Inflation Targeting and Target Instability*

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Monetary policy is modeled as being governed by a known rule, except for a time-varying target rate of inflation. The variable target can be thought of either as standing in for discretionary deviations from the rule or as the outcome of a policymaking committee that is unable to arrive at a consensus. Stochastic simulations of FRB/US, the Board of Governors' large rational-expectations model of the U.S. economy, are used to examine the benefits of reducing the variability in the target rate of inflation. We find that putting credible boundaries on target variability introduces an important nonlinearity in expectations. The effect of this is to improve policy performance by focusing agents' expectations on policy objectives. But improvements are limited; it does not generally pay to reduce target variability to zero. More important, this nonlinearity in expectations allows for policy to be conducted, at the margin, with greater attention to output stabilization than would otherwise be the case. The results provide insights as to why inflation-targeting countries use bands and why the bands they use are narrower than studies suggest they should be. A side benefit of the paper is the demonstration of a numerical technique that approximates to arbitrary precision a nonlinear process with a linear method, thereby greatly speeding and making more robust the computation of simulation results.

JEL Codes: E3, E5, C6.

*The views expressed in this paper should not be attributed to the Board of Governors, the FOMC, or staff members of the Federal Reserve System. I am thankful for the guidance and suggestions of the editor, John Taylor, and two anonymous referees. In addition, Steve Ferris, Ben Hunt, Tiff Macklem, Athanasios Orphanides, Dave Reifschneider, Larry Schembri, John C. Williams, and seminar participants at Carleton University, the Bank of Canada, and the Reserve Bank of Australia provided useful comments. All remaining errors are my own. E-mail: Robert.J.Tetlow@frb.gov. Tel: (202) 452-2437. Fax: (202) 452-5296. Web page: www.roberttetlow.com.

1. Introduction

> While the pursuit of price stability does not rule out misfortune, it lowers its probability. . . . If households are convinced of price stability, they will not see variations in relative prices as reasons to change their long-run inflation expectations. Thus, continuing to make progress toward this legislated objective will make future supply shocks less likely and our nation's economy less vulnerable to those that occur.
>
> (Greenspan 1998)

In recent years, a number of countries have adopted inflation targeting as the legislated objective for their countries, in pursuit of the same bounty that Alan Greenspan, then Chairman of the Board of Governors of the Federal Reserve System, outlines in the above quotation. New Zealand (1990), Canada (1991), the United Kingdom (1992), Finland (1993), and Sweden (1993), among other countries, have established explicit targets for inflation. The Federal Reserve, on the other hand, makes broad statements about "price stability" being the ultimate objective of policy, without defining quantitatively what the term means. Is this sufficient? What about announcing a "comfort zone," within which any rate of inflation is as good as any other, as in the case of Australia?[1]

As Chairman Greenspan's statement emphasizes, a key purpose of public declarations regarding policy objectives is to direct private agents' expectations toward policy objectives. Doing so successfully builds up reputation for policy, and policymakers, making the economy "less vulnerable" to adverse shocks. In this paper, we examine what role a limited form of policy credibility—specifically, the idea that *perceived inflation targets* might drift within bounds over time—might have on monetary policy outcomes.

[1] Siklos (1997) provides a nice short summary of the practices of various inflation-targeting countries; see especially the table on pp. 132–33.

We model perceived inflation targets as a bounded random walk with a band width that is under the control of the Federal Reserve. We think of this band width as representing either the degree of discretion that the Federal Open Market Committee (FOMC) allows itself or the byproduct of inertial responses by a committee that cannot come to consensus on the target over time. We embed this process for the target within the rational-expectations version of the Federal Reserve Board's macroeconometric model of the U.S. economy, FRB/US, and conduct stochastic simulations to provide a quantitative guide to the possible benefits that might be accrued with a regime where there is randomness in policy but only within bounds. We show that target bands for inflation control imply an important nonlinearity that increases in significance as the target bands narrow. A Federal Reserve that chooses the target band would find that narrow bands are beneficial for the economy because of their effect on providing a focal point for private agents' expectations. One contribution of the paper is the resolution of the numerical problem presented by the nonlinearity in combination with the large scale of the model.

To presage the results, we find that constraining the perceived drift in inflation targets engenders a "honeymoon effect" that facilitates inflation control above and beyond what arises from policy actions alone. More generally, for a given policy rule, narrowing the bands improves economic outcomes, although the gains decline as the bands get narrower. More important is that greater credibility of monetary policy in the form of a narrower perceived range of the target rate allows the central bank to be less hawkish in setting policy rates than otherwise would be the case. We argue that, together, these results favor point targets for inflation over target ranges, or "comfort zones."

The rest of the paper proceeds as follows. In section 2 we discuss variability in monetary policy, and how the behavior of central banks in general and the Federal Reserve in particular might be reasonably characterized by drifting but bounded targets for inflation. We also describe how "variability" is operationalized for this paper. The third section provides a brief encapsulation of the FRB/US model. Section 4 then discusses aspects of our simulation technique. The fifth section summarizes our results. A sixth section sums up and concludes.

2. Inflation Targeting and Variable Targets

2.1 Policy Rules and Policy Objectives

A formal way of characterizing monetary policy is the solution to a dynamic optimization problem. Another quite different method is where, in the words of Blinder (1998), decision makers "look out the window" and adjust policy according to whether the economy is currently running "too hot" or "too cold." The former method is an example of policy by rules; the latter is inherently discretionary. When the Federal Reserve, in pursuing discretionary policy, failed in the 1970s to adjust the funds rate sufficiently in response to inflationary shocks, the implication was that the implicit inflation target was being increased—not necessarily as a deliberate act of policy but perhaps as an implication of the Federal Reserve's unwillingness to forgo output objectives in order to maintain a fixed inflation target.[2] Between these two extreme characterizations of policy lie a wide range of alternatives embodying differing levels of commitment and flexibility.

In this paper, we hypothesize that the public has information about the broad objectives of policy but no information regarding a specific target. To illustrate, suppose Federal Reserve watchers were to "invert" a policy rule, like the Taylor (1993) rule, on the target rate of inflation, π_t^*:[3]

$$R_t = 2 + \tilde{\pi}_t + 0.5\left(\tilde{\pi}_t - \pi_t^*\right) + 0.5y_t, \tag{1}$$

where rule R is the nominal federal funds rate; the equilibrium real rate, rr^*, is taken, as Taylor did, to be 2 percent as shown; $\tilde{\pi}$ is the

[2] This characterization of policy is consistent with the rhetoric of Meltzer (1991, 34) when he accuses the Federal Reserve of having lost control of inflation in the 1970s because FOMC "members were reluctant to allow interest rates to rise by as much as required by staff forecasts. They hoped to achieve lower inflation by reducing money growth but were reluctant to allow interest rates rise by relatively large steps."

[3] A computer search of speeches by Board members over the period from 1993 to 1999 for the words "Taylor rule" and derivatives thereof reveals twelve hits for speeches by then Governors Meyer, Gramlich, Ferguson, and Yellen. No other rule had ever been publicly cited in speeches. The lessons of the Taylor rule have been reported to members of the Board "as principles to guide decisions about the setting of the federal funds rate at FOMC meetings" (Meyer 1998, 16).

Figure 1. Target Rate of Inflation as Implied by the Taylor Rule

four-quarter change in the chain-weight PCE price index; and y is the output gap.[4] An asterisk indicates an equilibrium or target level, as applicable. This results in the time series shown in figure 1.

The figure shows, first, that there has clearly been a large shift in either the equilibrium real interest rate or the target rate of inflation, or both, in the early 1980s.[5] This helps explain Taylor's focus on the 1987–92 period as one where the fit is "remarkable." Second, over both subsamples there have been large and persistent movements in the implicit target. High-frequency movements in π^* could

[4]We replace the original Taylor article's GDP price deflator as the relevant inflation measure to reflect current FOMC emphasis; otherwise, our formulation is the same as the original, up to the time-varying target. Other rules would give different answers, but no parsimonious rule would significantly alter our basic point.

[5]It is likely that both a shift in π^* and a shift in rr^* occurred. The early 1980s was the period of the Volcker disinflation, in which CPI inflation was deliberately brought down by the Federal Reserve from about 12 percent to approximately 5 percent. Bomfim (1997) shows that the equilibrium real interest rate apparently rose at about the same time, perhaps due to the accumulation in the early 1980s of large public-sector deficits.

be attributed to a missing term from the rule, associated perhaps with tactical concerns in the conduct of policy, or control errors. But movements as persistent as those shown are difficult to ascribe to something other than changes in the target. Third, with the exception of the once-and-for-all shift at around 1980, the shifts in the implicit target, however persistent, appear to have been bounded within ranges.

The Federal Reserve has not made a regular habit of explicitly discussing the quantitative objectives of policy and so it seems reasonable to characterize the inflation target as a latent variable of policy—something that falls out of funds rate settings given the stochastic shocks that are borne by the economy—rather than the other way around. The "zone-quadratic" preferences of Orphanides and Wieland (2000) are consistent with this characterization; Orphanides and Wilcox (2002) describe something similar to this on "opportunistic disinflation" as a description of Federal Reserve behavior in the 1990s.[6] The rhetoric of late of the FOMC to the effect that the Committee has a "comfort zone" within which the bulk of the membership is satisfied with inflation is very much like this depiction.[7]

Quantitative work by Aksoy et al. (2006) provided both an assessment of opportunistic disinflation and a symmetric extension of the concept that permits drift, within bounds, of actual inflation, while the Federal Reseve concerns itself with output stabilization and then strong inflation control at the edges of the band. This describes a "zone of indifference" regarding inflation—not unlike the policy practiced by Australia—and, as Riboni and Ruge-Murcia (2008) show, can arise from committee structures that can agree on a point when inflation is "too high" or "too low" but cannot come

[6]It is noteworthy that opportunistic disinflation was the name that Federal Reserve Governor Laurence Meyer gave to the policy he saw the FOMC following when he joined the Board in early 1995. The Orphanides and Wilcox (2002) paper was written as a theoretical explanation of Meyer's observation. See Meyer (1997) for a description of opportunistic disinflation, including the author's claim to paternity.

[7]The term "comfort zone" appeared in the headline of a September 2002 *New York Times* interview of former Governor Laurence Meyer. Since then, the term has been used repeatedly by various FOMC members, including Bernanke (2005) and Yellen (2006). It is normally, and imprecisely, taken as a range between 1 and 2 percent for the four-quarter growth rate of either the headline or core PCE price index.

to a consensus on intermediate cases. Under this interpretation, the upper and lower boundaries for the target rate of inflation are points at which a critical mass on the committee would say that trend inflation is out of line with long-term objectives. In between, there might be more of a bias toward going back to the long-run target—in the sense that the probabilities point in that direction—but not an overwhelming impetus; some committee members might be inclined to await further information (and more shocks) before acting.[8] At the midpoint of the bands, all FOMC members are in agreement that inflation is not a problem.

The next subsection formalizes the idea of inflation targets as a bounded, random process.

2.2 Modeling Inflation Target Bands

The preceding subsection has established at least a prima facie case for treating the target of monetary policy as a random variable; in this subsection, we operationalize this idea. We begin by assuming that monetary policy can be described by a simple interest rate reaction function, as follows:

$$R_t = rr^* + \sum_{i=0}^{3} \pi_{t-i}/4 + 2.2\left[\sum_{i=0}^{11} \pi_{t-i}/12 - \pi_t^*\right] + 1.5y_t. \qquad (2)$$

Equation (2) differs from the canonical Taylor rule in three ways. First, the rule's inflation term is expressed as a twelve-quarter moving average of inflation instead of four quarters. Williams (2003) shows that, in the context of FRB/US, equations with longer lags on inflation outperform shorter lags. Second, the coefficients on both inflation and the output gap are larger for our rule. In fact, Williams (2003) shows that this parameterization is an efficient one in that no other coefficient values can produce lower unconditional variances of output and inflation simultaneously without increasing the

[8] The practice of decision making by consensus at the FOMC is well known. See, e.g., Blinder (1998) and Meyer (1998). Blinder notes that this can lead to sluggish responses. As we shall argue below, it may also lead to a disconnection between long-term objectives and short-term practices of the Federal Reserve.

variability of the federal funds rate.[9] Formally, the parameterization of equation (2) is the solution to a problem that minimizes the following loss function:

$$E_0 \sum_{i=1}^{\infty} \varphi \left[\tilde{\pi}_{t+i} - \pi^*_{t+i} \right]^2 + (1-\varphi) y^2_{t+i} \tag{3}$$

subject to the model, the specification of the rule equation (2), and to a constraint on maximum variability of the federal funds rate.[10] By choosing a (constrained) optimal rule in this way, we avoid specious results that might arise simply from the use of a poorly performing rule. In addition, we have the advantage of being able to consider policymakers' preferences directly. The parameterization of equation (2) is optimal for an authority with relatively "hawkish" inflation preferences, $\varphi = 0.75$; we shall examine alternative preferences a bit later.

The third difference from the Taylor rule is that the target rate of inflation, π^*_t, carries a time subscript; we allow time variation in the monetary policy target. We also assume that private agents know the rule but do not know the target on a period-by-period basis, so that they can infer the target only with a one-quarter lag. We consider two possible data-generating processes for the target rate of inflation: a random walk and a bounded random walk. (Clearly, no authority would truly permit the target rate of inflation to vary from plus to minus infinity, so the pure random-walk case should be thought of as a benchmark.) In both cases, the law of motion for the target looks the same:

$$\pi^*_t = \pi^*_{t-1} + \mu_t. \tag{4}$$

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[9] Equation (2) also dominates rules with shorter moving averages in the inflation rate as judged by the same criterion of minimized unconditional variances. Note that, for expositional simplicity, we have arbitrarily rounded the many decimal places used in the rule actually used for simulation.

[10] The practice, following Williams (2003), among many others, of imposing a penalty on funds rate variability provides two benefits: (i) the optimally computed coefficients on the policy rule are of a magnitude that would be considered reasonable, and (ii) the implied variability of the federal funds rate is close to the historical experience. The same qualitative results obtain when funds rate volatility is mildly penalized instead of the hard constraint we use here.

The difference is in the distribution of innovations. In the pure random-walk case, the innovations, μ_t, are independently and identically distributed:

$$\mu_t \sim N(0, \sigma^2). \tag{5}$$

In the bounded random-walk case, innovations are bounded by the target bands. Letting $\bar{\pi}^*$ and $\underline{\pi}^*$ designate the upper and lower bounds for π^*, Johnson, Kotz, and Balakrishnan (1994, 156) show that the (truncated) probability density function of innovations is

$$\mu_t \sim \frac{1}{\sigma\sqrt{2\Pi}} \exp\left[\frac{-\mu^2}{2\sigma^2}\right] \left\{\frac{1}{\sigma\sqrt{2\Pi}} \int_{\left(\underline{\pi}^*-\pi^*_{t-1}\right)}^{\left(\bar{\pi}^*-\pi^*_{t-1}\right)} \exp\left[-\frac{\left(t-\pi^*_{t-1}\right)^2}{2\sigma^2}\right] dt\right\}^{-1}. \tag{6}$$

As ugly as equation (6) looks, it is simply a truncated normal distribution, with truncation points determined by band widths and the inherited rate of target inflation, given σ. That is, the truncation points, $\{\underline{\pi}^* - \pi^*_{t-1}, \bar{\pi}^* - \pi^*_{t-1}\}$, shift around with the inherited target inflation rate. We assume that the bands are spaced symmetrically around a given midpoint, which we set to zero.[11] Let us also assume that the bands on the target rate of inflation are $+1$ and -1 percent, respectively, as in our base-case simulations below. When the inherited target inflation rate happens to be zero, the distribution of innovations is simply the normal distribution with the tails beyond $+1$ and -1 chopped off. Besides being symmetric, with our base-case value of σ of 0.25, this distribution is functionally identical to the normal distribution because the truncation points are four standard deviations away. However, when the inherited target rate of inflation is positive, the upper bound on innovations moves to the right, eliminating more of the positive innovations that would otherwise be possible and adding more of the negative innovations. If the inherited target rate of inflation were exactly 1 percent, the

[11]We elect to ignore the zero lower bound on nominal interest rates in order to focus on the issue of interest. Other than the truncation described in the main text, the model is linear, so one can reinterpret the target rate as being at a rate where the likelihood of the zero-bound problem being binding is infinitesimally small, if so desired.

distribution of possible innovations would be exactly one-half of the normal distribution.[12]

The case of a fixed target rate of inflation is nested within equation (6), as $\underline{\pi}^* = \bar{\pi}^* = 0$. In addition, permitting $\bar{\pi}^* \rightarrow \infty$ and $\underline{\pi}^* \rightarrow -\infty$ gives the pure random-walk case.

It is important to note that these boundaries for the target do not imply the same boundaries for inflation itself. In the short run, many forces are at work on inflation—of which only one is monetary policy—and, in any case, inflation stabilization is not the sole concern of monetary policy. Thus, in general, inflation itself will be more variable than the target.

Two issues regarding the law of motion for π^* warrant discussion. First, we assume that π^* moves *randomly* within the target bands. As discussed above, the Volcker disinflation excepted, time variation in the de facto target of the Federal Reserve does not appear to have arisen from a conscious selection of different priorities. Instead, it appears to have come from an unwillingness to respond to shocks with sufficient strength to be consistent with a constant target. Indeed, the tendency in that period was, in the words of the Federal Reserve's then Director of Monetary Affairs (and current Board Vice Chairman) Donald Kohn, to "adjust nominal rates too slowly in the initial stages of a cycle, and then to overstay a policy stance" while awaiting further information.[13] While the process that Kohn alludes to will produce a correlation of shocks, this is only to the extent of the sign of the shocks—upward in the 1960s and 1970s, and downward in the 1990s.[14] In this context, the assumption adopted here is a tractable one and does not seem like

[12]We are modeling a discrete-time version of what is sometimes called reflecting barriers. With reflecting barriers, that proportion of the distribution of targets that would have called for targets outside of the bands is discarded. An alternative is absorbing barriers in which the truncated portion of the distribution is assigned to the boundary value, causing a tendency for target rates of inflation to mass at the boundary edges. With reflecting barriers, the target rate of inflation almost never reaches the boundary, as we shall see. Dixit (1993) provides a thorough discussion of the mathematics and modeling of both types of barriers in continuous time.

[13]See Kohn (1991, 101). As Meyer (1998, 18–19) notes, it is the Director of Monetary Affairs that presents the policy options to the FOMC.

[14]We might also note that to the extent to which innovations to the target were *systematically* correlated with shocks or other state variables, it should show up in the specification of the rule itself. And to the extent that these shocks are

an egregious oversimplification.[15] Second, we also assume that the bounds on the target are regarded as fully credible by private agents. Together, these two assumptions will permit us to model expected future inflation targets independent of the rest of the model.

2.3 Expected Future Inflation Targets

In the preceding subsection, the target rate of inflation was modeled with a truncated normal distribution. The truncation at any given date is determined entirely by (i) the inherited target inflation rate, (ii) the variance of innovations, and (iii) the band width. In this subsection, we describe the expected future target rate of inflation conditional on some initial value. The nature of this expectation is key to the results that follow because in the FRB/US model, expected *future* target rates of inflation feed into *current* price- and wage-setting behavior.

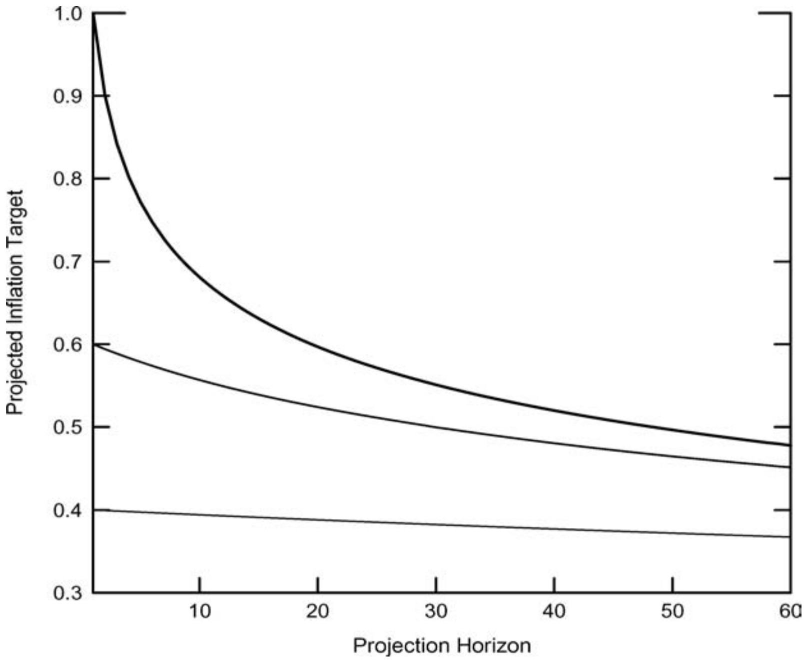
As noted, agents are assumed to know the process for the target rate of inflation, but not the current value of innovations. Since they know the inherited target inflation rate, the expected value of the current target can be computed, $E_{t-1}\pi_t^*$. And because innovations are independent, this value can then be taken as given and a value for $E_{t-1}\pi_{t+1}^*$ can be computed, and so on, in a straightforward application of the chain rule of forecasting.

At the midpoint of the bands the truncation is symmetric, the truncation points being equally distant from the inherited target rate; the pure random-walk prediction obtains in this special case. When $\pi^* = \bar{\pi}^* = 1$, the entire upper half of the normal distribution is truncated and only the lower half is pertinent. It follows that in this case the complete distribution of future target inflation rates is (weakly) less than the current target, and so the optimal prediction is for a decline in the future target and, symmetrically, for $\pi^* = -1$. More generally, it is clear that (i) the expected future target approaches the midpoint of the bands as time approaches infinity, and (ii) the initial rate of reversion toward the midpoint

correlated with the output gap, they may already be captured in the Taylor-rule coefficient for that variable.

[15] We note as well that this specification for the target rate of inflation allows a straightforward comparison of our results with those of the exchange-rate target-band literature that is related to the modeling undertaken here.

Figure 2. Agents' Inflation-Target Forecasts (Bounded Random Walk, Width = ±1)



will vary positively with the proximity of the inherited target rate to the bound, given the standard deviation of innovations. Johnson, Kotz, and Balakrishnan (1994, 156–62) show how to compute the probability density function for the truncated normal. Based on this, figure 2 shows the expected future path of $E_{t-1}\pi^*_{t+j}$ for three initial values of π^*_{t-1}, given $\sigma = 0.25$, and symmetric bands with the upper value arbitrarily set at $\bar{\pi}^* = 1$.[16]

The expected future path of target rates of inflation depends only on π^*_{t-1}, $\bar{\pi}^*$, and σ. Larger values of σ produce stronger nonlinearities because of higher probabilities of truncation for any given inherited target rate (other than zero). Symmetrically increasing the width of the target band, $\bar{\pi}^* - \underline{\pi}^*$, has the opposite effect.

[16]The standard deviation of innovations of 0.25 percent are taken from the standard deviation of changes in the Philadelphia survey of inflation expectations, ten years ahead, our proxy for the public's expectation of inflation in the long term.

Two other issues merit some attention. First, the discussion above has shown how the existence of credible bands serves to direct expectations of the target rate of inflation toward a fixed point as the horizon grows; the precise characteristics of the bands, together with the inherited target rate, determine the rate at which those expectations converge. This has the same flavor as the monetary policy frameworks employed by some central banks, most notably the Bank of England. In these frameworks, the central bank promises to bring inflation back to its target level *within a fixed horizon*. Just as in this paper, this introduces a nonlinearity into what might otherwise be a linear system and for the same purpose: to attempt to establish credibility. Second, for our base-case calibration, we have chosen $\sigma = 0.25$ on the basis of survey data for long-term inflation expectations. If one were to require learning on the part of private agents, rather than agents knowing the target with a one-period lag, one could then imagine that smaller shifts in the de facto target would support the same value of σ owing to the magnification that learning would entail.[17]

3. The FRB/US Model

In this section we outline the basic features of the FRB/US model. Limitations of space prevent us from doing justice to the features of the FRB/US model here; accordingly, we focus on those aspects that are germane to the issues studied in this paper. Our goal is to convince readers that the model is sensible and worthy of using to address the question at hand. Those interested in more information about the model can consult the working paper version of this article, as well as other publications.[18]

FRB/US is a relatively large rational-expectations structural model consisting of about thirty key behavioral equations and

[17]There would, of course, be other implications as well, most notably to the persistence of perceived shocks. We thank an anonymous referee for pointing out this angle in inquiry.

[18]Interested readers should consult Brayton and Tinsley (1996) on general aspects of the model. Particularly accessible descriptions of the modeling of expectations, and the monetary policy transmission mechanism, respectively, are Brayton et al. (1997) and Reifschneider, Tetlow, and Williams (1999). An application of the model to the analysis of disinflations is Bomfim et al. (1997).

several hundred identities. Rigidities in wage and price setting imply that monetary policy has effects on the real economy in the short run, but in the long run, policy can affect only the inflation rate.

The model is designed around the joint determination of private-sector expectations and public policy. In pursuit of this goal, about half of the model's dynamic behavioral equations are explicitly derived as decision rules governing the behavior of representative agents acting with foresight to achieve explicit objectives in the presence of constraints. Forward-looking agents plan in advance to adjust the value of their decision variables to converge over time on target levels, while balancing the cost of being away from the desired level against the cost of adjustment. In particular, the costs of adjusting wages and prices mean that private agents must plan in advance to set out a path for those variables—conditional on expected future demand, relative prices, and policy actions—and the expected future target rate of inflation.

We now demonstrate the basic properties of FRB/US. To do this, we compare the properties of the model and those of the historical data using three methods: inflation and output autocorrelations, impulse responses to a shock to the federal funds rate equation, and the parameters of a dynamic IS-curve equation. To begin, we need to characterize the behavior of monetary policy. To this end, we estimate a parsimonious interest rate reaction function, the results for which are shown in table 1. Like the Taylor (1993) rule, this rule is simple, but it adds some dynamic richness through the inclusion of two terms—one with the change in the output gap, and the other with the lagged federal funds rate.

Given the rule, figure 3 shows the autocorrelations of inflation, measured by the chain-weighted index of personal consumption expenditure prices, and the output gap. In both instances, the asymptotic model moments are represented by the dashed line and the moments estimated from the data are shown as the solid line. The dotted lines are one-standard-error bands for the data-based moments.[19] The model- and data-based moments are computed using the data and equation residuals from the 1980s and 1990s. This

[19]The model moments used here and below are computed from the formula for unconditional covariances. As such, the computed moments correspond to those that would be obtained from a stochastic simulation of infinite length.

Table 1. Estimates of a Simple Monetary Policy Reaction Function (1981:Q1–1999:Q4)

$R = (1 - \alpha_{R1})(\tilde{\pi} + rr^*) + \alpha_{R1}R_{t-1} + \alpha_{y0}y_t + \alpha_{y1}\Delta y_t + \alpha_{\pi}(\tilde{\pi} - \pi^*)$					
Symbol →	α_{R1}	α_{y0}	α_{y1}	α_{π}	π^*
Coefficient (Standard Error)	0.84 (0.05)	0.15 (0.05)	0.58 (0.39)	0.25 (0.09)	2.20 (0.60)
$rr^* = 2.5$ (assumed)			SEE = 0.81		

Notes: R is the nominal federal funds rate (quarterly average basis); $\tilde{\pi}$ is the four-quarter rate of change of the (chain-weighted) personal consumption expenditures price index; y is output measured in percent deviations from potential output; rr^* is the steady-state real interest rate (taken to be 2.5 percent); and π^* is the target rate of inflation. Estimation is conducted using instrumental variables with the lagged four-quarter inflation rate, two lags of the output gap, the lagged federal funds rate, and a constant as instruments.

sample period was chosen to approximate a single policy regime and to correspond with the estimated policy rule of table 1.

As emphasized by Fuhrer and Moore (1995), inflation has been very persistent, historically, even during periods in which there were no apparent shifts in the inflation target. Owing to the generalized adjustment cost structure for wages and prices, the FRB/US model also displays a significant amount of inflation persistence, albeit a bit less than is evident in the data. That said, some of the persistence evident in the data is due to the large disinflation that occurred during the first few years of the sample. If the first two years are removed from the sample, the model and data autocovariances are nearly identical at the first four lags. The model also shows considerable persistence in the output gap. Sluggish adjustment of demand components, combined with persistence in the real interest rate driven by the propagation of movements in inflation, drive this result. In this case, autocorrelations from the model and from the data correspond closely.

Now let us consider the impulse response from a disturbance to the estimated federal funds rate. Figure 4 shows the response of the funds rate, inflation, and the output gap. Also shown is the response from a VAR model estimated over the period from

Figure 3. Inflation and Output Persistence (Estimated Rule)

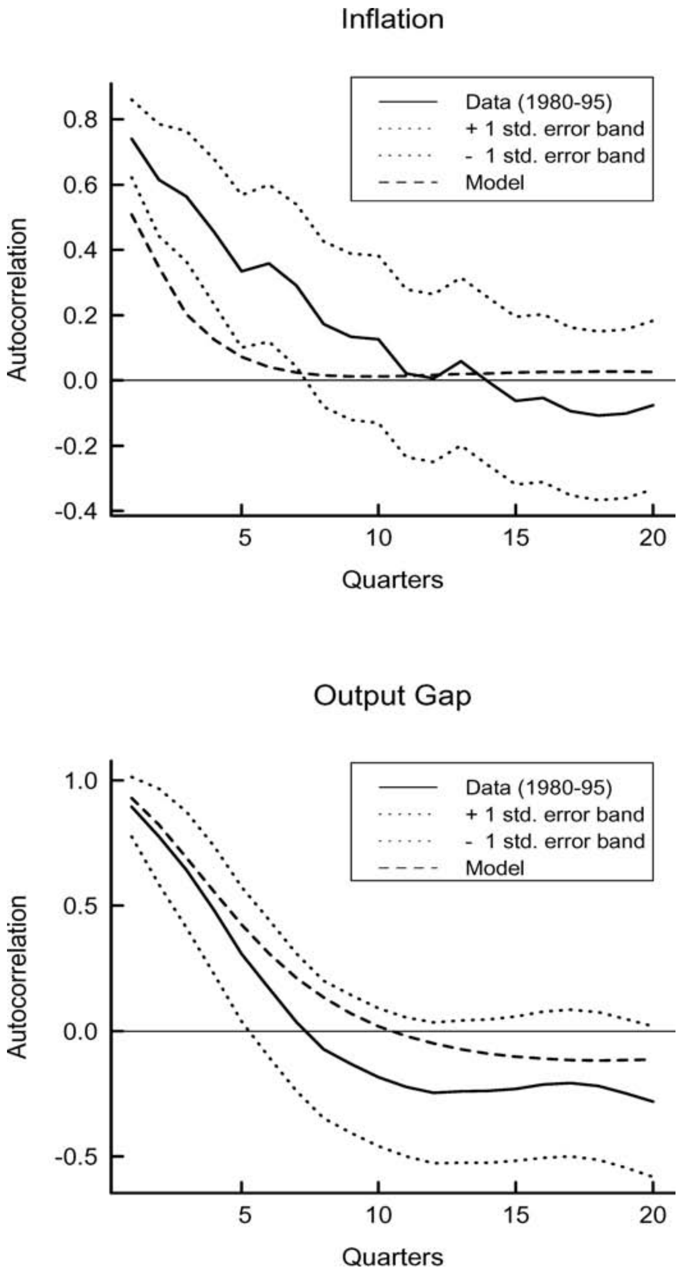
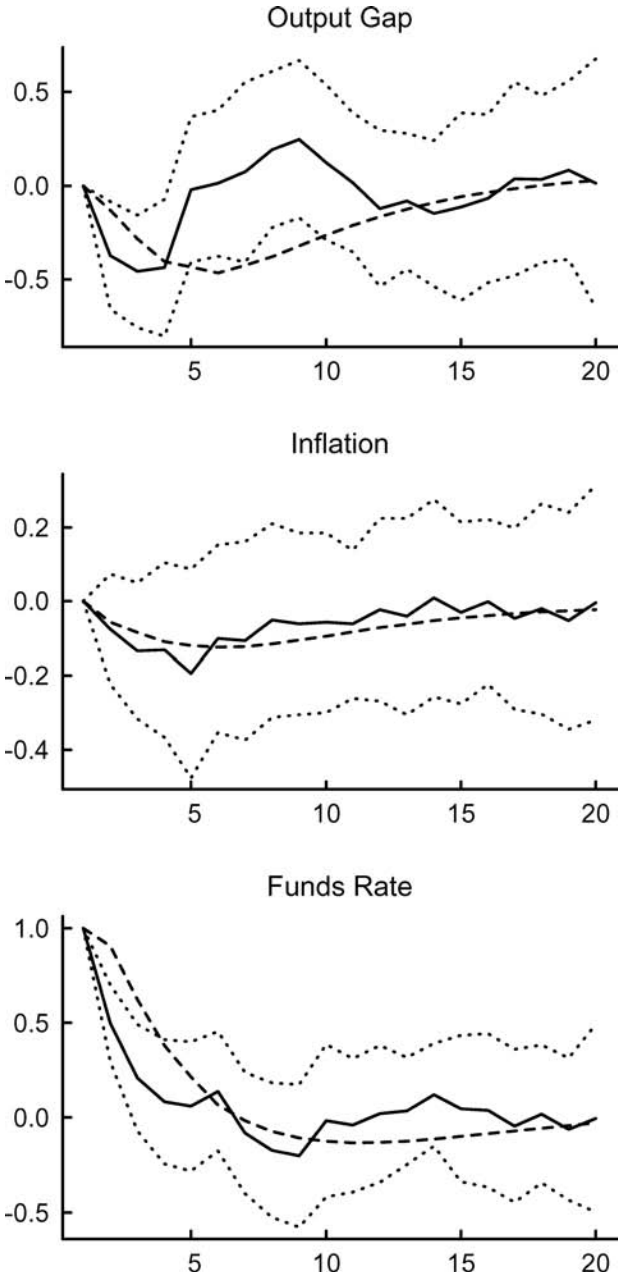


Figure 4. Impulse Response to Funds Rate Shock (100 Basis Points)



1981:Q1 to 1999:Q1, together with one-standard-error bands. The figure shows that the magnitude and the general pattern of output and inflation in FRB/US are close to those of the data.

In addition to the above, we also assessed the model's acceptability by estimating a standard IS-curve equation using model moments, and comparing the model-generated estimates with those from the historical data. The estimates for the model—which can be found in the working paper version of this article—and those in the data were very similar.

In sum, the model fits the data well, both in terms of the individual equations and in terms of its system properties. Furthermore, the model's explicit disentanglement of intrinsic sources of dynamic propagation from expectational sources makes it well suited for the policy analysis experiments to which we shall turn shortly. However, before doing that, we need to discuss the numerical techniques employed to study this issue.

4. Numerical Methods

In all cases studied in this paper, we use a linearized version of FRB/US. Thus, the only source of nonlinearity is the target bands. Setting aside the target bands, the model can be written compactly in companion form and solved employing the algorithm of Anderson and Moore (1985). But while the model itself may be linear, the preceding discussion makes clear that the expectations mechanism for future targets is fundamentally nonlinear. Even in the presence of this nonlinearity, however, there is a way in which we can exploit linear on-line algorithms for solving models.

Given some initial π^*_{t-1}, a vector $E_{t-1}(\pi^*_{t+i}|\pi^*_{t-1}, \sigma, \bar{\pi}^*)$ is computed outside of the model. Using a discrete approximation of the truncated normal distribution, this is possible because $E_{t-1}\pi^*_{t+j}$ is independent of the state variables of the system. Then this nonlinear path is approximated to arbitrary precision with a simple ARMA model, "reverse engineering" the shocks necessary to replicate the nonlinear $E_{t-1}\pi^*_{t+j}$ at each date. The form of the equation stays the same at each iteration of the algorithm; however, the historical shocks to the moving-average errors are changed depending on the initial value of $E_{t-1}(\pi^*_t|\sigma, \bar{\pi}^*)$. An ARMA(1,25) model was chosen, which means that specific values of the shocks can be chosen such that the linear ARMA model represents exactly the nonlinearity up to $j = 25$ and is approximately correct thereafter. In the state-space representation, each additional moving-average term adds an additional equation to the model, so there are trade-offs at work between speed and accuracy.

Some experimentation showed the ARMA(1,25) approximation to be a very good one. The state matrix is augmented with variables for the target and its artificial ARMA determinants by adding a block of dimension 25. The "random shocks" to the target are then selected in such a way that they just so happen to give a nonlinear expected future path for the target. This works because once the form of the recursive system is determined, any sequence of shocks can be supplied without having to bear the computational cost of resolving the model. Since the inherited target rate of inflation is known, the precise sequence of shocks consistent with the correct expected future path for the target can be fed in. The shocks necessary to generate the nonlinear forecast of π^*_{t+i} can be computed ahead of time, indexed against the initial π^*_{t-1} and stored in a grid, which also saves some computing time.

In short, we trick the linear algorithm to give nonlinear forecasts with nonrandom shocks of a particular sequence. By doing this, we can compute what is fundamentally a nonlinear process using linear methods with savings in computational costs that are very large.

5. Results

Our results come from stochastic simulations of the FRB/US model. Each experiment comprises 500 simulations of 200 periods each. After discarding the first 20 observations, we are left with 500 replications times 180 periods, or 90,000 observations per experiment. In most instances, we take the standard deviation of innovations to the target to be 0.25 percent. This is the standard deviation of innovations to the Federal Reserve Bank of Philadelphia's survey of expectations of inflation of ten years ahead; expectations of inflation this far into the future can be reasonably taken to be solely a monetary phenomenon and thus a measure of private agents' expectations of the target rate of inflation. This standard deviation is also close to the standard deviation of changes in the implied target rate of inflation shown in figure 1, for the period since Alan Greenspan assumed the chairmanship of the Federal Reserve in 1987.[20] The width of the bands is ± 1 percentage point, except as noted.

For most of these simulations, monetary policy is governed by equation (2), without error. Thus, at the beginning of each period, agents can infer π^*_{t-1} from last period's federal funds rate setting. Agents then form an expectation of the future path of the target using equations (4) and (5), or (4) and (6), as applicable.

5.1 Model Properties with Target Bands

Figure 5 shows the mapping of inflation against the target rate of inflation from our stochastic simulations. (Ignore the dotted lines for the moment.) Two cases are shown. The dashed line is the mapping of inflation against the target when the target follows a pure random walk. This mapping, which we designate $g_{rw}(\pi^*)$, is diagonal: the relationship, on average, between inflation and its target is one-for-one when the target follows a pure random walk.

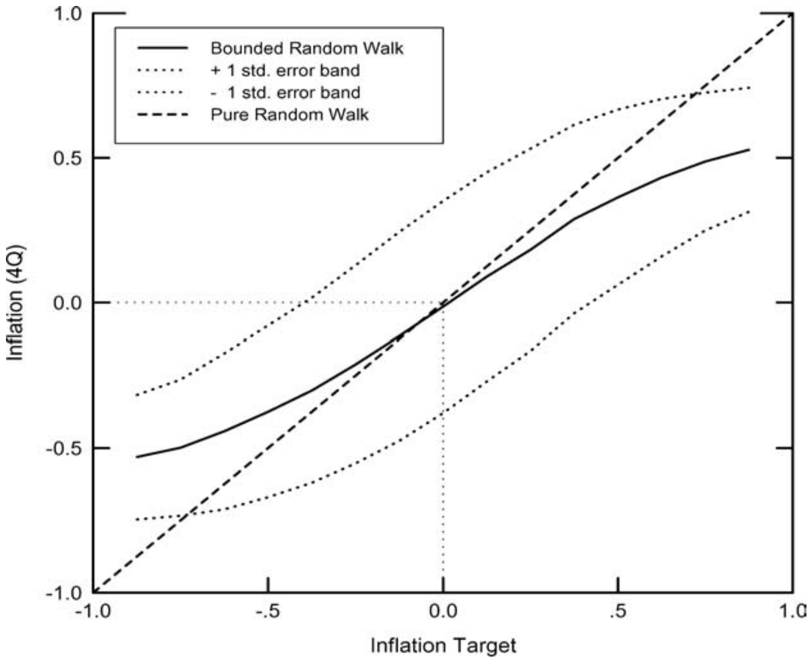
Now consider the solid line. Notice that it is roughly s-shaped. It is, moreover, flatter than g_{rw}, meaning that the range for actual average inflation is less than the range for target inflation. Let us designate this mapping $g(\pi^*) = E_{t-1}\pi(\pi^*|\bar{\pi}^*, \sigma)$, where the right-hand side of the equality notes that this is the expected value of the mapping of inflation on target inflation, conditional on the location of the upper (and lower) bound, and on the size of innovations to the target.[21]

Notice as well that while the bands are between $+1$ and -1 percentage point, the target never actually reaches the edge of the band. For this to happen, one would have to draw exactly the right shock to reach the edge of the band; and the probability of any one particular

[20] It is considerably smaller than innovations in the implicit target rate of inflation for the whole period, even if one omits the discrete shift in the early 1980s from the data. Thus, the magnitude of innovations used here appears to be a reasonable one.

[21] Figure 5 and all subsequent figures are constructed by sorting and ordering observations of π^* from $\underline{\pi}^*$ to $\bar{\pi}^*$, gathering the corresponding observations of π, y, rr, and so forth. The matrix of sorted observations is then grouped into cells of identical widths and averaged across the values of each cell. It is these averages for the cells that are shown in the graphs.

Figure 5. Inflation versus Inflation Target (Shocks to the Target Only)



value is vanishingly small.[22] Comparing this line with the mapping for our unbounded process shows the influence of the credible target band: as π^* gets up close to $\bar{\pi}^*$ (down close to $\underline{\pi}^*$), inflation itself falls below (rises above) the current π^*, on average. The extent to which this occurs is a function of the curvature of expected future target values. In the present case, at the upper end of the curve, where the target rate of inflation is nearing the upper bound, the four-quarter inflation rate averages about 0.55 percent, or more than four-tenths below the target inflation rate. By contrast, when π^* is close to the midpoint, $g(\pi^*)$ is very close to the linear mapping of the pure random-walk case. This outcome illustrates that the establishment of target bands for inflation gives rise to what the exchange-rate

[22]This is a manifestation of our using reflecting barriers. Absorbing barriers would reach the boundary with some probability mass.

target-band literature calls the "honeymoon effect": the promise of fidelity in constraining drift in the target rate of inflation variability is rewarded by restraint in the range of the average inflation rate.[23] As we describe in detail below, this operates through expectations of future target inflation rates impinging on current price- and wage-setting decisions.

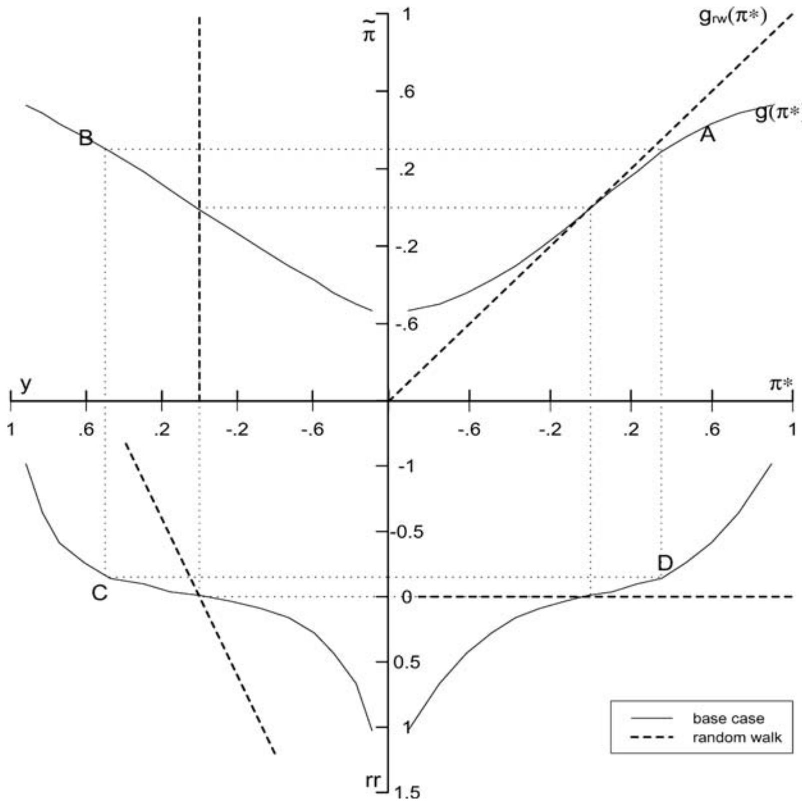
The two dotted lines on figure 5 are the one-standard-error bands for inflation in an economy where there are only shocks to the target rate of inflation. The widths of these bands are not particularly important per se, since the real world is subject to a much wider variety of shocks. What is interesting is the curvature of the confidence bands and their narrowing as the boundaries for the inflation target are approached. What this narrowing indicates is the smaller range of probabilities for future target rates of inflation when the current target is at the edge of the band. Recall that if the inherited rate of inflation were to reach the edge of the band, fully one-half of the distribution of target rates one step ahead would be truncated, reducing the range of future target rates of inflation.

We have established that credible inflation target bands can constrain the range of inflation outcomes, relative to a pure random walk. We now examine some general equilibrium aspects of policy design with credible inflation target bands. To do this, we need to consider a wider range of variables, which we can do with the aid of figure 6.

Before explaining the economics behind the lines in figure 6, let us first just describe what the four quadrants represent. The upper-right quadrant of this four-quadrant diagram shows $g(\pi^*|\bar{\pi}^* = 1)$ and so merely repeats figure 5—except without the error bands. Moving to the upper-left quadrant, we have the mapping of inflation on the output gap. This is *not* the slope of a Phillips curve as such; rather, it is the (mean of the) stochastic relationship between the target inflation rate and the actual inflation rate. The lower-left quadrant shows the mapping of output and the real federal funds rate, both measured in deviations from steady-state levels. Finally, the lower-right quadrant completes our macroeconomic tour with the mapping of the real federal funds rate against the target rate

[23] See, e.g., Krugman (1991).

Figure 6. Summary of Macroeconomic Outcomes (Random Walk versus Inflation Target Bands)



of inflation. This four-quadrant graph portrayal allows us to trace the average levels of four variables at once, as illustrated by the two cases marked by the dotted lines.

Now let us walk through the economics of figure 6. Our base case is shown as the thin solid line, with the case of the pure random walk shown by the dashed line. We begin with point A on the base-case mapping $g(\pi^*)$ in the upper-right quadrant. At this point, $E_{t-1}(\pi_t|\pi_t^*) < \pi_t^*$ because private agents know that the target is more likely to fall than rise in the future. Because firms find it costly to adjust prices and wages, firms must plan ahead to minimize costs, and so this expectation influences their price- and wage-setting behavior *today*, and thereby affects realized inflation today.

Moving along the dotted line to point B in the upper-left quadrant, we see that point A corresponds with an output gap that is positive, on average. We see that the relationship between the average level of output and inflation is positively sloped and linear in the base case, while in the random-walk case there is no output gain to be had from allowing drift in the target. The random-walk case is simply an outcome of the superneutrality of the model: there is no trade-off between output and inflation and thus no slope of the dashed line in the upper-left quadrant. For the base-case solution, the "bias" in inflation expectations relative to the current target rate of inflation means that output can be positive because inflation is expected to fall in the future.[24] To see why this is so, we need to move to the lower-left quadrant.

In the lower-left quadrant, we observe a negative relationship between the output gap and the average level of the real interest rate. Notice that at point C, the real federal funds rate is slightly *negative* even though output is substantially positive. This is feasible because the "bias" in expected inflation—which carries a large weight of 3 in the policy rule—offsets the positive output gap. To put the same idea a different way, the lower expected future inflation rate at point A means that there can be a lower real interest rate at the corresponding point C, which supports higher output at point B.

Note that the curved line for the base-case model implies that the quasi-steady-state interest elasticity changes nonlinearly with the target rate of inflation. The shape of the curve comes from

[24]It is also useful to think of this from the monetary authority's point of view. The authority is attempting to move inflation to the current-period target shown at point A. But because the expected future target is lower than the current target, current inflation is lower than the current target, on average. By contrast, in the random-walk case, inflation, on average, will be at the target value. This means that policy will be easier at target rates of inflation like point A with bands than it would be when the target follows a random walk. This we see in point C in the lower-left quadrant. The easier policy, in turn, implies an average positive output gap, as shown by point B in the upper-left quadrant.

the cumulative normal distribution. In the random-walk case, it is constant.[25]

Finally, moving to point D in the lower-right quadrant, we are reminded that the real interest rate is generally negatively related to the target rate of inflation. In the pure random-walk case, the horizontal dashed line shows that there is no relationship, on average, between the target rate of inflation and the real interest rate. At point D, the real interest rate is lower than it would be if agents did not believe the target was bounded. The expectation of a lower target rate of inflation in the future allows the current real interest rate to be lower than it otherwise would be, thereby supporting higher output than usual.

In sum, we see that the implications for the monetary authority of credible target bands for inflation are (i) a narrower range of inflation for a given range of the inflation target; (ii) a positive range of output, meaning that there exists a trade-off between output and inflation (although it cannot be said that this is a long-run trade-off); and (iii) a range for real interest rates.

5.2 Quantitative Performance

The choice of target band limits of ± 1 percentage point was an arbitrary one. To explore the implications of alternative assumptions, table 2 shows the effect on aggregate (unconditional) volatility of alternative choices. The statistics are based on stochastic simulations using the full set of stochastic shocks and pooling over all simulated observations. The first column in the body of the table corresponds to a credible fixed target rate of inflation, the usual assumption undertaken in assessments of policy rules. The last column covers the pure random-walk case. In that case, the values of many simulated variables are unbounded and are shown as “n/a.”[26]

[25] We show the interest elasticity of aggregate demand in the random-walk case to be the -0.33 value computed in table 1.

[26] In this case the range is for consumer price inflation as measured by the four-quarter growth rate in the chain-weighted PCE price index. All the countries that have announced specific targets for inflation have named a twelve-month rate of some consumer or retail price index as the target variable. The FRB/US model does not have a CPI and is a quarterly model. Thus, we use the growth rate of the four-quarter PCE price index here.

Table 2. Simulated Standard Deviations of Target-Band Regimes

Column No. → Endogenous Variable	Bound on Inflation Target				
	(1) $\pi^* = 0$	**(2)** $\pi^* \in [\pm 0.5]$	**(3)** $\pi^* \in [\pm 1.0]$	**(4)** $\pi^* \in [\pm 1.5]$	**(5)** $\pi^* \in [\pm\infty]$
R	2.76	2.87	3.01	3.11	n/a
y	2.70	2.74	2.90	2.98	3.10
$\tilde{\pi}$	0.88	0.93	1.04	1.21	n/a

Notes: See the notes to table 1 for variable mnemonics. The column heading $z \in [\pm x]$ indicates that z is bounded within values of $-x$ and $+x$, inclusively. Numbers in the rows of the body of the table are standard deviations computed from pooling 500 draws of 180 periods each, after discarding twenty observations per draw to account for initial conditions. In all cases, fifty-one stochastic shocks are drawn using the variance-covariance matrix of the period from 1981:Q1 to 1995:Q4.

The most remarkable observation from table 2 is how unremarkable the differences are: tighter target-band limits improve performance of the economy measured in terms of the unconditional standard deviation of output, inflation, and the funds rate, but not by a great deal. Furthermore, the gains get smaller as one moves from right to left in the table.

At the outset of this paper, we noted that among the devices through which inflation-targeting countries attempt to commit to constraining their discretion are *ranges for inflation itself* (as opposed to bands for target inflation).[27] In table 3 we examine some aspects of the efficacy of ranges for inflation as a device for containing discretion, or policy drift, by looking at the likelihood of inflation rate departing from selected ranges. These ranges are shown in the far left column of the table. Observe that they refer to *ranges* for

[27] It is interesting in this regard to note the motivation for ranges for inflation as given by John Crow, then Governor of the Bank of Canada (1991, 11): "The purpose of setting out formal targets is to provide a clear indication of the downward path for inflation over the medium term so that firms and individuals can take this into account in their economic decision-making. . . . [If people] base their economic decisions on this declining path for inflation, the objectives can be readily achieved and will contribute to lower interest rates. The inflation targets also provide information . . . [that] should provide a better basis than before for judging the performance of monetary policy."

Table 3. Likelihood and Duration of Inflation Target Range Violations

		Bound on Inflation Target				
Column No. → **Inflation Range**		**(1)** $\boldsymbol{\pi^*} = [\mathbf{0}]$	**(2)** $\boldsymbol{\pi^*} \in [\pm\mathbf{0.5}]$	**(3)** $\boldsymbol{\pi^*} \in [\pm\mathbf{1.0}]$	**(4)** $\boldsymbol{\pi^*} \in [\pm\mathbf{1.5}]$	**(5)** $\boldsymbol{\pi^*} \in [\pm\infty]$
$\lvert\tilde{\pi}\rvert > 2.0$	Likelihood	0.03	0.03	0.05	0.10	0.45
	Duration	2.10	2.20	2.50	3.00	n/a
$\lvert\tilde{\pi}\rvert > 1.5$	Likelihood	0.10	0.11	0.15	0.22	0.57
	Duration	2.60	2.60	3.00	3.80	n/a
$\lvert\tilde{\pi}\rvert > 1.0$	Likelihood	0.28	0.28	0.34	0.43	0.70
	Duration	3.20	3.30	3.90	4.90	n/a

Notes: "Likelihood" is the average proportion of quarters in which $\tilde{\pi}$ exceeded the absolute value of the range for inflation, measured relative to the long-run target. "Duration" is the average length of time $\tilde{\pi}$ spends outside of the range, once a violation is recorded. Computations come from averages across the 500 draws for 180 dates in each draw. See also the notes to table 2.

inflation itself. We examine three ranges for inflation—$\tilde{\pi}$, without the asterisk but with a tilda overstrike to indicate that it is the four-quarter rate. To keep the syntax clear, we shall refer to desired variability of inflation itself as *ranges*, and limits on the inflation target as *bands*. An examination of this sort gives an idea of the extent to which commitment to a range of inflation (an observable variable, but arguably not controllable) can stand in for commitment to a band width on target inflation (an unobservable variable, but controllable).

Across the top of the table, we show widths for the band for target inflation. In the far left column of the table are shown three ranges for inflation variability. The body of the table shows, therefore, the bands on inflation targets that would have to be kept to in order to deliver the performance on four-quarter inflation ranges that is shown. Performance in this regard is shown in two dimensions—the likelihood of being outside the inflation range shown at left measured in terms of the proportion of quarters outside the range, and the duration of the average range violation in quarters. As a concrete example, the first row of column 1 of the table shows that with no variability of the inflation target at all, inflation will depart from a range for inflation of ±2 percentage points about 3 percent of time. The 2.10 number immediately below says that these departures tend to last only about six months. The last row of the same column shows that even with a fixed target rate of inflation—and central bank preferences that weight inflation control fairly highly—the authority should not expect to keep inflation within ±1 percentage point of the target much more than about 70 percent of the time.

Reading the table from right to left across any given row shows that as the range of target inflation rates is narrowed, the likelihood and duration of inflation ranges diminishes. This much is hardly surprising. A more interesting observation is that there are sharply diminishing returns, regardless of the width of the inflation range. For example, for an announced inflation range of ±1.5 percentage points (the third row), cutting the target band width from ±1 percentage point (column 3) to .5 percentage point (column 2) reduces the frequency of violations from 0.15 to 0.11. A further cut of the target band width to zero (column 1) reduces the frequency only a trivial amount.

In general, there is a notably high frequency of range violations for all target band widths and for most inflation ranges: to get the likelihood of range violations below 10 percent one must accept very wide inflation ranges of ±2 percentage points. Economically speaking, ranges this wide have little meaning for an economy like the United States. Focusing on ranges for inflation of ±1 percentage point—that is, on the range that most inflation-targeting countries use—we see a substantial likelihood of violations, and departures usually last more than three quarters when they occur.

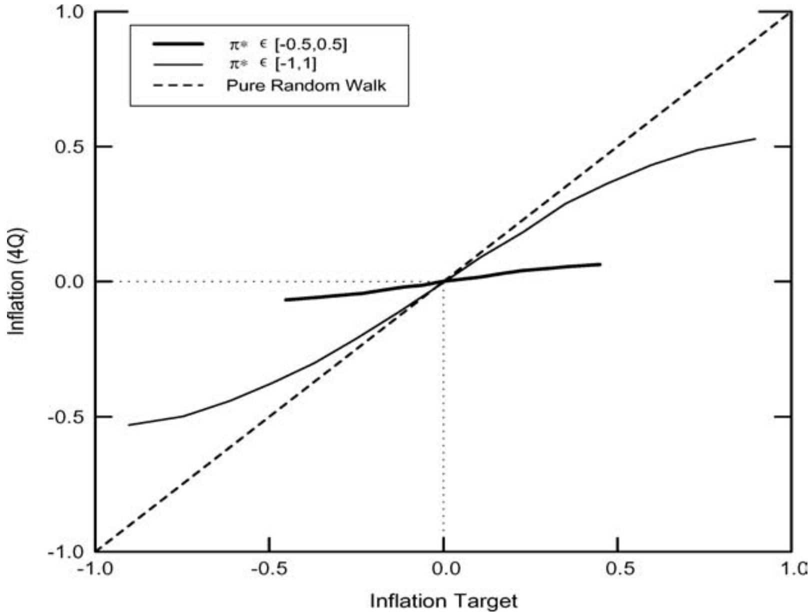
More than anything else, this reflects the fact that a substantial portion of the variability of inflation comes from shocks to the wage-and-price block of the model. There is little that the monetary authority can do to offset such shocks. Blackburn and Christensen (1989) emphasize that monetary policy credibility comes from a combination of the *willingness* of the monetary authority to pursue its inflation objective and the *ability* of the authority to achieve the objective. Table 3 suggests that there are limits to what the Federal Reserve can expect to deliver in terms of outcomes of monetary policy, even if bounds on inflation targets are specified, kept, and believed. On the positive side, however, the table also shows that reductions in the width of the inflation target bands below ±.5 percentage point yield very little in terms of the frequency of range violations, regardless of the range selected.[28]

5.3 Comparative Statics

The unconditional standard deviations shown in table 2 mask some considerable variation in the conditional statistics. Figure 7 replicates figure 5 in showing the mapping from the inflation target to inflation, this time for target-band limits of ±.5 percentage point

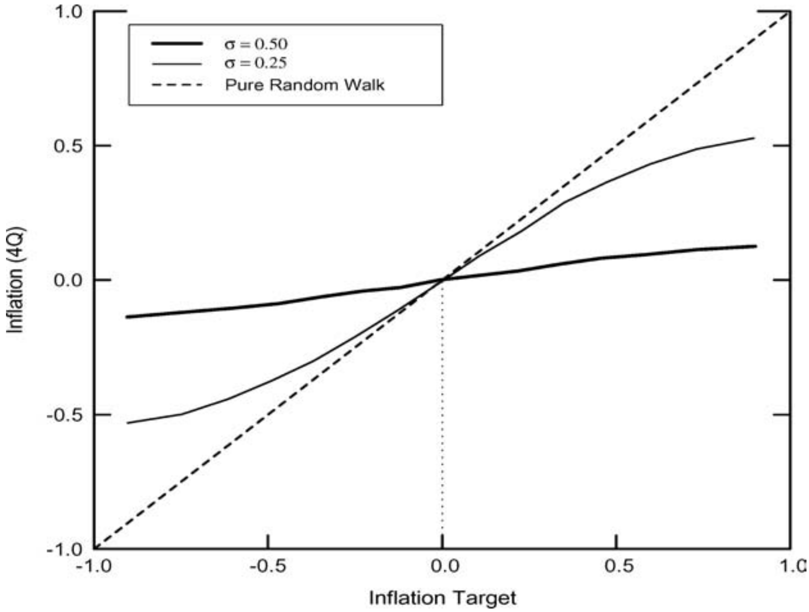
[28]There is also the prospect, alluded to by Chairman Greenspan in the quote at the beginning of this paper, that some of the "exogenous shocks" to the model's wage-price blocks might be expectations scares brought about by low credibility, on average, through history. This would be the case, for example, if policy control were so languid as to induce sunspot equilibria; see, e.g., Clarida, Galí, and Gertler (1998). To the extent that this is true, the variance of these "supply shocks" will be lower in the future than in the past, the honeymoon effect of figure 5 will be larger, and the probability of inflation-range violations will be lower than what is shown in table 3.

Figure 7. Inflation versus Inflation Target (Selected Band Widths)



(the thick line) together with our base-case assumption of ±1 percentage point (the thin line). The differences here are much more pronounced than table 3 might have led one to believe; the honeymoon effect is apparent and substantial at all ranges of $\pi^* \neq 0$, not just beyond the first couple of tenths of a percentage point away from the midpoint of the range. Even in the presence of the unconditional inflation variability of 0.93 (table 2, third row, column 2), this is an economically important difference in performance. By the same token, however, a widening of the target band produces a flattening in $g(\pi^*)$ and a region near the midpoint of the bands in which $g(\pi^*)$ and g_{rw} are observationally equivalent. It follows that fidelity in controlling inflation target drift would not necessarily be rewarded with rising credibility and hence a honeymoon effect. This observation goes some way in explaining why countries that target inflation expend so much time and effort communicating their policy intentions. They hope to reverse the causal order of good targeting

Figure 8. Inflation versus Inflation Target (Selected Standard Deviations of Target Shocks)



performance leading to enhanced reputation and thus higher credibility with public declarations so that the promised improvement is easier to achieve in the first place.[29]

The other parameter that affects the honeymoon effect is the magnitude of innovations to the target rate of inflation. In our base case, the assumed standard deviation of disturbances to π^* is 0.25 percentage point. Figure 8 shows the implications of higher variability in the monetary authority's target, holding constant the

[29]That inflation targeting with bands is an attempt to get a "free lunch" along the lines described in the text is made clear for the case of Canada by Freedman (1995, 27): "These ranges were in fact smaller than were called for in empirical work done at the Bank. There is a trade-off . . . [t]he wider are the bands, the higher is the probability of successful achievement of the targets but the less useful are the targets in changing behavior. In the end, we decided to use somewhat narrower bands to avoid the problem that overly wide bands might leave the impression that the authorities were not serious about bringing inflation down." In fact, violations of the bands have been much less common than the Bank's prior empirical would have suggested was possible.

target band width at ±1 percentage point. As discussed above, a larger σ implies a more substantial nonlinearity in expected future target values for any initial $\pi^* \neq 0$. Not surprisingly, therefore, figure 8 shows $g(\pi^*|\sigma = 0.5)$ to be flatter than in the base case. With the larger σ, there is a honeymoon effect even with relatively wide target bands. This shows that a monetary authority with erratic preferences has considerably more to gain from the establishment of target band widths, if such an authority can secure credibility. It also may help explain why those countries that have adopted inflation targets with bands have done so after abandoning under duress an exchange-rate targeting regime, while those countries that have announced imprecise inflation-targeting objectives do not have a record of such difficulties.[30]

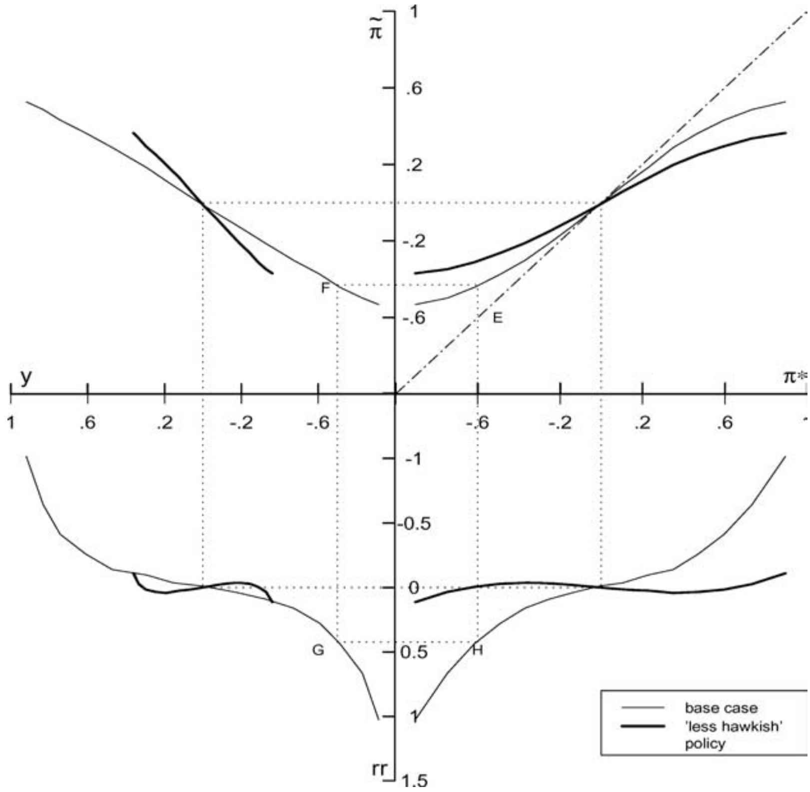
5.4 Alternative Policies

Let us now compare our base-case results with those of a few alternatives, beginning with a less hawkish policy. Recall that for our base case, we assumed that the monetary authority placed three times the importance on inflation stabilization as on output stabilization. We now consider a policy rule derived with the opposite loss function weights: 0.75 on output and 0.25 on inflation. This raises the coefficient on the output gap of 0.9 in our base-case rule to about 1.1 and lowers the coefficient of the twelve-quarter moving average of inflation from 3 to approximately 0.75.

The thin lines in figure 9 are the same lines as in figure 6; they represent our base case. The thick lines are computed in exactly the same way as the thin lines, except using the coefficients of the less hawkish rule. Starting, once again, in the upper-right quadrant, we see that $g_{lh}(\pi^*)$ is flatter than it is in the base case. This means that there is a larger honeymoon effect, or to put the same point a different way, there is less variability in inflation for a given degree of variability in the target than in the base case. In the upper-left quadrant, we see a steeper relationship between the average level

[30]Canada is the only country whose decision to adopt a well-defined inflation-targeting regime was not prompted by a crisis. In most cases, inflation-targeting countries had previously failed to maintain an exchange-rate targeting regime.

Figure 9. Implication of Different Policy Preferences Under Inflation Target Bands



of output and inflation, and, more importantly, a much narrower range of output gaps is implied by that relationship. In the lower-left quadrant, we see that the range of real interest rates associated with these output gaps is not only smaller, but a slight backward bend appears: a decline in the output gap, beginning from zero, arising from a decline in the target that is accompanied by a smaller decline in inflation, results in a (very small) decline in the real interest rate.

The quantitative assessment of this rule is shown in table 4. Each column in the body of the table records aspects of the performance of a particular policy rule: the first column shows the performance of our base-case rule; column 2 shows the performance of the less hawkish rule. (We will ignore column 3 for now.) The upper panel

Table 4. Simulated Standard Deviations of Target-Band Regimes for Alternative Policies

Column Number → **Policy Rule in Use →**	**(1)** **Base Case**	**(2)** **Less Hawkish**	**(3)** **Forward Looking**
y Standard	2.90	2.04	2.75
$\tilde{\pi} - \pi^*$ Deviations	0.99	1.40	1.05
$R - \pi^*$	3.07	2.78	3.79
Preferences	**Normalized Losses**		
Base Case: $\varphi = 0.75$	1.00	0.88	0.96
Less Hawkish: $\varphi = 0.25$	1.81	1.00	1.65
	Range Violations $(\pm\bar{\pi} = 1)$		
Likelihood	0.15	0.29	0.16
Duration	3.00	4.90	3.20
Loss Function: $\sum_{i=1}^{180} \varphi[\tilde{\pi}_{t+i} - \pi^*_{t+i}]^2 + (1-\varphi)y^2_{t+i}$			

of the table shows the standard deviations of this rule for the base-case parameterization of the bounded random walk. As one would expect, the standard deviation of output is lower for the less hawkish rule than for the base-case policy rule, while the standard deviation of inflation is higher.

The middle panel of the table is more interesting. There we record the loss associated with each rule indexed against the preferences that generate the rules. In each case, we have normalized the losses for the two rules so that, for example, the base-case rule in column 1 is assessed a (normalized) loss of unity for base-case preferences. Similarly, in column 2, the less hawkish rule carries a normalized loss of unity for less hawkish preferences. The interesting result is in the other two entries in these two rows of this panel: notice in column 1 that the performance of the base-case rule under less hawkish preferences is poor: there would be an 81 percent deterioration in performance from the perspective of a less hawkish monetary authority from adopting the base-case rule as an operating procedure. Now examine the performance of the less hawkish rule under base-case preferences in the first column. With a value shown there of 0.88, we see that *the base-case policymaker actually prefers the less hawkish rule.*

The result shown is not an error. It arises because the so-called optimal rule for base-case preferences is actually only optimal *conditional on a fixed target rate of inflation* (or a random walk).[31] In the presence of a bound on the random walk, the rule is no longer optimal. This is because the credibility of the target bands does much of the work for the authority; given the bands, adding tough inflation targeting to the policy mix only makes matters worse. To see why this arises, consider point E on the thin line in the upper-right quadrant of figure 9. Observe that the level of output that corresponds with this, point F in the upper-left quadrant, is low. With output low, all else equal, the real rate should be low as well. The reason why the real rate is *not* low is that the monetary authority is trying to move $\tilde{\pi}$ *down* to π^*, the current target rate of inflation. However, private agents know that π^* is likely to be higher in the future. The inflation rate that arises reflects this expectation on the part of price and wage setters who, after all, must consider current and future costs of adjusting prices: it is optimal for them to avoid reducing prices today if they would only have to raise them again in the near future.

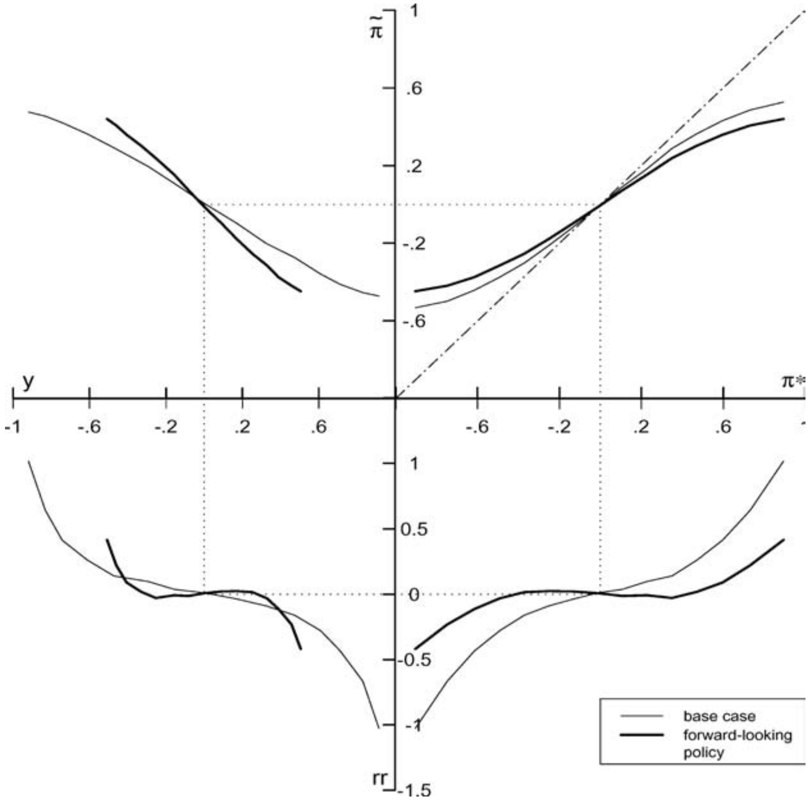
But the monetary authority is working against the very effect it has created by adopting target bands in the first place. It follows that a rule that puts less weight on inflation control, in recognition that private agents are doing some of the controlling of prices through their expectations, will do better on average.

There are other policy recipes that outperform our base-case rule. Figure 10 provides one example. The thin line in figure 10 is, once again, our base case. The thick line represents a rule that is forward looking in inflation. In particular, we have replaced the twelve-quarter moving average of current and past inflation less the current target in equation (2) with a four-quarter moving average of current and future inflation less the *expected* future inflation target:

$$R_t = rr^* + \sum_{i=0}^{3} \pi_{t-i}/4 + 3.0 \left[\sum_{i=0}^{3} \left(\pi_{t+i} - \pi^*_{t+i} \right) \right] + 0.9 y_t. \quad (7)$$

[31] The base-case rule is optimal for the case of a pure random walk, provided that the loss is computed around the (possibly drifting) target rate of inflation, since a fixed target and a pure random walk are identical in expected value terms.

Figure 10. Implication of Forward Looking Policy Under Inflation Target Bands



In our base-case scenario, the monetary authority is conducting policy myopically, carrying out short-term target-seeking actions without regard to how the longer-term process of determining the future of the target will play itself out. With the forward-looking rule, the central bank takes into consideration expected future target changes, even if it is not solving an optimization problem for the future target simultaneously with the determination of the coefficients of the rule.

The results in this case are qualitatively similar to those in figure 6. A forward-looking monetary authority recognizes that private agents know that the target rate of inflation will regress toward the midpoint of the bands over time. By acknowledging this fact in making policy decisions, the monetary authority can improve average policy outcomes in terms of both output and inflation. The middle panel of table 4 shows us that based on the loss calculation shown, the base-case monetary authority would once again prefer the forward-looking rule to the base-case rule, if only by a slight amount. It would be easy to make too much of this comparison, however, since the real federal funds rate variability is significantly higher for the forward-looking rule than for the base-case rule.

We leave this section of the paper, and this topic, with two observations. First, under the assumptions of this section, it is possible to improve on the economic performance of the simple monetary policy rules that depend, linearly and axiomatically, only on a small set of past values. If monetary policymakers' targets do shift over time but are bounded in some way, and if agents believe in these bounds, then private agents' expectations will be biased, ex post, in a way that is completely consistent with the economic environment. An optimizing policy authority that chooses to ignore such biases will forgo improvements in average policy outcomes that can be accrued by encompassing a wide range of indicators of expected future inflation. Similarly, since expectations of target movements on the part of private agents are doing part of the work of the authority in directing price-setting behavior toward long-term monetary policy goals, a Pareto-improving response of the authority is to substitute away from inflation stabilization and toward output stabilization. Second, our analysis offers a rationale for the passivity in monetary policy operations that many observers have noted appears to be a characteristic of policy in the United States.[32] To see this, examine the thick lines associated with the forward-looking policy rule in the two right-hand-side quadrants of figure 10. The honeymoon effect implies that both inflation and the real interest rate are much flatter than they would be under the random-walk case. Because expectations are being anchored by the credible target band, there is less impetus to adjust the nominal interest rate as the target inflation rate moves over time. Essentially, the public is doing part of the Federal Reserve's work for it. We hasten to add, however, that it would be easy to take this argument too far: the lines in our figures represent

[32]See, in particular, Huizinga and Eijffinger (1999), Rudebusch (1999), and Woodford (1999).

averages across hundreds of business cycles. Within those cycles, policy is not "passive" at all. Still, this observation, combined with the results portrayed in figure 9 for the less hawkish rule, does provide some insights on these issues.

6. Concluding Remarks

This paper has considered the implications of uncertain policy targets for the conduct of monetary policy. In particular, we have modeled target variability as either a random walk or a bounded random walk, and examined the implications of the bounds for policy and economic outcomes. Uncertain policy targets were argued to be a manifestation of either discretionary policy or the unwillingness of monetary authorities to respond to disturbances in a timely fashion.

Conditional on a given policy rule, we found that credible constraints on the variability of the target rate of inflation can reap benefits in reduced inflation variability, without increasing output variability, in the same channels as Chairman Greenspan outlined at the outset of this article. However, the improvements are diminishing as band width gets narrower and narrower. All else equal, this provides modest support for point targets for inflation as opposed to Australia-style ranges.

More important, consistent with popular wisdom, we found that a central bank that enjoys credibility in the range of target drift can exploit that credibility by substituting, at the margin, away from inflation control and toward output stabilization. This arises because the expectation that the central bank is likely to contain drift in the target creates a nonlinearity in agents' expectations. This pins down expectations of future inflation on the part of firms and workers, and thereby constrains their inclination to respond to shocks by touching off a wage-price spiral. It is this pinning down of future inflation that allows the monetary authority to be less aggressive in its inflation-control policies than would be the case with either a random-walk target or a fixed target. Taken together, the results here make a case for favoring time-invariant point targets for inflation, as opposed to target ranges, or comfort zones.[33]

[33] See Mishkin (2008) for a spirited and multifaceted argument in favor of point objectives, in part along the lines of this paper.

This finding is reminiscent of Orphanides and Williams (2005), who find that if the central banks can alleviate the need of private agents to learn the target rate of inflation, the resulting anchoring of inflation allows an easier policy regime than would be the case.[34]

The question remains as to how a central bank might establish credible constraints on inflation targets. We noted in our discussion of figure 7 that for some band widths it is hard to demonstrate policy fidelity and hence hard to build reputation through performance. One way to overcome this is to employ public announcements of a fixed inflation target and a range for inflation outcomes like most inflation-targeting countries have done. Table 4 of this paper described how doing so can direct agents' expectations toward the ultimate objective of policy, while still permitting some time variation in policy setting. A central bank that starts out with a reputation for allowing its inflation target to drift can benefit from a "honeymoon effect" wherein the bank reaps the reward of decreases in average inflation variability that are greater than the restriction in the variability of the target.

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[34] As a referee has pointed out, a useful extension of the current paper would be to drop the assumption that agents know the time-varying inflation target with a one-period lag and instead have agents formally learn the target over time. Our conjecture is that this would magnify the findings herein.

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