation targeting has improved substantially over time. Part of this improvement is the result of the shift of the tradeoff toward the origin across the time periods. Recall that commodity prices were included in an effort to control for differing economic conditions, so at least in a crude sense this inward shift in the tradeoff is due to factors other than supply shocks. In the three years prior to the 1983 experiment, the variance of the commodity price inflation rate was .006. By the onset of the 1993 experiment, this volatility had fallen to .002. By the onset of the 2001 experiment, however, it had risen to .005, notably without an outward shift in the tradeoff. The other part of the shift in the tradeoff is due to the flattening of the tradeoff from 1993 to 2001 (recall that the 1983 period, while characterized as a disinflationary policy regime, is not part of the implicit inflation targeting era). That is, compared with the early 1990s, by early 2001 a given decline in inflation variability was associated with a smaller rise in the variability of output.

Second, again comparing the most recent two periods, a shift occurred in the inflation-interest rate tradeoff; see Figure 6. That is, a given inflation variability is achieved with smaller interest rate volatility over time.

Third, while we have not constrained the analysis to produce policy inertia, our results in the first two rows of Part I of Table I suggest that persistent (i.e., consecutive, monthly) policy applications for up to half the policy horizon are needed in order to maintain inflation within the inflation bands. While the tendency is for policy tightness (i.e., positive interventions to the interest rate equation), this data reflects policy shocks that enhance (or offset) the endogenous movement of the interest rate in response to other macroeconomic forces within the model. To obtain a perspective on the interest rate itself, and hence whether there is substantial variability in the interest rate, consider Figure 7. In this Figure, the solid line represents the actual data, the short-dashed line represents the average interest rate path for the ±1% band and the long-dashed line is the interest rate path for the ±2% band.[30] (Not pictured is the plot for the ±0% band; as might be expected, it is substantially more variable since the inflation objective is constrained to be maintained exactly.) As we compare the experiments, we notice several features regarding interest rate volatility. First, there is no obvious instrument instability in movements of the federal funds rate under our hypothetical inflation targeting scheme. Second, the volatility of rates associated with the ±1% bandwidth is higher than for the ±2% bandwidth for the 1980s disinflationary regime and the early 1990s implicit inflation targeting regime. Third, by 2001, with inflation and its expectations well contained,[31] there was almost no difference between the average paths for the interest rate for the alternative bandwidths.

V. Summary and Conclusion

Our focus in this paper is twofold: (i) illustration of how a VAR model can be used to implement and evaluate inflation targeting and (ii) the derivation of the policy frontier available to the central bank and

[30] While it is obviously not possible to present the interest rate path for each trial, we note that the smoothness of the average interest rate path for a given experiment does not mask substantial volatililty of interest rates with a given trial.

[31] The press release for the December 19, 2000 FOMC meeting (http://www.federalreserve.gov/boarddocs/press/general/2000/20001219/default.htm) indicated that "While some inflation risks persist, they are diminished by the more moderate pace of economic activity and by the absence of any indication that longer-term inflation expectations have increased." The press release (http://www.federalreserve.gov/boarddocs/press/general/2001/20010103/default.htm) for the Jan. 3, 2001 FOMC meeting indicated that "…inflation pressures remain contained." Subsequent FOMC statements in 2001 indicated a greater risk of economic weakness than resurgence of inflation. Longer-term expectations of inflation from the Livingston Survey and the Survey of Professional Forecasters were stable at approximately 2.5% for 1999-2002.

estimation of how this frontier has changed over time in terms of the position and slope of the available tradeoff between output gap variability and inflation variability under inflation targeting, controlling for variability in commodity price inflation as a proxy for supply shocks. Tolerance bands of varying widths around transitional inflation targets constructed to achieve 2% inflation are considered.

Our inflation forecast targeting approach is based on stochastic simulations of the average inflation rate over a two-year horizon using the moving average representation of the VAR model. Deviations of the forecast average inflation rate from target generate interventions in the form of changes in the federal funds rate designed to gradually push the forecast inflation rate back to target, and we show how to compute the required adjustments to the federal funds rate.

The technique is illustrated through three counterfactual experiments using real-time data. The first experiment begins in 1983:10 and is based on a VAR estimated over 1962:1-1983:9 whereas the second and third experiments begin in 1993:1 and 2001:1, respectively, using models estimated over 1980:1-1992:12 and 1980:1-2000:12, respectively. In broad terms, the results from these counterfactual experiments indicate a substantial improvement in the policy frontier over time, i.e. a reduction in the increase in output variability associated with a given reduction in inflation variability, and that this improvement reflects a favorable shift in the tradeoff toward the origin as well as a change in the slope of the tradeoff function.

More specifically, as we move from experiment 1 to experiment 2 and then to experiment 3, we find, for the cases in which the bands are ±1% and ±2%,

1. The number of interventions per trial needed to attain the target band falls. In addition, as we move from experiment 1 to experiment 3, the early pattern that most interventions are restrictive rather than accommodative disappears.

2. The number of consecutive interventions per trial declines.

3. The number of interventions in total falls, regardless of whether the interventions are consecutive.

4. The magnitude of the interventions falls.

5. The position of the inflation-output variability tradeoff has improved.

6. The slope of this tradeoff has improved.

7. The position and slope of the interest-rate inflation variability tradeoff has improved.

8. Not only do the positions of the inflation-output variability and interest rate-inflation variability tradeoffs improve, but the variability in the interest rate declines.

An important question that is beyond the more narrow technical focus of this paper on how to use a VAR model to implement and evaluate inflation targeting is whether the results of our experiments primarily stem from "good policy" or "good luck". The consensus from studies such as Stock and Watson (2002), Ahmed, Levin, and Wilson (2004), and Sims and Zha (2006) is that "good luck" in the form of reduced variability of non-monetary policy shocks is primarily responsible for the increased stability of the real economy since the mid-1980s. However, Stock and Watson (2002) attribute from 10-25% of the reduced variability in the real economy to improved monetary policy, and Ahmed, Levin, and Wilson (2004) find that, although "good policy" doesn't seem to explain much of the reduced variability in real output, "good policy" is important in understanding the reduction in inflation variability.

Keeping in mind that much of the reduction in output and inflation variability we find as we move from experiment 1 to experiments 2 and 3 may simply reflect "good luck", we note that "good policy" might also help explain these results. Much of the recent literature on monetary policy suggests that inflation targeting allows central banks to gradually gain credibility. Clarida, Gali and Gertler (1999) suggest that credible policy "… enables the central bank to stabilize the economy with relatively modest movements in the short rate" (pp. 1689-90), and Carlstrom and Fuerst (2005) present simulations showing that central bank credibility allows the Fed to achieve given objectives with smaller policy interventions than in the case where credibility is lacking. Clarida, Gali and Gertler also show that policy commitment can improve the tradeoff between inflation and output variability. Woodford (1999) argues that inertia in the policy instrument is optimal in an economy with forward-looking agents, with the inertia serving to validate agent expectations.[32] Each of the results enumerated above are consistent with the literature cited.

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[32] In Woodford's analysis, policy inertia is not the result of preferences for interest rate smoothing or due to assumed serial correlation in the residuals. Rather, it is the result of the fact that agents exhibit forward-looking behavior, which the central bank takes into account in setting policy. Furthermore, a credible central bank that wishes to retain its credibility is constrained in its subsequent actions to honor its commitments made in the past. A similar argument is made in Carlstrom and Fuerst (2005), who focus on the "considerable period of time" language in recent FOMC statements.

Technical Appendix: Implementing Inflation Target Simulations

In this appendix, we provide technical detail on computation of the FAIR and how we compute the policy actions needed to maintain it on or inside a target band. Let the elements k and j in the vector y_t represent the federal funds rate and inflation, respectively. Consider the j[th] equation in text equation system (3) when n=1, which is the one-period-ahead inflation equation:

$$y_{j,t+1} = \sum_{i=1}^{N} d_{0,ji}\varepsilon_{i,t+1} + BP_{j,1} \qquad \text{(A1.1)}$$

Under the assumption that policy makers are concerned with a 24 month average inflation rate, for periods 2 through 24, the analogous equations are

$$y_{j,t+2} = \sum_{i=1}^{N} d_{0,ji}\varepsilon_{i,t+2} + \sum_{i=1}^{N} d_{1,ji}\varepsilon_{i,t+1} + BP_{j,2} \qquad \text{(A1.2)}$$

$$\vdots$$

$$y_{j,t+24} = \sum_{i=1}^{N} d_{0,ji}\varepsilon_{i,t+24} + \sum_{i=1}^{N} d_{1,ji}\varepsilon_{i,t+23} + \cdots + \sum_{i=1}^{N} d_{23,ji}\varepsilon_{i,t+1} + BP_{j,24} \qquad \text{(A1.24)}$$

Summing equations (A1.1) through (A1.24) and then averaging yields

$$\frac{1}{24}(y_{j,t+1} + y_{j,t+2} + \cdots + y_{j,t+24}) = \frac{1}{24}\{\sum_{i=1}^{N} d_{0,ji}\varepsilon_{i,t+1} + \sum_{i=1}^{N} d_{0,ji}\varepsilon_{i,t+2} + \sum_{i=1}^{N} d_{1,ji}\varepsilon_{i,t+1} + \cdots +$$

$$\sum_{i=1}^{N} d_{0,ji}\varepsilon_{i,t+24} + \sum_{i=1}^{N} d_{1,ji}\varepsilon_{i,t+23} + \cdots + \sum_{i=1}^{N} d_{23,ji}\varepsilon_{i,t+1} + BP_{j,1} + BP_{j,2} + \cdots + BP_{j,24}\}$$

$$= \frac{1}{24}\left\{\sum_{\substack{i=1\\ i\neq k}}^{N} d_{0,ji}\varepsilon_{i,t+1} + d_{0,jk}\varepsilon_{k,t+1} + \sum_{i=1}^{N} d_{0,ji}\varepsilon_{i,t+2} + \sum_{\substack{i=1\\ i\neq k}}^{N} d_{1,ji}\varepsilon_{i,t+1} + d_{1,jk}\varepsilon_{k,t+1} + \cdots + \right.$$

$$\left. \sum_{i=1}^{N} d_{1,ji}\varepsilon_{i,t+23} + \cdots + \sum_{i=1}^{N} d_{22,ji}\varepsilon_{i,t+2} + \sum_{\substack{i=1\\ i\neq k}}^{N} d_{23,ji}\varepsilon_{i,t+1} + d_{23,jk}\varepsilon_{k,t+1} + BP_{j,1} + \cdots + BP_{j,24}\right\}.$$

We next show how to compute the current period policy shock needed to attain the FAIR. Define $Y_{j,t+1} = \frac{1}{24}(y_{j,t+1} + y_{j,t+2} + \cdots + y_{j,t+24})$ to be the forecast inflation rate and let the targeted, average inflation rate be $Y^*_{j,t+1} = \frac{1}{24}(y_{j,t+1} + y_{j,t+2} + \cdots + y_{j,t+24})^*$.[33] Assume for now that the goal is to achieve this target exactly; that is, assume for now that the width of the inflation band is zero. Then conditional on $\varepsilon_{i,t+1}, i \neq k,$ as well as on $\varepsilon_{t+2}, \varepsilon_{t+3,} \cdots \varepsilon_{t+24}$, there is a value for the current policy innovation, $\varepsilon_{k,t+1}$ that will achieve this inflation target. Specifically, we solve the previous equation for the policy innovation undertaken at the beginning of period t+1 designed to attain the target:

$$\hat{\varepsilon}_{k,t+1} = \left(\sum_{\ell=0}^{23} d_{\ell,jk}\right)^{-1} \{(y_{j,t+1} + y_{j,t+2} + \cdots + y_{j,t+24})^* - \sum_{\substack{i=1 \\ i\neq k}}^{N} d_{0,ji}\varepsilon_{i,t+1} - \sum_{i=1}^{N} d_{0,ji}\varepsilon_{i,t+2} - \sum_{\substack{i=1 \\ i\neq k}}^{N} d_{1,ji}\varepsilon_{i,t+1} - \cdots -$$

$$\sum_{i=1}^{N} d_{0,ji}\varepsilon_{i,t+24} - \sum_{i=1}^{N} d_{1,ji}\varepsilon_{i,t+23} - \cdots - \sum_{\substack{i=1 \\ i\neq k}}^{N} d_{23,ji}\varepsilon_{i,t+1} - BP_{j,1} - BP_{j,2} - \cdots - BP_{j,24}\} \qquad \text{(A2)}$$

We next relax the assumption that the average inflation rate is targeted exactly, and show how to pursue a policy objective of constraining inflation to lie within a given, predetermined bandwidth. For period t+1, we want the inflation rate within the pre-specified band $Y^*_{j,t+1} \pm \tau$ where τ is half the bandwidth.[34] It may be that no policy intervention is needed, which will occur when the shocks to the economic system are such that

$$Y^*_{j,t+1} - \tau < Y_{j,t+1} < Y^*_{j,t+1} + \tau .$$

If, on the other hand,

$$Y_{j,t+1} < Y^*_{j,t+1} - \tau$$

or if

[33] If the target inflation rate is constant, then Y^*_j could be expressed more simply as the target level, such as 2%. However, if actual inflation is above target and the target is to be approached gradually, then the y_{t+k}, k=1,…,24, will gradually fall so that the general notation in the text is appropriate.

[34] As specified, the band is symmetric. If the policy maker were to set policy actions to return inflation to a particualr path strictly within the band, then asymmetric bands would also be of interest. For example, the policy maker might respond to a given upward shock to the inflation rate, but not to a downward shock of the same absolute value, as in an opportunistic disinflation policy. It is straightforward to allow for asymmetric bands.

$$Y_{j,t+1} > Y^{*}_{i,t+1} + \tau \,,$$

a policy intervention is needed to return the inflation rate either to the edge of the band or to some pre-specified value interior to it. For instance, if the policy choice is to return to the edge of the band, then the policy innovation is computed by replacing the term $(y_{j,t+1} + y_{j,t+2} + \cdots + y_{j,t+24})^*$ in equation (A2) with $(y_{j,t+1} + y_{j,t+2} + \cdots + y_{j,t+24})^* \pm \tau = Y^{*}_{i,t+1} \pm \tau$, depending on whether the FAIR is computed to be above or below the tolerance range.

The policy action undertaken in period t+1 implies a subsequent path for the system's variables, and later evaluation of policy actions must take t+1 policy into account; again, the policy approach implies history dependence. Given this policy action, the average, prospective inflation for the h-period horizon covering periods t+2 through t+25 may be computed similarly to the discussion in equations (A1.1) through (A1.24):

$$\frac{1}{24}(y_{j,t+2} + y_{j,t+2} + \cdots + y_{j,t+25}) =$$

$$= \frac{1}{24}\left\{ \sum_{\substack{i=1 \\ i\neq k}}^{N} d_{0,ji}\varepsilon_{i,t+2} + d_{0,jk}\varepsilon_{k,t+2} + \sum_{\substack{i=1 \\ i\neq k}}^{N} d_{1,ji}\varepsilon_{i,t+1} + d_{1,jk}\,\hat{\varepsilon}_{k,t+1} + \cdots + \right.$$

$$\sum_{i=1}^{N} d_{0,ji}\varepsilon_{i,t+24} + \sum_{i=1}^{N} d_{1,ji}\varepsilon_{i,t+23} + \cdots + \sum_{\substack{i=1 \\ i\neq k}}^{N} d_{22,ji}\varepsilon_{i,t+2} + d_{22,jk}\varepsilon_{k,t+2} + \sum_{\substack{i=1 \\ i\neq k}}^{N} d_{23,ji}\varepsilon_{i,t+1} + d_{23,jk}\,\hat{\varepsilon}_{k,t+1} +$$

$$\left. \sum_{i=1}^{N} d_{0,ji}\varepsilon_{i,t+25} + \cdots + \sum_{\substack{i=1 \\ i\neq k}}^{N} d_{24,ji}\varepsilon_{i,t+2} + d_{23,jk}\varepsilon_{k,t+2} + \sum_{\substack{i=1 \\ i\neq k}}^{N} d_{24,ji}\varepsilon_{i,t+1} + d_{24,kj}\,\hat{\varepsilon}_{k,t+1} + BP_{j,2} + BP_{j,3} + \cdots BP_{j,25} \right\}$$

To attain the target inflation rate exactly, solve for $\varepsilon_{k,t+2}$ conditional on $\hat{\varepsilon}_{k,t+1}$:

$$\hat{\varepsilon}_{k,t+2} = \left(\sum_{\ell=0}^{23} d_{\ell,jk} \right)^{-1} \{(y_{j,t+2} + y_{j,t+3} + \cdots + y_{j,t+25})^* - \sum_{\substack{i=1 \\ i\neq k}}^{N} d_{0,ji}\varepsilon_{i,t+2} - \sum_{\substack{i=1 \\ i\neq k}}^{N} d_{1,ji}\varepsilon_{i,t+1} - \cdots -$$

$$\sum_{i=1}^{N} d_{0,ji}\varepsilon_{i,t+24} - \sum_{i=1}^{N} d_{1,ji}\varepsilon_{i,t+23} - \cdots - \sum_{\substack{i=1 \\ i\neq k}}^{N} d_{22,ji}\varepsilon_{i,t+2} - \sum_{\substack{i=1 \\ i\neq k}}^{N} d_{23,ji}\varepsilon_{i,t+1} - \sum_{i=1}^{N} d_{0,ji}\varepsilon_{i,t+25} - \cdots -$$

$$\sum_{\substack{i=1 \\ i\neq k}}^{N} d_{23,ji}\varepsilon_{i,t+2} - \sum_{\substack{i=1 \\ i\neq k}}^{N} d_{24,ji}\varepsilon_{i,t+1} - \sum_{i=1}^{h} d_{i,jk}\,\hat{\varepsilon}_{k.t+1} - BP_{j,t+2} - BP_{j,t+3} - \cdots BP_{j,t+25}\} \qquad \text{(A3)}$$

If the bandwidth is nonzero, then analogous to the earlier discussion, replace

$(y_{j,t+2} + y_{j,t+3} + \cdots + y_{j,t+25})^*$ with $(y_{j,t+2} + y_{j,t+3} + \cdots + y_{j,t+25})^* \pm \tau = Y^*_{i,t+2} \pm \tau$.[35]

Note that, generalizing equations like (A2) or (A3) to period t+j, computation of the t+j period policy shock needed to attain the FAIR for the subsequent 24 months would include two kinds of terms: policy interventions needed return the average inflation rate to the band and shocks from the random draw for those periods in which no intervention is needed.

For the various bandwidths of each experiment, we specify a target path and specify a band around this path. Since we sample from the estimated residuals, we do not impose any arbitrary assumptions about the probability density generating the shocks to the economy. For each trial, computed values for the system variables are those the economy will follow using the assumed policy interventions that keep the FAIR inside the designated band, given the shocks to the other equations.[36]

[35] Note that in equations (A2) and (A3), our policy actions generally respond to all the information in the model. In contrast, policy actions based on the well-know Taylor rule only respond to, say, information on output (relative to potential) and deviations of inflation from target.

[36] While it is possible to do so, we do not take into account the possibility that the model coefficients may be estimated imprecisely.

Data Appendix

1. Real time real gdp data are from the routput.xls file from the qvad folder available for download from the Philadelphia Federal Reserve Bank. The relevant columns of this file are: routput83q4 for the sample that ends in 1983:9, routput93q1 for the sample that ends in 1992:12, and routput01q1 for the sample that ends in 2000:12. Data in columns routput93q1 and routput01q1 were known in the first quarter of the respective years, and we assume this data was known by the Fed at the beginning of the relevant counterfactual experiments. Data in column routput83q4 was known in the fourth quarter of 1983. Since our 1983 counterfactual begins in November 1983, the Fed may not have had all the information in this column at the beginning of the counterfactual. However, we wanted to begin the counterfactual a year after the end of reserve targeting, and this was the closest approximation to real time gdp data we could obtain for November 1983.

As noted in the text, for each sample the HP filter was used to construct a potential gdp series, and the output gap was then constructed as actual real gdp minus the HP-potential gdp. The quarterly real time output gaps were then interpolated to monthly data using the distrib.src procedure in RATS 6.02b.

2. Real time personal consumption expenditure deflator data were taken from various issues of the Survey of Current Business.
a. 1962:1-1983:9 sample. 1961-1976: November 1979 Survey of Current Business; 1977-1978: October 1982 Survey of Current Business; 1979-1983:9: July 1983 Survey of Current Business. Monthly data.
b. 1980:1-1992:12 sample. December 1992 Survey of Current Business, Table 3 and the February 1993 Survey of Current Business, Table 7.1. The data in these tables were quarterly, and were interpolated to monthly using the distrib.src procedure in RATS 6.02b.
c. 1980:1-2000:12 sample. August 2000 Survey of Current Business, Table 3 and the February 2001 Survey of Current Business, Table 7.1. The data in these tables were quarterly, and were interpolated to monthly using the distrib.src procedure in RATS 6.02b.
d. We note that the data sets for 1980:1-1992:12 and 1980:1-2000:12 are not totally pure real time data sets since data at the very end of 1992 and 2000 were pulled from the earliest Survey of Current Business in 1993 and 2001, respectively.

3. The federal funds rate is taken from the Global Insight Basic database, series fyff, and the commodity price index is the Commodity Research Bureau spot market index for all commodities (Global Insight Basic database, series psccom). These series are not revised and hence the data pulled from the Global Insight databases were used in the real-time estimations.

Table 1

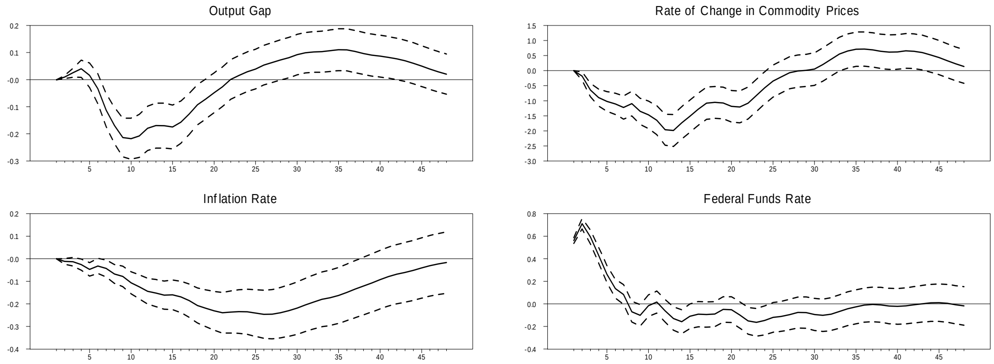
A: 1983 Experiment: Decline to 2% over 48 Months				
	0% band	1% band	2% band	∞ band
I. Summary Statistics				
Interventions per trial	24.0 (14.1 9.9)	12.8 (12.2 0.6)	9.9 (9.8 0.1)	0
Average maximum consecutive interventions	24.0	11.66	9.43	0
Trials (of 1000) with any intervention	1000	945	764	0
II. Range of Policy Interventions				
Actual maximum shock to interest rate equation	.026	.026	.026	.026
95% maximum simulated shock to interest rate equation	.150	.108	.064	.026
Actual minimum shock to interest rate equation	-.044	-.044	-.044	-.044
5% minimum simulated shock to interest rate equation	-.041	-.040	-.039	-.044
III. Fundamental Results				
Standard deviation of indicated variable around trial mean				
Output Gap	.02043	.01521	.01141	.00861
Inflation	.00662	.00975	.01300	.01655
Interest rate (Fed funds)	.04627	.02720	.01654	.01160

B: 1993 Experiment: Decline to 2% over 48 Months				
	0% band	1% band	2% band	∞ band
I. Summary Statistics				
Interventions per trial	24.0 (21.2 2.7)	10.1 (10.1 0.0)	3.6 (3.6 0.0)	0
Average maximum consecutive interventions	24.0	9.3	3.5	0
Trials (of 1000) with any intervention	1000	865	502	0
II. Range of Policy Interventions				
Actual maximum shock to interest rate equation	.018	.018	.018	.018
95% maximum simulated shock to interest rate equation	.141	.047	.041	.018
Actual minimum shock to interest rate equation	-.025	-.025	-.025	-.025
5% minimum simulated shock to interest rate equation	-.020	-.011	-.025	-.025
III. Fundamental Results				
Standard deviation of indicated variable around trial mean				
Output Gap	.01077	.00703	.00538	.00536
Inflation	.00538	.00597	.00607	.00614
Interest rate (Fed funds)	.03625	.02721	.01561	.01045

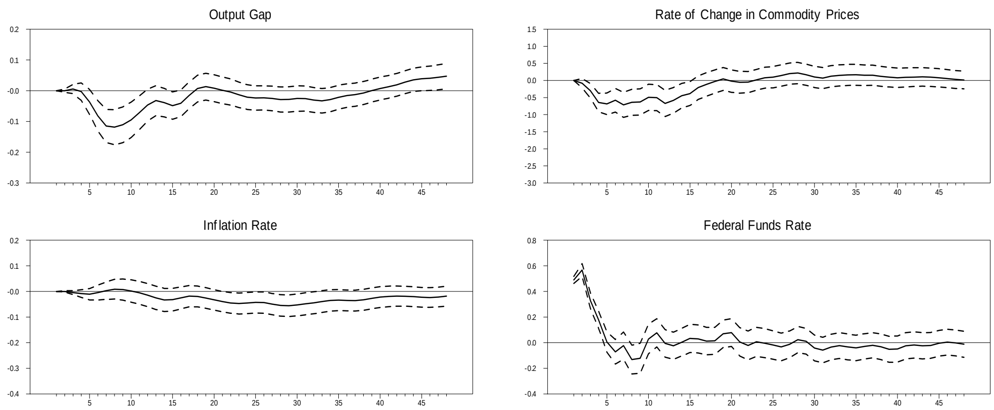
C: 2001 Experiment: Decline to 2% over 48 Months				
	0% band	1% band	2% band	∞ band
I. Summary Statistics				
Interventions per trial	24.0 (15.2 8.8)	3.3 (1.9 1.4)	0.3 (0.2 0.1)	0
Average maximum consecutive interventions	24.0	3.0	0.3	0
Trials (of 1000) with any intervention	1000	370	39	0
II. Range of Policy Interventions				
Actual maximum shock to interest rate equation	.024	.024	.024	.024
95% maximum simulated shock to interest rate equation	.117	.024	.024	.024
Actual minimum shock to interest rate equation	-.038	-.038	-.038	-.038
5% minimum simulated shock to interest rate equation	-.044	-.037	-.029	-.019
III. Fundamental Results				
Standard deviation of indicated variable around trial mean				
Output Gap	.00693	.00468	.00478	.00478
Inflation	.00424	.00564	.00631	.00630
Interest rate (Fed funds)	.02668	.01140	.01070	.01051

Figure 1: Impulse Response Functions

1962:1-1983:9



1980:1-1992:12



1980:1-2000:12

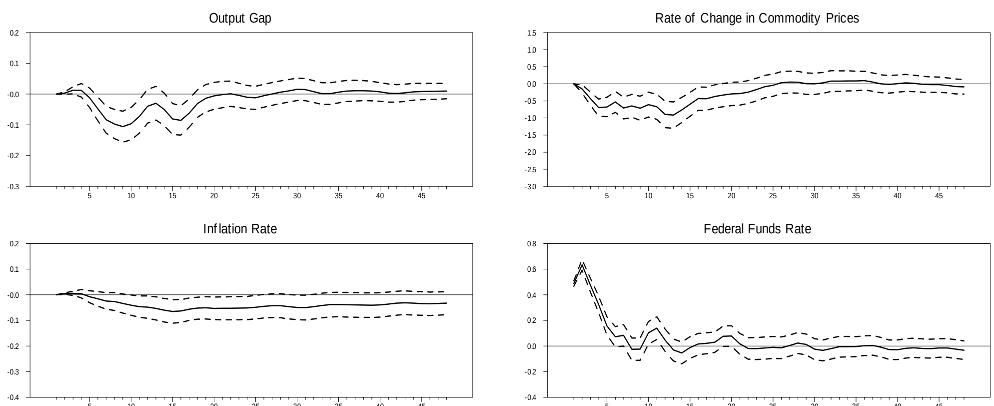


Figure 2: Actual Inflation, Base Projections, and Target Bands:1962:1-1983:9 Sample

Actual Inflation: Solid Line, Base Projection: Short Dashes, 1% Band: Short & Long Dashes, 2% Band: Long Dashes

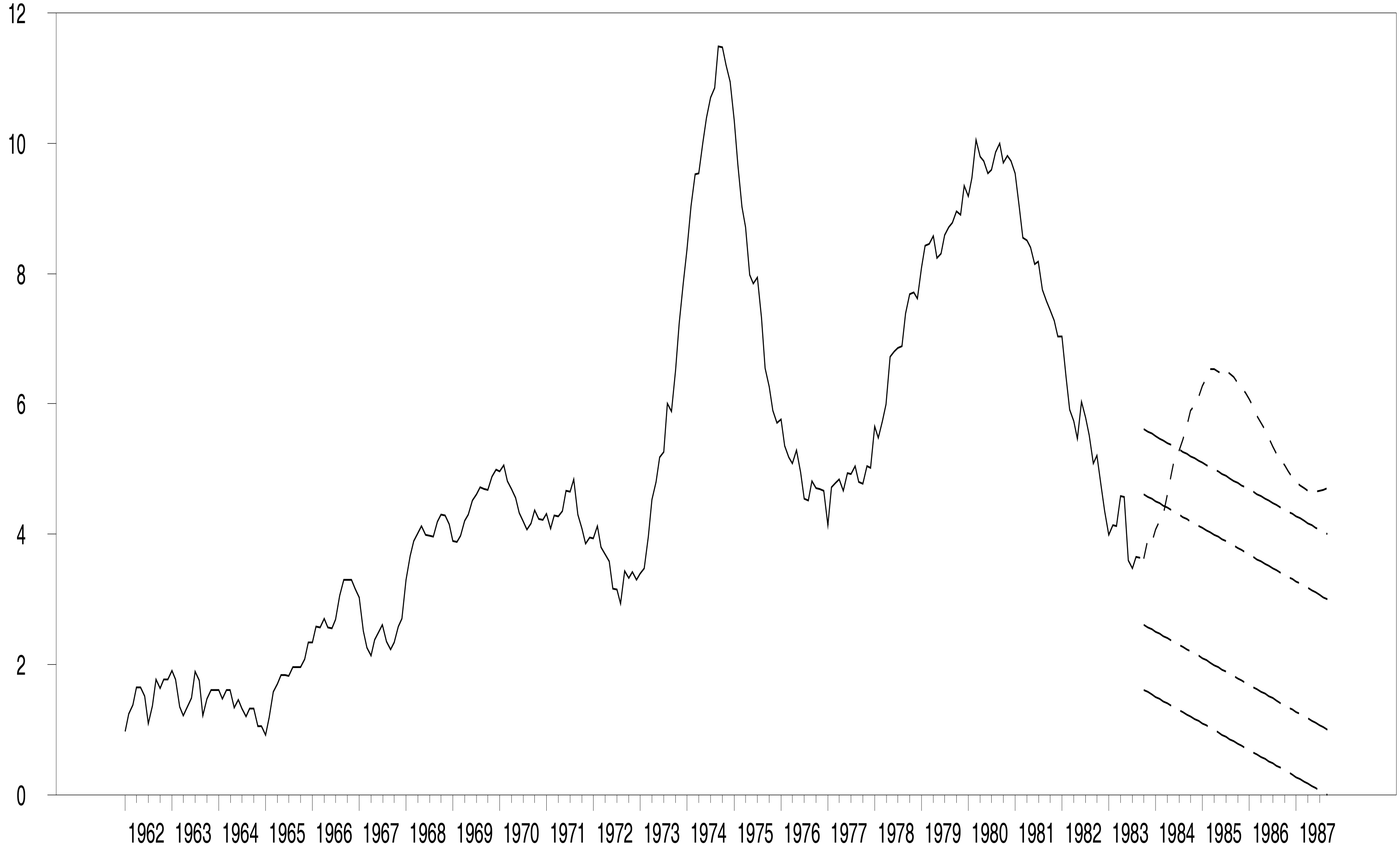


Figure 3: Actual Inflation, Base Projections, and Target Bands:1980:1-1992:9 Sample

Actual Inflation: Solid Line, Base Projection: Short Dashes, 1% Band: Short & Long Dashes, 2% Band: Long Dashes

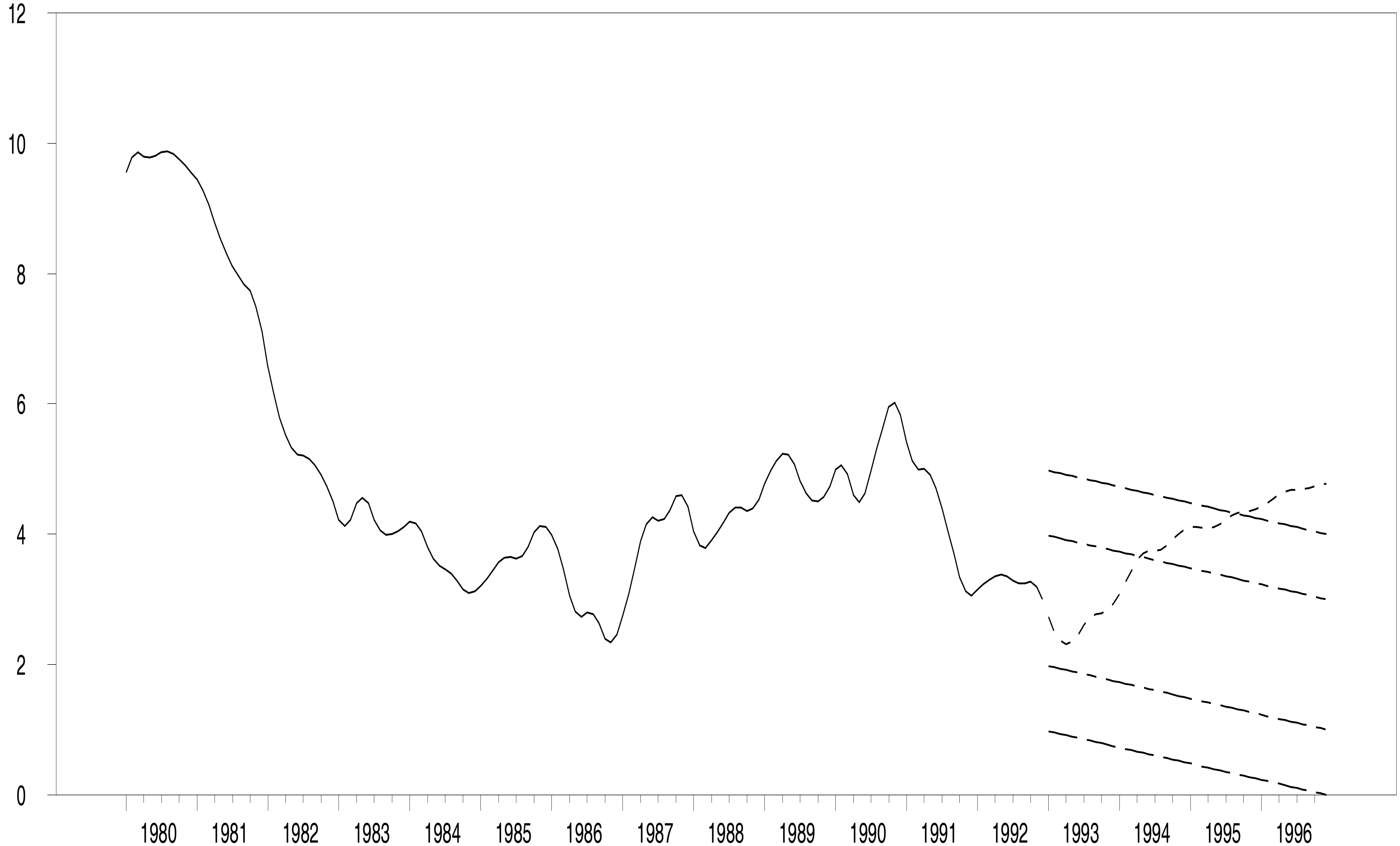


Figure 4: Actual Inflation, Base Projections, and Target Bands: 1980:1-2000:12 Sample

Actual Inflation: Solid Line, Base Projection: Short Dashes, 1% Band: Short & Long Dashes, 2% Band: Long Dashes

Figure 5: Inflation-Output Standard Deviation Tradeoffs Over Time: 2% Target

1983: Solid Line, 1993: Short Dashes, 2001: Long Dashes

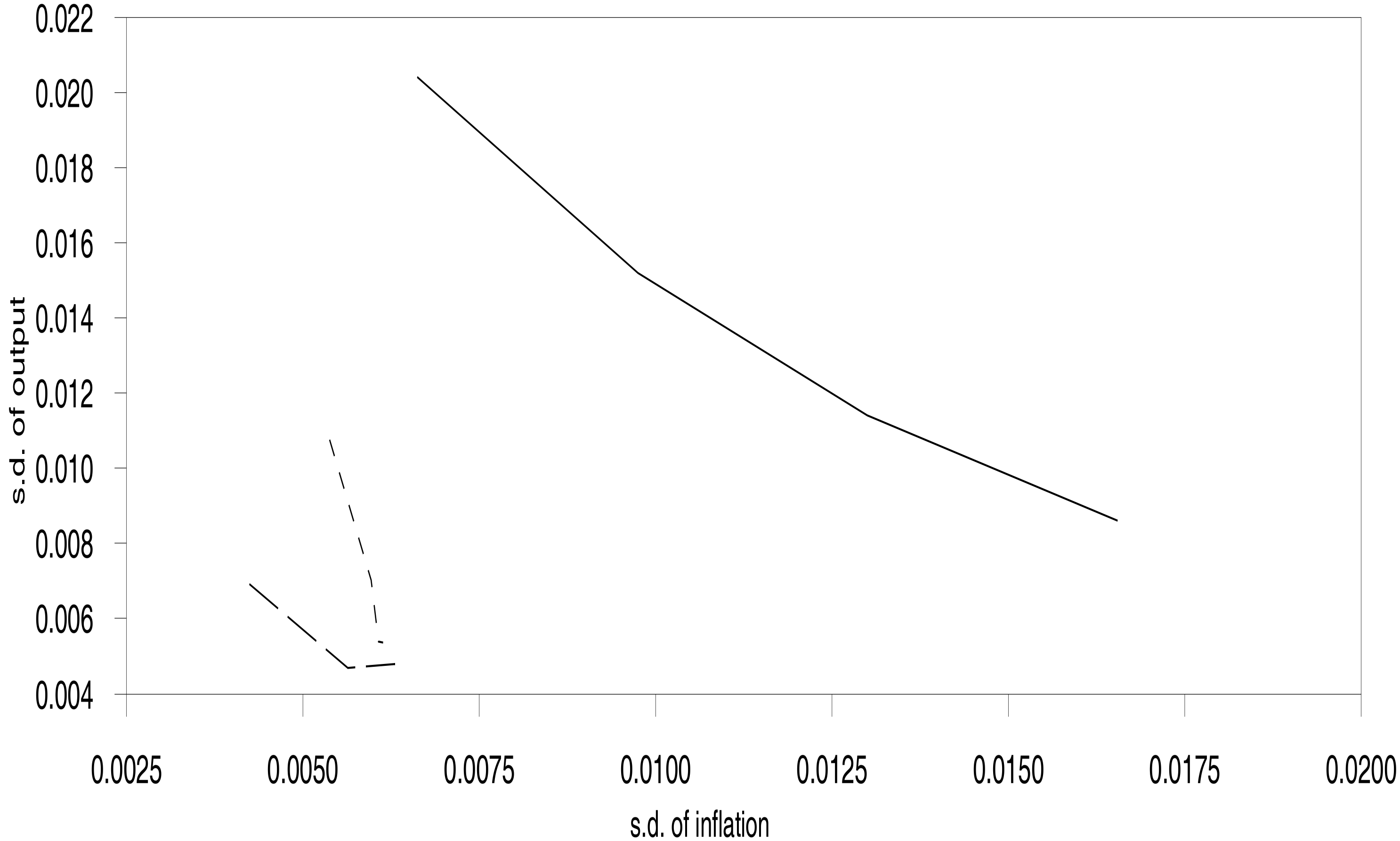


Figure 6: Inflation-Interest Rate Standard Deviation Tradeoffs Over Time: 2% Target

1983: Solid Line, 1993: Short Dashes, 2001: Long Dashes

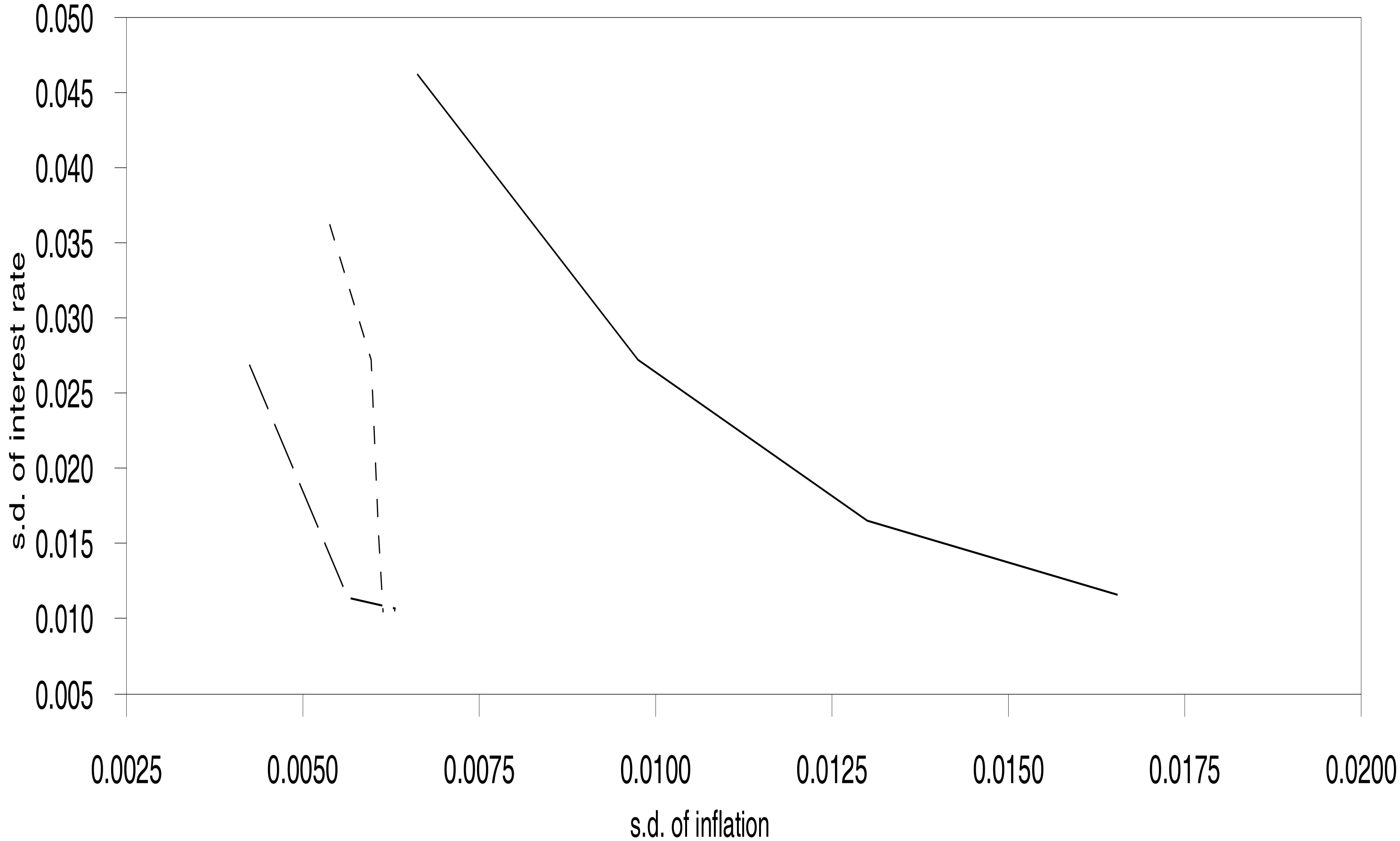
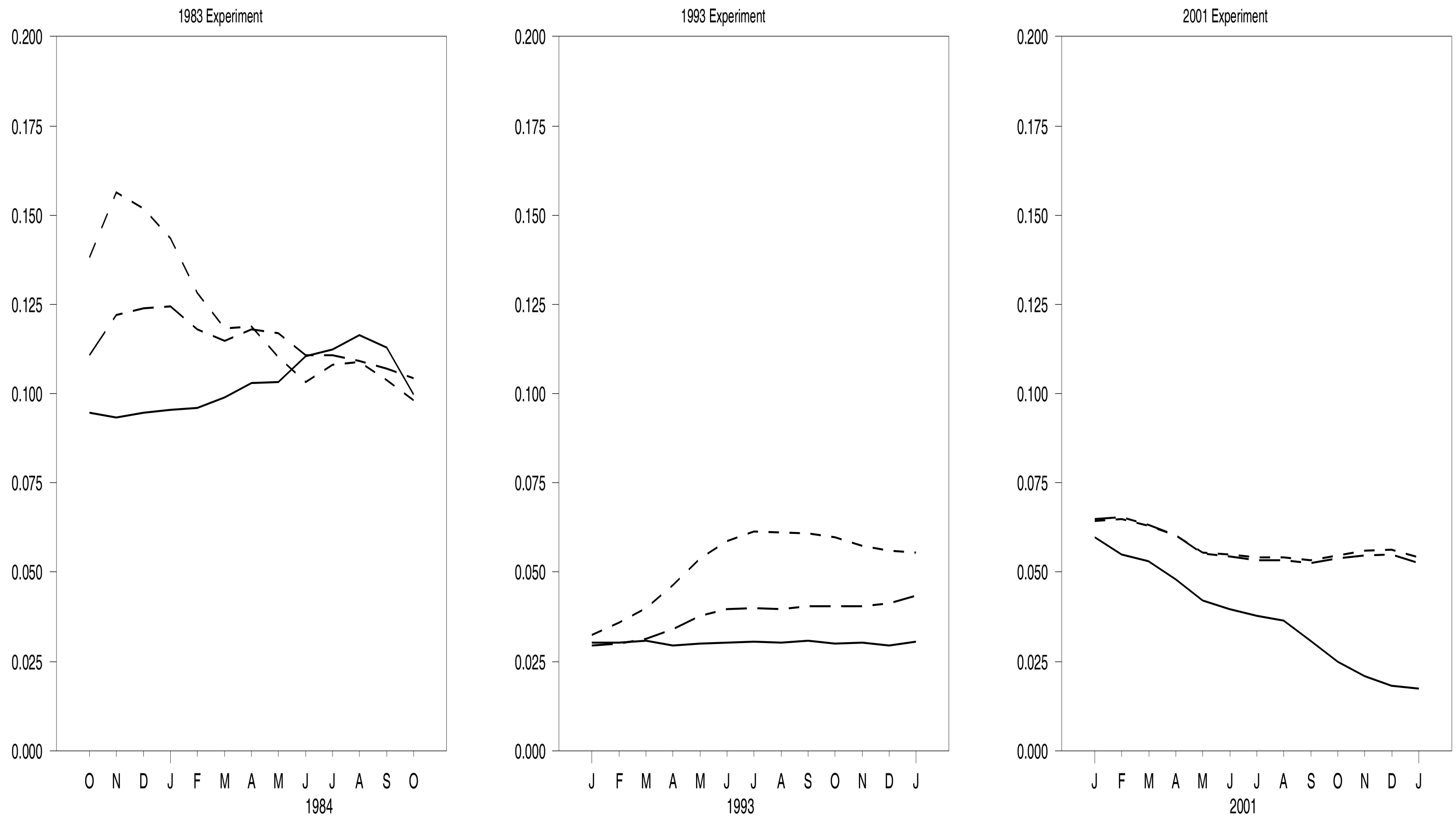


Figure 7: Actual and Average Counterfactual Interest Rates

Actual Fed Funds Rate: Solid Line, Avg Funds Rate 1% Band: Short Dashes, Avg Funds Rate 2% Band: Long Dashes



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