Three Lessons for Monetary Policy in a Low Inflation Era[1]

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Abstract

The zero lower bound on nominal interest rates constrains the central bank's ability to stimulate the economy during downturns. We use the FRB/US model to quantify the effects of the bound on macroeconomic stabilization and to explore how policy can be designed to minimize these effects. During particularly severe contractions, open-market operations alone may be insufficient to restore equilibrium; some other stimulus is needed. Abstracting from such rare events, if policy follows the Taylor rule and targets a zero inflation rate, there is a significant increase in the variability of output but not inflation. However, a simple modification to the Taylor rule yields a dramatic reduction in the detrimental effects of the zero bound.

Keywords: monetary policy, macroeconometric models, liquidity trap

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1 Introduction

Early in this decade, Lawrence Summers (1991) argued that, because nominal interest rates cannot fall below zero, monetary policy faces a trade-off between achieving zero average inflation and macroeconomic stability, given that the latter occasionally requires negative real interest rates to offset contractionary disturbances.[2] Until the past few years, this issue appeared moot in the United States and most other developed economies. However, with inflation lately falling to very low levels here and abroad, the proposition that policy could be constrained with interest rates stuck at zero for a prolonged period of time no longer seems far-fetched. Indeed, this possibility has become reality in Japan where, as shown in Figure 1, the call money rate has been below 50 basis points for the last 2 years, accompanied by rising unemployment and the emergence of consumer price deflation. Because of these developments, there has been renewed interest in the implications of the zero bound for monetary policy. In this paper, we attempt to quantify the effects of the zero bound on macroeconomic stability for different levels of average inflation, and to illuminate how these effects can be diminished through the design of monetary policy.

While Japan's current troubles are instructive, it is as yet an isolated example and therefore provides few data on the likely effect of the zero bound on macroeconomic

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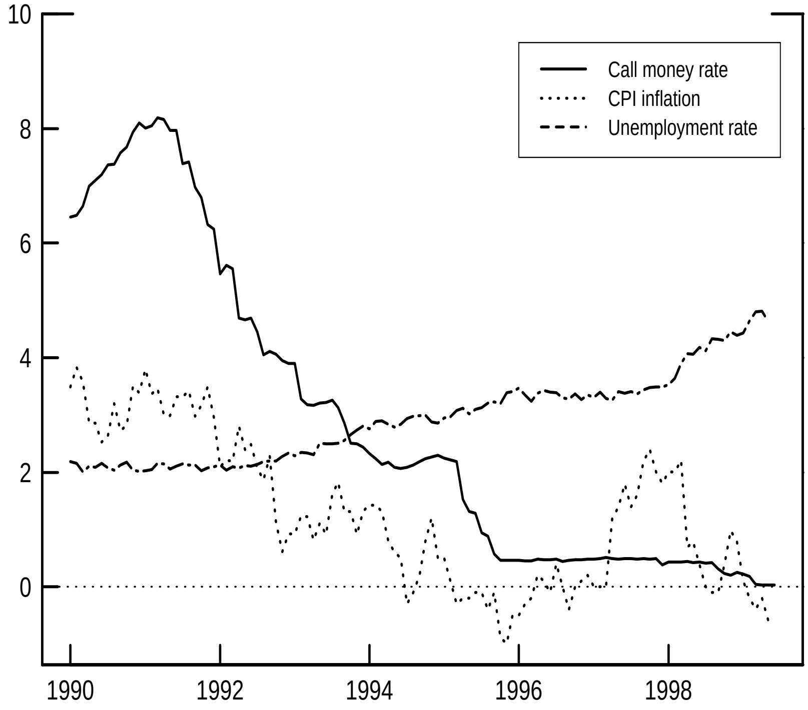
[2] Summers also points to the existence of downward wage rigidity as a reason to target an inflation rate "as high as 2 or 3 percent" (p.627). Bernanke, Laubach, Mishkin and Posen (1999), making the additional point that persistent deflation can lead to liquidity and solvency problems that might exacerbate contractions, propose a target rate of inflation in the vicinity of 1 to 3 percent (p.30). John Taylor argues that an inflation target of zero (but not lower) probably poses no serious stability problems; nevertheless, he proposes a 2 percent inflation target on the grounds that this rate is approximately consistent with zero percent "true" inflation given the upward bias to measured inflation. (Solow and Taylor (1998), pp. 33–34, 45.) However, recent and upcoming methodological improvements to the CPI and other price indices have probably reduced the bias in measured price inflation below the figure cited by Taylor—see Boskin, Dulberger, Gordon, Griliches and Jorgensen (1996) and Council of Economic Advisors (1999), pgs. 93-94—and for the measure of inflation used in this study (the PCE chain-weight price index), the bias is probably under 1 percent.

Figure 1
Japanese Interest Rates, Inflation, and Unemployment



performance in general. As for the experience of the 1930s or even the 1950s, the evolution of financial markets over the past 50 years, as well as other structural changes, limit its relevance for modern economies. Therefore, the approach of most recent studies of this issue has been to use simulations of macroeconometric models to address the question of how macroeconomic stability might change when the non-negativity constraint binds.[3]

Fuhrer and Madigan (1997) provide the first detailed simulation evidence showing that, in a low inflation environment, there is a reduction in the effectiveness of monetary policy in restoring macroeconomic stability following contractionary distur-

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[3] Although the non-negativity constraint has been frequently implemented in earlier model-based studies—see, for example, Taylor (1993), p.225, and Fair and Howrey (1996)—only very recently has its effect been the subject of detailed study.

bances. Using a small-scale rational expectations model of the U.S. economy, in which output and inflation are characterized by a significant degree of inertia, they study how the impulse responses of the system to aggregate demand and supply shocks are altered by changes in the policymakers' target rate of inflation. In the examples they report, the depth and length of recessions worsen modestly as the average rate of inflation is reduced from 2 percent to zero. However, because their analysis is based on a few illustrative shocks, it cannot be easily used to gauge the overall effect of the zero bound on the average variability of output and inflation as the policy target approaches zero.

Orphanides and Wieland (1998), using a model similar to that of Fuhrer and Madigan, employ stochastic simulations—based on random draws from the distribution of the residuals of the model's equations—to estimate the tradeoff between average aggregate variability and the target rate of inflation. They find that the zero bound has a larger effect on output stabilization than on inflation variability; they also quantify the degree to which the frequency and duration of simulated recessions rises in low inflation environments. By their nature, such quantitative results depend on the model's properties, recommending a comparison with results from other models. In particular, the model used by Orphanides and Wieland has two noteworthy features that are both important to the analysis of zero bound effects and which differ substantially from those of many other models. First, the equilibrium real funds rate of their model is estimated to be only 1 percent, well below the value embedded in the model used in our analysis (as well as its historical average over the 1960 to 1998 period, 2-1/2 percent). Second, the asymptotic standard deviations of the output gap and inflation generated by their model under the Taylor rule (ignoring the zero bound) are 1.0 and 0.7 percent, respectively, figures that are much smaller than results obtained from most other statistical models (Levin, Wieland and Williams

(1999) and Rudebusch and Svensson (1999)).

Wolman (1998) considers the role of inflation dynamics in the effects of the zero bound, and finds that the zero bound has little relevance if it is the price level alone that is "sticky," and not—as in the models used by Fuhrer and Moore and Orphanides and Wieland—the rate of inflation. This irrelevance arises because, in models without significant inflation inertia, the monetary authority is able to engineer large short-run changes in the growth of prices, thereby allowing it to sharply reduce real interest rates even when nominal interest rates are already low.[4] On theoretical grounds, one might be tempted to discount the possibility of sticky inflation and thus accept Wolman's finding that the zero bound is of little concern. However, such a step may not be prudent, given the ongoing debate over whether the high degree of persistence displayed by inflation historically is evidence of intrinsic inertia, irrespective of theoretical arguments. For examples of the two sides of this debate, see Fuhrer (1997) and Rotemberg and Woodford (1997).

Wolman also investigates how the design of policy can be improved in light of the zero bound. He finds that, even in the case of sticky inflation, policies directed at stabilizing the price level around a deterministic trend—as opposed to damping fluctuations of inflation around a desired rate—greatly diminish the effects of the zero bound on the variability of output and inflation. As we shall see, price-level targeting represents a special case of a class of policy rules that have the property of diminishing the detrimental effects of the zero bound.

The research described above focuses on the limitations placed by the zero lower

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[4] Using a dynamic stochastic general equilibrium model that is similar to Wolman's, Rotemberg and Woodford (1997) also find that the existence of the zero lower bound has only a small effect on the optimal target rate of inflation. Because Rotemberg and Woodford linearize their model, they do not directly impose the non-linear zero bound constraint on interest rates in their simulations. However, they are able to account for its effect indirectly by placing a high penalty on variability in the interest rate in the policymaker's loss function.

bound on the effectiveness of standard open-market operations. Krugman (1998), studying the current Japanese experience, considers various alternatives to standard open-market operations open to the Japanese government to mitigate its current difficulties; in particular, he proposes ways in which the Bank of Japan might influence expectations so as to restore its ability to alter real borrowing costs. In a similar vein, Lebow (1993) and Clouse, Henderson, Orphanides, Small and Tinsley (1999) discuss options that the Federal Reserve might pursue in lieu of open-market operations to stabilize the economy.

In this paper, we build and expand on this body of work in two ways. First, we use the FRB/US model—a large-scale open-economy rational expectations model of the U.S. economy employed at the Federal Reserve Board as a tool for forecasting and policy analysis—to provide additional quantitative estimates of the effect of the zero bound on macroeconomic stability. As discussed in Levin et al. (1999), the basic dynamic properties of FRB/US differ significantly from both sticky-price models of the type used by Wolman and the sticky-inflation FM and MSR models employed by Fuhrer and Madigan and Orphanides and Wieland, respectively. In particular, the persistence of inflation in FRB/US lies between that of the Taylor model—which uses a staggered wage contract structure that implies little inflation persistence—and that of the FM and MSR models (which share the same basic price specification). In addition, output persistence in FRB/US lies between that of the MSR and FM models. As such, the FRB/US model occupies a potentially informative middle position in the debate over the correct empirical characterization of the economy.

Our second contribution is an exploration of how the effect of the zero bound varies under alternative monetary policies. In particular, we investigate how policy rules might be designed to increase macroeconomic stability in an environment of zero inflation. In this investigation, we consider the effects of various modifications to the standard Taylor rule. We also review the macroeconomic performance of rules that have been found to be efficient in the absence of the zero bound, and how it changes as the non-negativity constraint begins to bind.

It is important to stress that our analysis considers only the effects of the zero bound on nominal interest rates, and not other factors that may affect macroeconomic stabilization in a zero inflation environment. Thus, for example, we do not address the implications of a possible downward rigidity in wages, an important issue discussed by Akerlof, Dickens and Perry (1996), Card and Hyslop (1997), Kahn (1997), and Lebow, Saks and Wilson (1999). Nor do we include in our analysis any benefits from low inflation, such as those associated with a reduction in distortions related to interactions of inflation with the tax system (see Feldstein (1997)). For these reasons, this paper addresses only one of the many issues involved in the determination of an optimal rate of inflation—a topic for which there is a large literature, beginning with Keynes (1923), with more recent contributions from Fisher and Modigliani (1978), Fisher (1981), Driffill, Mizon and Ulph (1990), Orphanides and Solow (1990), Sarel (1996), and Clark (1997), as well as the collection of papers contained in Feldstein, ed (1999).

The structure of the paper is as follows. In the following section we review the underlying mechanism of the zero bound problem. In particular we show, in the context of a simple stylized macromodel, how the non-negativity constraint can render conventional open-market operations ineffective and in certain circumstances give rise to deflationary spirals. From this general overview we turn to the specifics of the approach used to quantify the costs of the zero bound, including a review of the principal features of the FRB/US model as well as several methodological issues. Next we turn to our first set of results, and consider how the steady-state distributions of output, inflation, and interest rates vary as policymakers—following the Taylor rule—change the target rate of inflation. From there we turn to a discussion of how monetary policy could be designed in light of the zero bound, and demonstrate that simple modifications of the Taylor rule can mitigate the costs associated with the zero bound in a low inflation environment. Finally, we conclude with a summary of our results.

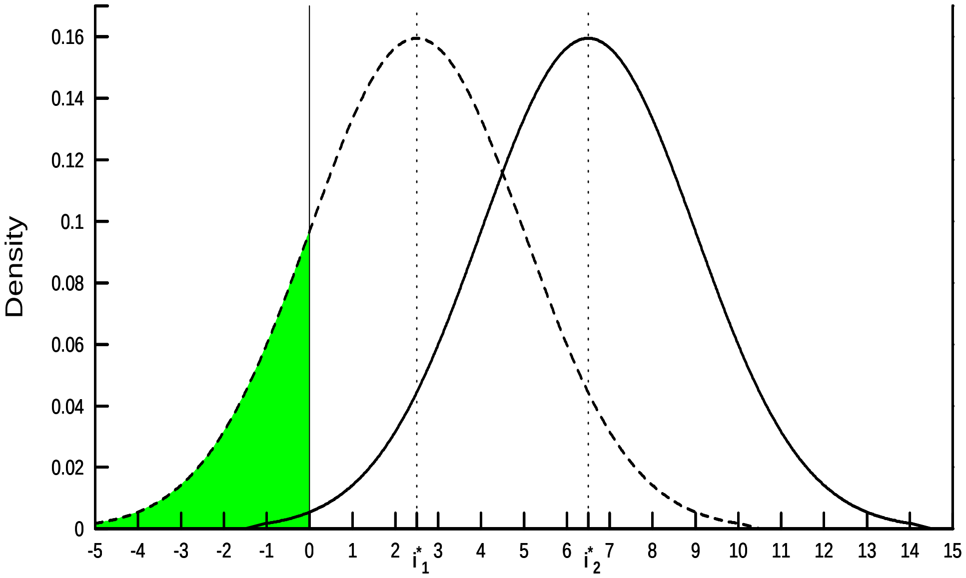
2 The Mechanism of the Zero Bound Problem

Central to all the recent studies noted in the introduction is the idea that the zero lower bound may, under some circumstances, interfere with the ability of the monetary authority to stabilize the economy through adjustments to the level of real interest rates. To illustrate this concern, consider the following stylized model:

$$\begin{aligned} y_t &= \delta y_{t-1} + \theta(r_{t-1} - r^*) + \varepsilon_t \\ \pi_t &= \pi_{t-1} + \phi y_{t-1} + \nu_t \\ r_t &= i_t - \pi_t \\ i_t &= \max[0, r^* + \pi_t + \alpha(\pi_t - \pi^*) + \beta y_t]\ . \end{aligned} \tag{1}$$

In this system, y, the output gap—the percent difference between real GDP and its trend level—depends on the lagged output gap, the lagged level of the real short-term rate of interest r relative to its equilibrium value r^*, and transitory shocks ε. The inflation process is modeled using a backward-looking accelerationist Phillips curve that is also subject to transitory disturbances ν, while the real interest rate is equal to the difference between the nominal short-term rate i and current inflation. To close the model, i is set using a generalized version of the Taylor rule, implying that

Figure 2
Inherent Variability in the Stance of Monetary Policy:
Illustrative Distributions of the Federal Funds Rate



policymakers respond in a systematic fashion to deviations in output from trend and inflation from its target level π^*. The max function captures the zero lower bound on nominal interest rates.

Abstracting from the zero bound for the moment, in an economy described by such a model, random shocks to aggregate demand and prices, in conjunction with the coefficients of the system, yield stable probability distributions for all macroeconomic variables, including interest rates. This property implies that the normal conduct of monetary policy involves a predictable degree of variation in the level of the federal funds rate over time. This variation is illustrated by Figure 2, which shows two hypothetical distributions for the short-term nominal interest rate, both of which are drawn ignoring the non-negativity constraint. The means of both distributions are equal to the equilibrium nominal funds rate (denoted by i_1^* and i_2^*); this rate is the sum of two components—one outside the control of policymakers (r^*), and one chosen by the central bank (π^*). In the examples shown, the two distributions differ only because policymakers target a lower average level of inflation in the case of the dashed curve.

Under the high inflation target (the solid curve), essentially the entire range of nominal interest rate outcomes produced by the policy rule is to the right of zero; only in very rare instances—shown by the shaded region under the curve—would the non-negativity constraint prevent policymakers from responding to changes in output and inflation by the full amount dictated by the reaction function. By contrast, under a low inflation regime—or alternatively, in economies with a low equilibrium real interest rate—the zero bound would routinely impinge on normal monetary operations. As illustrated by the shaded region under the dashed curve, in this case a large portion of the mass of the unconstrained interest rate distribution lies to the left of zero, indicating that in practice nominal interest rates would be at or close to zero a large fraction of the time.

It is at such times that the ability of monetary policy to stabilize the economy through open-market operations is sharply diminished. If the nominal interest rate is at zero, it is no longer possible to reduce the real interest rate further to counteract deflationary pressures. In fact, under extreme conditions a self-perpetuating deflationary cycle can develop, in which a decrease in inflation endogenously raises the level of the real rate, causing demand to weaken and push inflation down more, thereby raising the real interest rate even further. With the monetary authority powerless to stop this downward spiral through conventional open-market operations, the deflationary episode ends only if the economy experiences some other stimulus to spending.

The phase diagram for the simple model shown in Figure 3 helps illustrate this process. For this figure we have assumed that π^* equals 2 percent and that r^* equals

2-1/2 percent.[5] The model has two states, inflation and output. In this model, the inflation rate increases (decreases) when the output gap is positive (negative), and is unchanged when $y = 0$, as indicated by the $\Delta\pi = 0$ line. The change in the output gap depends on the level of the gap and the difference between the real interest rate and its long-run equilibrium, r^*. For positive nominal interest rates, the $\Delta y = 0$ curve slopes downward and intercepts the $y = 0$ axis at π^*. Once the zero bound constrains policy—as indicated by the dashed line—the $\Delta y = 0$ curve bends backwards, because in this region the policy rule is replaced by the condition $r = -\pi$. There are two steady states, both occurring at an output gap of zero. The first, labeled E_1, is locally stable with inflation equaling π^*, and corresponds to the unique steady state in the absence of a lower bound. The second point, E_2, is saddle-path stable, with steady-state inflation equaling the negative of the equilibrium real interest rate, and the nominal interest rate equaling zero.

It is useful to distinguish between three regions in the figure. First, in the area above the dashed line the zero bound is not a constraint on policy and has no effect. In the region between the dashed line and the saddle path leading to the constrained steady state E_2, the effectiveness of monetary policy is diminished by the zero bound but the economy eventually returns to equilibrium on its own. However, if the economy finds itself in the third region—the shaded area to the southwest of the saddle path leading to E_2—the system is unstable with output and inflation continuously falling. Such a region amounts to a *deflationary trap* for monetary policymakers, for in the absence of some positive external shock (such as stimulative fiscal policy), conventional open market operations are unable to restore equilibrium.

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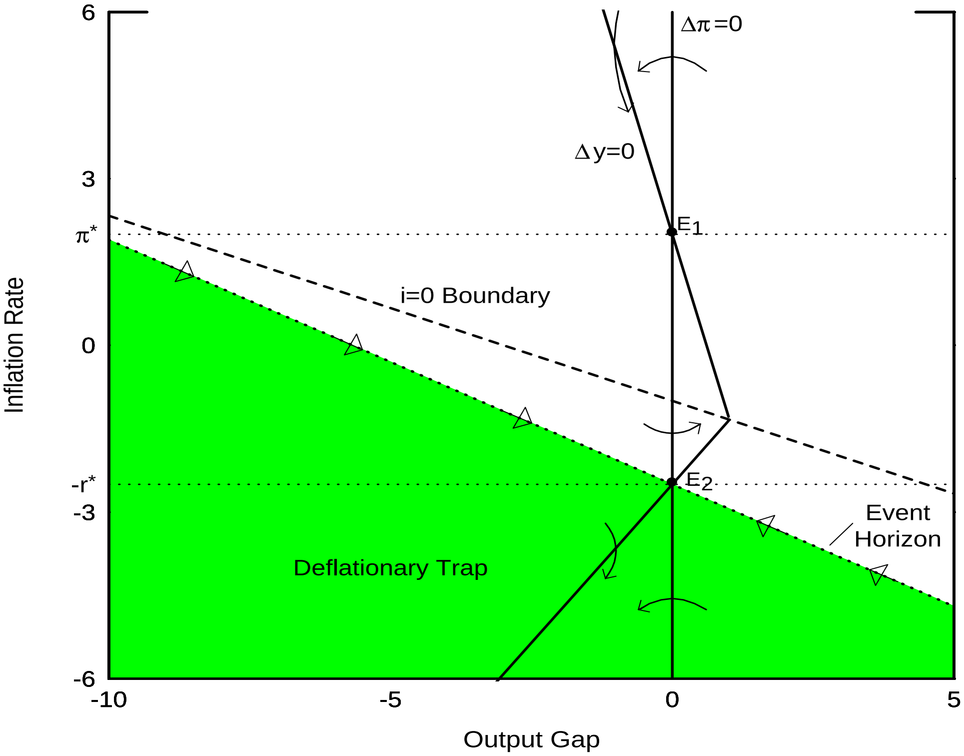
[5] In addition, $\delta = .6$, $\theta = -.35$, and $\phi = .25$—roughly the values obtained from least-squares estimation using annual data over the period 1960 to 1998. In addition, the parameters of the monetary policy rule are assumed to be identical to the Taylor rule ($\alpha = .5$, $\beta = .5$).

Figure 3
The Mechanism Underlying the Zero Bound Problem:
System Dynamics



This result—that standard open-market operations may be insufficient to restore equilibrium—holds for almost any macroeconomic model in which (1) monetary policymakers influence aggregate spending primarily through actual and anticipated changes in real short-term interest rates, and (2) inflation displays significant inertia. Its implication for monetary policy is a cautionary one: If policymakers pursue a very low inflation target, they increase the risk that under extreme conditions they may not be able to stabilize the economy using conventional means.

Under such circumstances, stabilization may require action on the part of the fiscal authority, such as reductions in tax rates and increases in expenditures. However, even if one were confident on theoretical grounds that any deflationary spiral could be eventually stopped through sufficiently expansionary fiscal action, one might be less sanguine about the practical success of using fiscal policy to stabilize the economy. For example, at times it may be difficult to enact major changes in the budget, particularly in a timely manner; Japan's current experience is perhaps instructive in this regard. More generally, the legislative process is slow relative to central bank deliberations. As a result, in situations where the non-negativity constraints binds, it is unlikely that fiscal policy would ever be so effective a substitute for monetary policy as to undo all the consequences of the zero bound for macroeconomic stability.

Alternatively, the central bank on its own could attempt to stimulate the economy using non-standard procedures, such as massive purchases of long-term securities or foreign exchange. However, the likely effectiveness of such actions is unclear from a theoretical perspective, and they have never been put to a definitive test. Thus, their ability to substitute for conventional open-market operations is open to question.

3 The FRB/US Model

In the absence of direct empirical evidence on macroeconomic performance in a low inflation environment, assessment of the threat posed by the zero bound must rely on simulations of macroeconomic models. For this study, we use FRB/US, a large-scale open-economy model of the United States, that is used at the Federal Reserve Board as a tool for forecasting and policy analysis. This model is well-suited for our purposes, because it satisfies several criteria that, we believe, are needed by any model if it is to provide reliable quantitative estimates of the consequences of the non-negativity constraint—goodness of fit, model-consistent expectations, and a well-specified description of the transmission mechanism.[6]

Goodness of fit

To assess the actual threat posed by the zero bound, a model should provide a reasonably accurate empirical representation of the economy. The questions under consideration are at heart quantitative: How often does the zero constraint bind as the average rate of inflation is reduced? To what degree does the expected frequency, length, and depth of recessions change as the target rate of inflation falls? FRB/US satisfies this criterion because considerable care was taken in estimation to ensure that the model's simulated dynamics for GDP, inflation, interest rates, and other aggregate variables approximately match that of the data over the 1965 to 1997 period.

As discussed in Brayton and Tinsley (1996) and Brayton et al. (1997a), goodness of fit is manifested by FRB/US in several ways: by high R^2s on individual equations; by a relatively close correspondence between the impulse response functions of the model and those of a small-scale VAR model; and by the similarity of the moments generated by the model with those of the historical data. The model's empirical strengths are also illustrated by Figure 4. The solid lines of the figure show the unconditional autocorrelations of the output gap and inflation implied by the model.[7] The dashed lines show the autocorrelations estimated using quarterly data from 1980

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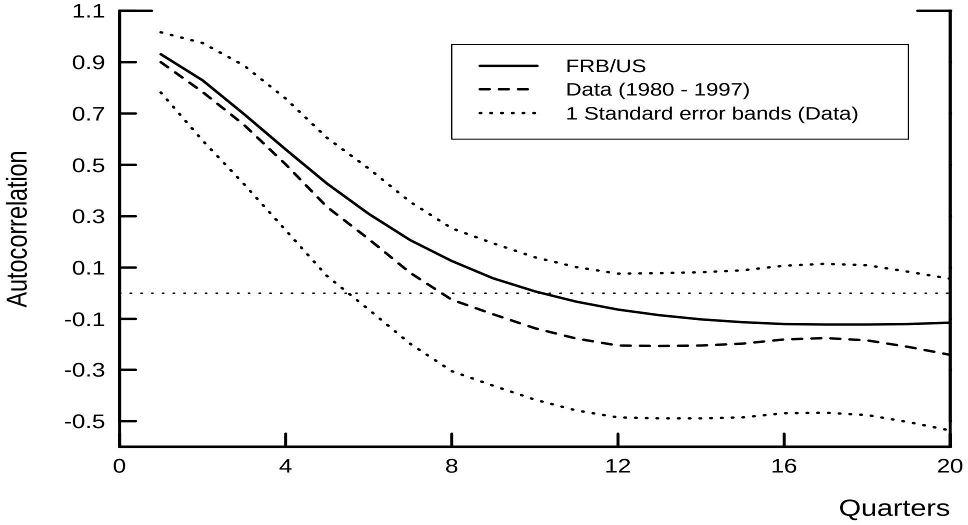
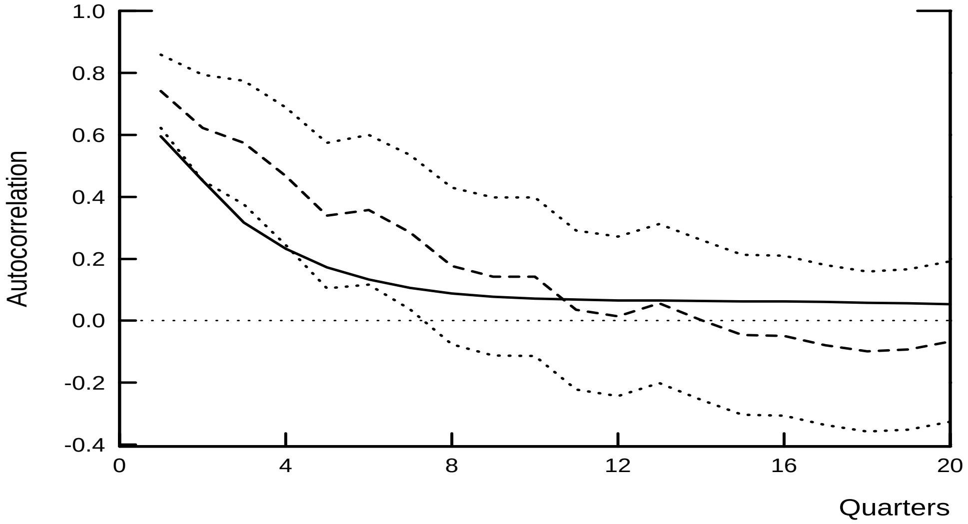
[6] Documentation on FRB/US is available in a number of studies. For example, Brayton and Tinsley (1996) provide an overview of the principles behind the model's design, while Brayton, Levin, Tryon and Williams (1997a) discuss the use of FRB/US and other macroeconometric models at the Federal Reserve Board. Recent papers that use FRB/US to analyze monetary policy issues include Bomfim, Tetlow, von zur Muehlen and Williams (1997), Levin et al. (1999), Williams (1999). An informal essay by Brayton, Mauskopf, Reifschneider, Tinsley and Williams (1997b) reviews the role of expectations in the model; a similarly styled essay by Reifschneider, Tetlow and Williams (1999) provides a overview of the model's simulation properties, including the predicted response of output and inflation to a number of standard macroeconomic disturbances. A complete listing of the model's equations is available from the authors upon request.

[7] To generate the autocorrelations, monetary policy was defined using a formal rule estimated over the period 1980 to 1997, where the funds rate depends on the lagged funds rate, the output gap, and the average growth rate of PCE chain-weight prices over the past four quarters.

Figure 4
Autocorrelations of the Output Gap and Inflation


Output Gap


Inflation

to 1997, while the dotted lines show the one standard error bands for the data-based estimates. As seen in the top panel, the model's predictions for the autocorrelation of output closely track those found in the data. The fit for inflation is not quite so impressive—the model generates somewhat less inertia in the inflation process—but the differences between the predictions of FRB/US and the data are generally small in both an economic and statistical sense.

Model-consistent expectations

Because analysis of the zero bound involves simulating conditions that are quite dissimilar to those experienced during the past 40 years (the period over which most macromodels are estimated), results generated using models with implicit adaptive expectations could be misleading. For example, such models are unlikely to take adequate account of a radical change in the nature of monetary policy that occurs when the non-negativity constraint binds. This change, which implies accompanying alterations to the nature of expectations, is probably better accounted for in models that employ explicit rational expectations—that is, models in which the public's beliefs about the future path of a given variable are equal to that predicted by the model itself, under the assumption that there are no future shocks to the economy. (Alternatively put, the use of model-consistent expectations makes our results less susceptable to the Lucas critique.) Such rational expectations are also better suited to assessing the likely success of policy strategies that hinge on influencing the public's expectations, such as those proposed by Krugman (1998). Thus, for this paper all the expectational variables of FRB/US are assumed to be model-consistent.[8]

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[8] An important corollary of this assumption is that policy is perfectly credible. In particular, in all our model simulations there is no doubt on the part of the public about the monetary authority's objectives and procedures: The public is fully aware that policymakers follow a specified policy rule without fail, except when prevented from doing so by the zero bound.

The monetary transmission mechanism

In analyzing the effects of the zero bound, models that use a simple version of the transmission mechanism may be disadvantaged relative to ones that provide a more detailed treatment of the channels through which policy influences the real economy. To see this, consider a model employing a reduced-form characterization of the link between output (or inflation) and the real interest rate, estimated using current and lagged information on the federal funds rate and inflation. In such a model, there is no role for anticipated policy responses beyond that captured by average historical correlations with past actions. However, in a more fully articulated model that includes a bond market, such expectational effects do matter and interact in important ways with the zero bound. In particular, such expectational channels—which in yet more complicated models include effects operating through a variety of financial markets, including corporate equity, foreign exchange, and bonds of various maturities and risk—provide a means for the monetary authority to influence aggregate resource utilization today even if the funds rate is currently trapped at zero, by adopting policies that alter the public's beliefs about the future.

FRB/US has a relatively detailed description of the monetary policy transmission mechanism. To begin, policymakers are assumed to respond systematically to current macroeconomic conditions, specifically by using a formal rule to determine the federal funds rate. Investors, based on their expectations for the future path of the funds rate, set bond prices to continuously equalize risk-adjusted expected rates of returns on government and private securities of different maturities; similar arbitrage relationships determine equity prices and the foreign exchange value of the dollar. These various asset prices, in turn, influence the spending of utility-maximizing consumers and profit-maximizing firms; they respond gradually to changes in real long-term interest rates and other financial variables, as well as to movements in their expectations for future income, sales, and inflation. Finally, current inflation responds both to past and expected future changes in prices and to current and expected resource utilization, in a manner similar in spirit to that introduced by Buiter and Jewitt (1981) and empirically implemented by Fuhrer and Moore (1995). As already discussed, the result is considerable inertia on the part of the inflation rate in the model.

The FRB/US characterization of the transmission mechanism is in accord with the "conventional" view that monetary policy primarily influences real activity indirectly, through changes in the funds rate that alter bond rates and other asset prices; less emphasis is placed on the "credit channels" view of Bernanke and Gertler (1995) and others. However, the model does include two specific channels for credit-type effects to influence aggregate demand—a cash-flow variable in the equation for investment in producers' durable equipment, and an assumption that a portion of consumer spending is accounted for by liquidity-constrained households (estimated at 10 percent). Moreover, as noted by Romer and Romer (1990), a substantial portion of the movements in loan volumes and non-rate credit terms are correlated with changes in interest rates, money, and output, suggesting that some of these channels are probably captured by FRB/US despite its focus on asset prices.

The role of money is another area where the FRB/US model differs from some macromodels. In FRB/US there is no mechanism for a change in the money supply to influence the economy—other than through its role in standard open-market operations[9]—in contrast with models that postulate a role for money in the macroeconomy via real-balance effects, cash-in-advance constraints, or the inclusion of money holdings in consumers' utility functions. Nor does the model allow for changes in the

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[9] Any change in the federal funds rate is associated with a corresponding change to the reserves of the banking system, and thus the monetary base. The correspondence between changes in money and changes in the funds rate is determined by the joint interaction of the money demand equation and the reserves multiplier.

relative supply of financial assets to affect prices, thereby ruling out the possibility that the central bank could reduce the spread between long and short-term interest rates through massive purchases of bonds: Although term and risk premiums in FRB/US are endogenous, they respond only to changes in current and expected resource utilization. In principle, these various channels may offer policymakers levers to influence aggregate demand even when short-term interest rates fall to zero, and by using a model that ignores them, we may overstate the threat posed by the zero bound. However, the effectiveness of such levers is untested.

For example, the view is often expressed that, even with interest rates stuck at zero, a central bank could always pull the economy out of a deflationary episode through "helicopter drops" of money, which would increase spending through the real-balance effect. If such drops are not accompanied by corresponding acquisitions of bonds—the opposite of conventional open-market operations in which changes in central bank liabilities are matched by changes in assets—then there is the practical problem of how the funds would be distributed to households and firms (absence an accompanying increase in government outlays). As discussed by Clouse et al. (1999), the Federal Reserve does not have legal authorization to simply give money to individuals and corporations, although there may be alternative methods that are legal and have the same practical effect. However, these methods are clearly outside the realm of the historical practices of the Federal Reserve.

4 Methodology

To evaluate the likely effect of the zero bound on macroeconomic performance, we perform stochastic simulations of the FRB/US model to generate artificial time series for the output gap, inflation, interest rates, and so forth. From this data we compute distributional statistics that allow us to analyze how the distributions of these variables are affected by changes in the target rate of inflation and other aspects of monetary policy. To obtain reliable estimates of the effect of the zero bound on the distribution of simulated macroeconomic outcomes—particularly as regards the lower tail, which has an especially important influence on the frequency, depth, and duration of recessions—we generate several sets of very long time series of simulated data (12000 quarters per set). Details on the algorithm used to generate the stochastic simulations are presented in the appendix.

Stochastic disturbances

In running stochastic simulations, we assume that disturbances to the approximately 50 estimated equations of the model—including various components of aggregate spending, labor force participation, productivity, wages and prices, bond and equity premiums, and foreign economic conditions—are distributed normally $N(0,\Omega)$.[10] The variance-covariance matrix Ω is estimated from equation residuals for the period 1966 to 1995. Because this period includes the relatively volatile 1970s, the average magnitude of the disturbances is significantly larger than would be obtained if the sample only included the 1980s and 1990s, as in Orphanides and Wieland (1998). Specific values for the disturbances are obtained from random draws from this distribution. These residuals generally appear to be white noise, but in a few cases (notably bonds and equity prices), they display significant autocorrelation. In such

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[10] In the stochastic simulations there are no shocks to the monetary policy rule, such as might inadvertently occur in practice because of real-time mismeasurement of the output gap or inflation; however, the policy rule is subject to implicit "shocks" whenever the non-negativity constraint binds. On the fiscal side, the simulations do incorporate transitory disturbances to effective tax rates and government spending. The simulations also take into account transitory disturbances to important "exogenous" variables such as imported oil prices, because FRB/US includes simple stochastic equations for these variables.

cases, this serial correlation is incorporated into the model.

There are two important implications of the assumption that the stochastic disturbances are normally distributed. First, in a large sample some of the shocks will be drawn from well out in the tails of the distribution. In fact, our stochastic simulation exercises include some rare episodes driven by sequences of disturbances whose overall magnitude are greater than that actually experienced during any recession of the past 30 years. Second, in the context of a linear model, normally distributed shocks imply that the distributions of all simulated variables will be symmetric in large samples. However, because the non-negativity constraint introduces an important nonlinearity into the system, the distributions of output, inflation, interest rates, and other variables display asymmetries around their means when the zero bound is an active constraint on policy.

Bias adjustments to the policy rule

Using stochastic simulations of a model in which policy is described by linear Taylor-style policy rules, Orphanides and Wieland (1998) find that, on average, inflation is below its target and output is below potential in situations where the non-negativity constraint frequently binds. This result arises because policy deviates from the prescriptions of the unconstrained rule whenever the zero bound is hit, implying that at such times the rule is, in effect, subjected to a positive “shock”. In the absence of offsetting negative deviations from the rule at times when interest rates are unconstrained, nominal interest rates therefore will on average be higher than would be prescribed by the unconstrained policy rule.

To reduce the effects of this phenomenon, in our simulations we incorporate a notional upward adjustment to the inflation target of the policy rule to offset the average effect of the positive deviations to the rule that occur when interest rates fall to zero. In this way, policy attains its inflation goal on average.[11] As shown in the next section, this bias adjustment is a non-linear function of the target rate of inflation, among other factors. We use this form of adjustment because of its simplicity and transparency, not because it is optimal. Intuitively, a better strategy would be to employ a conditional adjustment to the policy rule that adjusts the funds rate down immediately before or after episodes of zero interest rates; in this way offsetting movements in the funds rate would be more likely to occur when economic activity is still weak and inflation low. We consider just such a strategy in Section 6 of the paper.

Fiscal policy

In the model simulations, we assume that fiscal policy generally acts according to estimated equations that capture the average behavior of the main tax and expenditure categories seen in post-war business cycles. However, the stochastic simulations occasionally yield severe deflationary episodes that are historically unusual. During these periods, with the nominal funds rate stuck at zero, the economy could become trapped in a deflationary spiral.

To avoid this type of catastrophic collapse in simulation, we make allowance in the formation of expectations for the possibility of emergency fiscal stimulus in cases of extremely persistent periods of zero rates. Specifically, it is assumed that firms and households anticipate that a fiscal stimulus "rescue package" will eventually be enacted if the funds rate is projected to be at or near zero for seven years into the

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[11] In a backward-looking model, this adjustment would entirely eliminate the effects of the bias. In forward-looking models, however, both realized <u>and</u> anticipated episodes of a binding non-negativity constraint affect the economy, implying that a simple bias adjustment will not eliminate all effects of the bias. This problem is further complicated by the fact that our simulation algorithm imposes certainty equivalence—that is, all future shocks are assumed to be zero—which introduces additional biases to the means of all variables.

future.[12] The stimulus is assumed to be of sufficient magnitude to exactly offset the effect of the zero bound until the economy recovers. The exact specification of this rescue package is not crucial to the results presented in this paper; its impact is only felt in very severe contractions. Overall, its effect is to constrain the worst-case recession to output declines of about 20 percent below potential. In the simulations reported below, the rescue package is invoked only rarely—about once a millennium (!) on average for an inflation target of 2 percent, and once a century for a zero target.

Equilibrium real interest rate

A final issue concerns the calibration of the equilibrium real funds rate, the rate consistent with a normal long-run average level of resource utilization. Whether this rate is high or low has a great influence on our quantitative results, because the sum of this variable and the target rate of inflation determines the maximum stimulus policymakers can provide on average to counteract contractionary shocks. As noted earlier, if this policy buffer is large, the zero bound is likely to be of little practical relevance; if small, the non-negativity constraint binds a significant percentage of the time. Furthermore, given the one-for-one tradeoff between the real equilibrium rate and target inflation inherent in the definition of i^*, the higher the estimated value of r^*, the more target inflation can be reduced and still be judged consistent with a given level of macroeconomic variability.

To compute historical estimates of the real funds rate (actual and equilibrium), we use as our measure of inflation the growth rate of the chain-weight price index for personal consumption expenditures. With this measure, we find that 2–1/2 percent is a reasonable value for the long-run equilibrium real funds rate, based on: the average

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[12] A delay of seven years may seem unduly slow, but our goal is to gauge the full consequences of the zero bound for the effectiveness of monetary policy; therefore, we use fiscal policy as a substitute for open-market operations only as absolutely necessary in extreme circumstances.

value of the real funds rate over the 1960-1998 period (2.55 percent); estimates derived from simple dynamic IS curves (e.g., regression of the output gap on a constant and lags of the gap and the real funds rate); and a more thorough study of the issue by Bomfim (1998) that uses the entire FRB/US model. It is straightforward to determine how the results reported in the next section would be affected by adopting an alternative estimate of r^*. For example, the outcomes for a 0 percent inflation target and a 3–1/2 percent equilibrium real rate would be the same as those we report for a 1 percent inflation target.[13]

5 Effects of the Zero Bound Under the Taylor Rule

We now use stochastic simulations to measure and analyze the model's view of the macroeconomic effects of the zero bound. We begin by assuming that the funds rate is set in accordance with the Taylor rule,

$$i_t = r^* + \pi_t^{(4)} + .5 * (\pi_t^{(4)} - \pi^*) + .5 * y_t \ . \tag{2}$$

where $\pi^{(4)}$ denotes the four-quarter percent change in the level of chain-weight PCE prices. To see how expected macroeconomic conditions are altered as the zero bound becomes more of a factor, we run a series of simulations in which π^*, the target rate of inflation used in the rule, is progressively lowered. Given the one-for-one correspondence between changes in π^* and i^*—recall that r^* is assumed to be constant at

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[13] Throughout our analysis, we assume that the long-run value of the equilibrium real rate is constant (although the value of the real funds rate consistent with a zero output gap in the short to medium run varies considerably in the simulations). However, there is reason to suspect that r^* may shift gradually over time, owing to low-frequency movements in supply and demand factors. For example, Bomfim (1998) finds that the equilibrium real funds rate may have been as high as 4 percent during the 1980s, when the stance of fiscal policy was quite expansionary.

Table 1: Distribution of the Federal Funds Rate Under the Taylor Rule

	Inflation Target				
	0	1	2	3	4
Percent of time funds rate bounded at zero[1]	14	9	5	1	<1
Mean duration of periods funds rate bounded[2]	6	5	4	3	2
Constant bias adjustment to target inflation	.7	.3	.1	.0	.0
Standard deviation of:					
Output gap	3.6	3.2	3.0	2.9	2.9
Inflation	2.0	1.9	1.9	1.9	1.9
Federal funds rate	2.3	2.4	2.5	2.5	2.5

Notes:
1. Percent of quarters funds rate $\leq$ 5 basis points.
2. Mean number of consecutive quarters funds rate $\leq$ 5 basis points.

2-1/2 percent—these simulations allow us to analyze the link between inflation objectives and the distributions of simulated outcomes for the funds rate, inflation, and output. Because the disturbances used in the stochastic simulations are, for the most part, similar in magnitude to those experienced over the past four decades, this distributional information can be used to estimate the expected cost in macroeconomic stability (if any) that is likely to be incurred in low inflation environments.

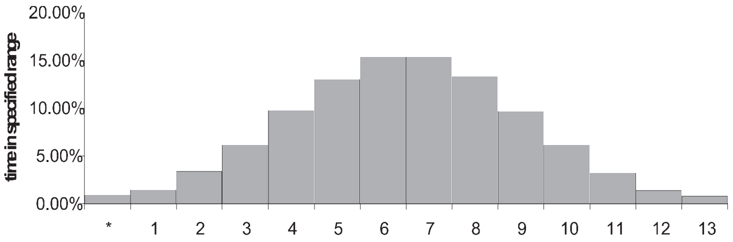
The top portion of Table 1 shows the quarterly frequency and average duration of episodes where the federal funds rate falls to zero in the simulations. For an inflation target of 4 percent, the zero bound is reached less than 1 percent of the time and the average duration of a spell of zero interest rates is about 2 quarters, suggesting that policy would find itself constrained about once every 100 years on average. As the inflation target falls, the policy buffer shrinks and the frequency of hitting the constraint rises, as does the mean duration of periods spent stuck at the constraint. Moreover, the relationship between the inflation target and the frequency of hitting the zero bound is nonlinear: The frequency and duration of time spent constrained at the lower bound is little affected by changes in the target in the region above 2 percent, but as it falls below 2 percent, such episodes become increasingly more common and prolonged. In the case of a zero percent inflation target, the funds rate is bounded at zero 14 percent of the time, and the mean duration of a spell of zero interest rates is one and a half years.

Figure 5 shows the model-generated distribution of the funds rate for inflation targets of 0, 2, and 4 percent. The height of each bar shows the percentage of time that the funds rate lies in the specified range. With a 4 percent inflation target, the distribution of the funds rate is symmetric about its mean (in this case, 6–1/2 percent)—a not unexpected result, given the assumption of symmetrically distributed disturbances and a model that is linear outside the vicinity of the zero bound. The median of the distribution shifts to the left as the inflation target falls, and the impact of the zero bound is seen in the altered shape of the funds rate distribution, an effect that is the result of two factors. First, in times when the policy rule prescribes negative rates, the actual funds rate is zero because of the bound; this shows up in the figure as an increase in the frequency of rates that fall between 0 and 1/2 percentage points. In effect, the mass in the tail of the distribution that ordinarily would appear to the left of zero piles up at the lower bound. Second, as illustrated below, the existence of the zero bound influences the distributions of output and inflation, and thereby the distribution of interest rates.

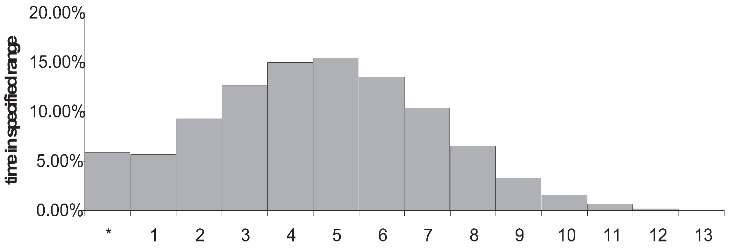
Figure 6 shows the distribution of inflation for the same three inflation targets. Under a zero percent inflation target, inflation rates frequently lie well below zero in the simulations; the duration of such deflationary episodes is on average 1 or 2 years. The combination of a very low inflation target and the zero bound suggests that the economy would regularly experience relatively lengthy bouts of falling prices. For

Figure 5
Distribution of the Federal Funds Rate Under the Taylor Rule

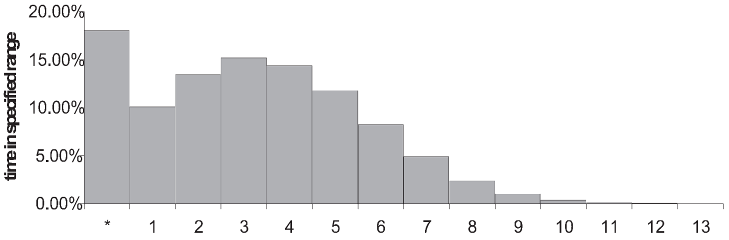
4% Inflation Target



2% Inflation Target



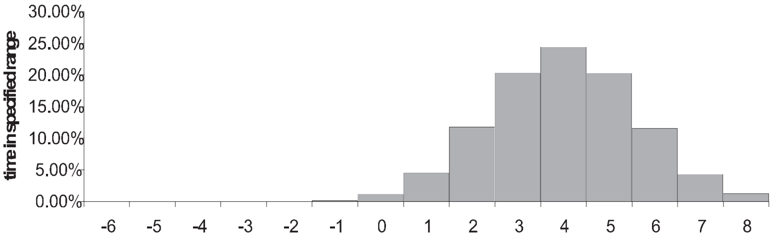
0% Inflation Target



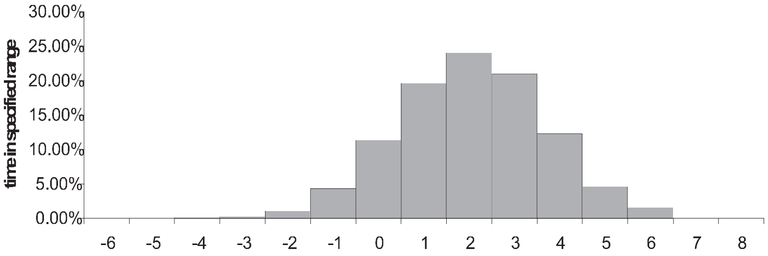
* The range farthest to the left represents values between 0 and 0.5.

Figure 6
Distribution of the Inflation Rate Under the Taylor Rule

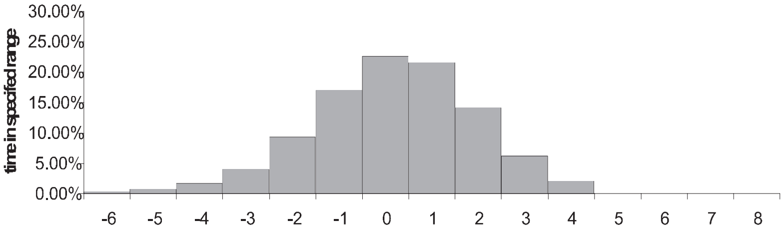
4% Inflation Target



2% Inflation Target



0% Inflation Target



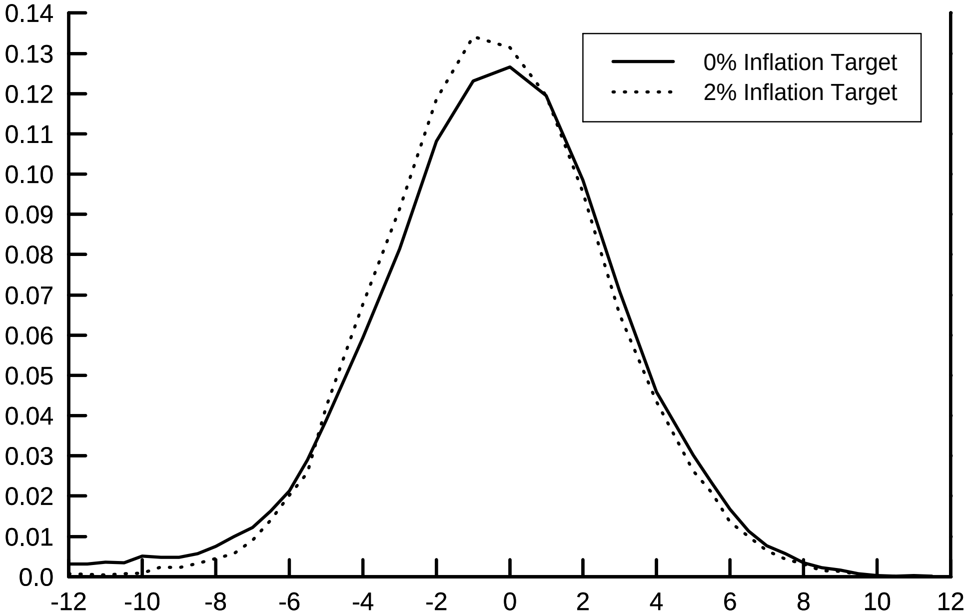
* The range farthest to the left represents values less than -5.5.

example, with a zero percent inflation target, the four-quarter *deflation* rate exceeds 1 about 10 pecent of the time. Another feature of these distributions is a loss of symmetry that accompanies a very low inflation target. In the case of a 2 or 4 percent inflation target, inflation outcomes are evenly distributed about the target rate. However, this is no longer true under a zero inflation target, in which case the distribution is skewed to the left. Nevertheless, the standard deviation of inflation (shown in Table 1) is virtually invariant to the inflation target: The zero bound does not involve a significant tradeoff between the level and variance of inflation.

Recall that we introduced a bias adjustment to the policy rule to offset the one-sided nature of the zero bound. The magnitude of the bias adjustment—which can be thought of as a notional shift in the target rate of inflation that is used operationally to achieve the true desired rate of inflation on average—depends on the frequency and magnitude of deviations from the policy rule caused by the zero bound. As shown in table 1, for inflation targets of 2 percent and above the adjustment is tiny. As the target approaches zero, however, the zero bound becomes more of a problem and and the adjustment rises in magnitude. In effect, policymakers who set the funds rate using the Taylor rule should effectively behave as if they are targeting a 1-1/4 percent inflation rate if their objective is really to have inflation be 1 percent on average; if their goal is a 0 percent average rate of inflation, they should set the notional target in the rule to about 3/4 percent.

The effect of the zero bound on the distribution of the output gap is shown in Figure 7. Because outcomes under a 4 percent inflation target appear so similar to those obtained with a 2 percent target, we show only the distributions for targets of 0 and 2 percent. The two distributions are overlaid to facilitate the comparison of the outcomes. The most noticeable effect of the zero bound on the distribution of output is a decline in the frequency of mild recessions, and a corresponding increase

Figure 7
Distribution of the Output Gap Under the Taylor Rule



in the likelihood of severe contractions. The overall effect of the zero bound on output variability is seen in the rise of the standard deviation of the output gap—particularly under a zero inflation target—as reported in Table 1.

Because of the limited manuevering room available to policymakers with an inflation target of zero, such an objective significantly diminishes the effectiveness of monetary policy in reducing the depth and duration of contractions. For example, following the approach of Orphanides and Wieland (1998), we define a period of "low activity" to occur when the two-quarter moving average of the output gap falls below -6 percent. Such a gap constitutes a relatively deep recession by post-war standards, but our results would not be greatly changed if we were to use a smaller cut-off value. The frequency and duration of periods of low activity is essentially constant for cases where the inflation target is 2 percent or more, with the economy in a low activity state about 2 percent of the time; the average duration of these episodes is under a year. As the inflation target is reduced to zero, the frequency of low activity rises to about 5 percent, and the average duration of such periods rises to about one and half years.

Overall, these results suggest that macroeconomic stability would likely deteriorate somewhat if the target rate of inflation were to fall below 1 or 2 percent, assuming that policymakers follow the Taylor rule and the equilibrium real rate of interest is around 2-1/2 percent. Under these conditions, the zero bound gives rise to a tradeoff between the average rate of inflation and the variability of output; however, there is no significant tradeoff between the average rate of inflation and inflation variability, at least for the range of inflation targets considered here.

6 The Design of Monetary Policy in Light of the Zero Bound

The results reported in the previous section were derived under the assumption that policymakers follow the Taylor rule in setting the funds rate. In this section we investigate how the effects of the zero bound are altered by changing the nature of the policy rule in place. We begin with an alternative to the Taylor rule that is more responsive to changes in macroeconomic conditions but retains the Taylor rule's basic specification. We then investigate the performance delivered by rules that represent more substantial modifications to Taylor-style presciptions for setting the funds rate.

Performance under the Henderson-McKibbin rule

Consider a policy rule of the same form as the Taylor rule but with larger coefficients on the deviations of output and inflation from their respective target levels, such as the one advocated by Henderson and McKibbin (1993):

$$i_t = r^* + \pi_t^{(4)} + 1 * (\pi_t^{(4)} - \pi^*) + 2 * y_t \quad . \tag{3}$$

Research with the FRB/US model, as well as with other macroeconometric models, has shown that such a policy rule does a better job at stabilizing inflation and real output, but leads to greater fluctuations in the funds rate (Levin et al. (1999)). The fact that the Henderson-McKibbin rule prescribes, on average, larger movements in the funds rate suggests that it is likely to violate the zero bound—in the sense of calling for negative interest rates—more frequently and by larger magnitudes.

The results from the Henderson-McKibbin rule mirror those of the Taylor rule. As shown in Table 2, the variability of real output and inflation is nearly unaffected by changes in the inflation target in the region of 2 percent and above. However, the volatility of output rises significantly as the inflation target is reduced to zero. Nevertheless, the Henderson-McKibbin rule outperforms the Taylor rule in output and inflation stabilization, even with a low inflation target: Although the rule hits the zero bound more frequently (by as much as one third of the time with an inflation target of zero), it does such a better job of damping fluctuations in output and inflation that it manages to avoid entering into potentially destabilizing deflationary situations into the first place. Thus, the zero bound does not necessarily diminish the benefits of more aggressive rules.

Augmenting the Taylor rule

In our analysis of both the Taylor and Henderson-McKibbin rules, the upward bias to interest rates directly resulting from the zero bound was offset by introducing a constant downward bias term to the reaction function. This modification, however,

Table 2: Macroeconomic Performance of the Henderson-McKibbin Rule

	Inflation Target				
	0	1	2	3	4
Percent of time funds rate bounded at zero[1]	31	24	17	11	7
Mean duration of periods funds rate bounded[2]	6	5	4	3	3
Constant bias adjustment to target inflation	.7	.4	.3	.2	.1
Standard deviation of:					
Output gap	2.4	2.1	1.9	1.8	1.8
Inflation	1.9	1.9	1.9	1.9	1.9
Federal funds rate	3.6	3.8	3.9	4.1	4.1

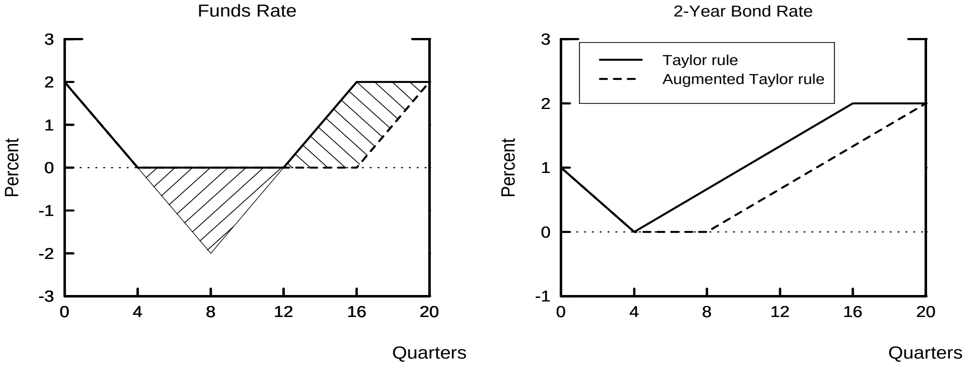
Notes:
1. Percent of quarters funds rate $\leq$ 5 basis points.
2. Mean number of consecutive quarters funds rate $\leq$ 5 basis points.

does not directly address the issue of reducing the stabilization costs associated with the zero bound. Intuitively, a preferable modification to a linear policy rule would be one where the funds rate is lowered relative to the original rule when the economy is or is anticipated to be weak—that is, before entering, and after pulling out of, a period of zero short-term interest rates. Because of expectational effects in the pricing of bonds and other long-term assets, such a modification should prove to be stimulative during constrained periods even if the departure from the rule occurs considerably later when the economic recovery is in full swing: Confidence that policy will be easier in the future than would normally be the case could lower bond rates today and raise current expectations of future inflation.

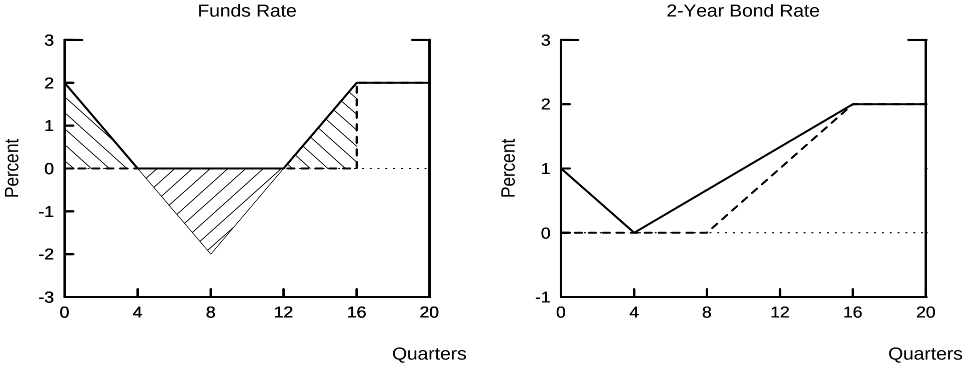
For example, following a period in which the funds rate is constrained at zero, policymakers might continue to hold the rate at zero beyond the point at which the Taylor rule would normally prescribe a positive rate. In this way policy would make up for lost opportunities to lower rates when the non-negativity constraint binds. Such

Figure 8
Possible Modifications to the Taylor Rule in the Vicinity of the Lower Bound

Backward-Looking Adjustment



Forward-Looking Adjustment



a strategy is illustrated by a simple example shown in the top left panel of Figure 8. Consider a scenario where the Taylor rule—ignoring the zero bound—prescibes a path for the funds rate that falls from an initial level of 2 percent, reaching -2 percent before rising back to 2 percent after 5 years. As indicated by the thick solid line, one possible policy is to set the funds rate according to the Taylor rule until the zero bound is reached; thereafter short-term rates remain at zero until the unconstrained path for the funds rate raises above zero, at which point the funds rate rises in tandem with the Taylor rule. Alternatively, as indicated by the dashed line, policymakers might choose to hold down rates relative to the Taylor rule during the recovery period (quarters 13 through 19). As shown in the upper right panel, this strategy keeps bond rates lower than they otherwise would be during and immediately after the period of zero short-term interest rates, thereby mitigating the fall in output and inflation.[14]

Policymakers also might choose to lower rates pre-emptively if they anticipate that the non-negativity constraint will bind in the near future. This strategy is illustrated by the dashed line of the bottom left panel of Figure 8. In this case, short-term interest rates fall earlier than they do under the Taylor rule; the funds rate is also slower to rise above zero. As a result, bond yields fall to zero a year before they do under the Taylor rule, and stay lower for the next three years (bottom right panel).

To evaluate the quantitative effect of such changes to monetary policy in the vicinity of the zero bound, consider the following modification to the Taylor rule. Let $d_t = i_t - i_t^{\text{Taylor}}$ denote the deviation at time t of the actual funds rate from the prescription of the standard unconstrained Taylor rule, and let Z_t equal the cumulative sum of all past deviations. When the zero bound constrains policy, d_t will be positive and Z_t will be rising. What we seek is a policy that deviates from the Taylor rule in a negative direction at times when interest rates are unconstrained and there is a "backlog" of past deviations—i.e., immediately following episodes of zero interest rates, when Z_t is positive. One policy that does this is given by

$$i_t = \max\{i_t^{\text{Taylor}} - \alpha Z_t, 0\}\ , \tag{4}$$

where $\alpha \in (0, 1]$. Under this policy, d_t will be negative whenever nominal rates are positive, provided that the stock of cumulative past deviations is still positive; over an extended period of unconstrained rates, the resultant string of negative deviations causes Z_t to decline to zero, so that the prescriptions of the rule eventually converge to

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[14] For this illustrative scenario, we abstract from the issue of interest rate bias arising from the one-sided nature of the zero bound.

that of the standard Taylor rule. An advantage of this specification is that the upward bias to interest rates arising from the zero bound is offset by automatic downward adjustment at other times.

Table 3 reports the standard deviations of inflation and the output gap using the augmented Taylor rule for values of π^* of -1 through 2 percent. Under the modified rule, even when the target rate of inflation is *below* zero, the zero bound has only a negligible effect on inflation and output stabilization, assuming, as before, that fiscal policy steps in to guarantee an eventual return to macroeconomic equilibrium during especially severe contractions. A similar experiment was conducted using the Henderson-McKibbin rule discussed above with the same result: The effects of the zero bound were nearly completely negated by introducing adjustment to the past stock of deviations from the rule.

Table 3: Macroeconomic Performance Under the Augmented Taylor Rule

	Inflation Target			
	-1.0	0.0	1.0	2.0
Percent of time funds rate bounded at zero[1]	33	19	9	4
Mean duration of periods funds rate bounded[2]	7	5	4	3
Standard deviation of:				
Output gap	3.0	3.0	2.9	2.9
Inflation	1.8	1.8	1.9	1.9
Federal funds rate	1.9	2.2	2.4	2.4

Notes:
1. Percent of quarters funds rate $\leq$ 5 basis points.
2. Mean number of consecutive quarters funds rate $\leq$ 5 basis points.

Why does this modification work so well at neutralizing the effects of the zero bound? As suggested by Figure 8, the answer is in its implications for the behavior of bond yields, which in FRB/US play a central role in determining aggregate spending. Because most contractions are of shorter duration than the typical bond, the effect of the zero bound on long-term interest rates is minimal: If the non-negativity constraint causes the funds rate to be "high" for a year or two, under the augmented rule investors expect a subsequent period of "low" rates, implying that the associated increase in yields on 5-year bonds is small on net; for longer-term securities, the effect on yields is miniscule. (Presumably, the effect on bonds of short maturity would be strengthened further if policymakers also responded to anticipated as well as past periods of zero funds rate, along the lines discussed above.[15]) This mechanism explains why this modification is so effective in FRB/US and suggests that its effectiveness may depend on the duration of bonds relevant to spending and the degree of inertia in inflation and output.

There are certain similarities between this modification of the Taylor rule and the proposals made by Krugman (1998) to mitigate Japan's current macroeconomic problems—in particular, his suggestion that the Bank of Japan should publicly pledge to target a relatively high rate of inflation over the medium term (specifically, 4 percent for the next 15 years). Like the augmented Taylor rule, such a policy entails a promise to keep the stance of monetary policy easier than it would otherwise be for a substantial period of time, in order to influence the public's assessment of the level of real long-term interest rates today. Of course, the effectiveness of either type of policy hinges on the credibility of policymakers. In the simulations reported in this paper, such effectiveness is enhanced by our assumption that policymakers enjoy perfect credibility. However, we should stress that this credibility is realistic, because

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[15] Given the negligable effects of the zero bound when the Taylor rule is augmented to respond to only past episodes of zero rates, we have not bothered to evaluate the performance of rules that respond to anticipated episodes as well.

the public's beliefs are fully consistent with what the monetary authority can actually deliver, taking account of the non-negativity constraint.

Policy frontiers and the zero bound

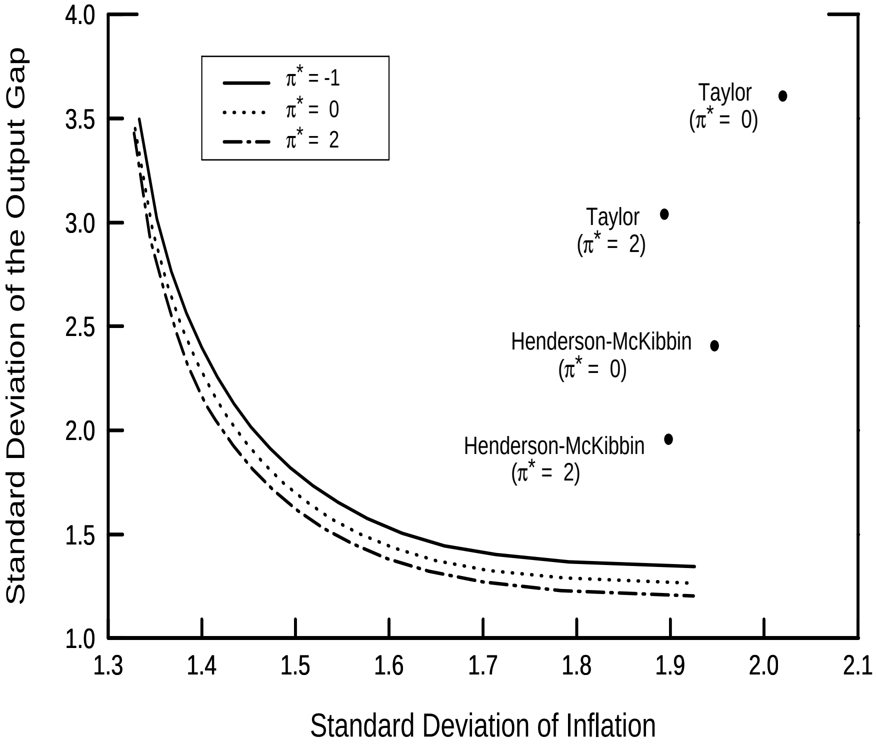
The preceding discussion highlighted the usefulness of augmenting the Taylor rule to respond to episodes of zero interest rates, either in the recent past or expected in the near future. One drawback to focusing on the Taylor rule is that, in the context of the FRB/US model, it is known to be inefficient in terms of stabilizing the variances of inflation and output subject to constraints on interest rate volatility. We now turn our attention to the effect of the zero bound on the types of simple policy rules that were found to be efficient in research that ignored the non-negativity constraint on nominal rates.

As shown by Williams (1999), in the FRB/US model efficient simple rules for monetary policy—abstracting from the effects of the zero bound—take the following form:

$$i_t = r^* + \pi^* + \theta \sum_{j=0}^{\infty} (\pi_{t-j}^{(12)} - \pi^*) + \phi \sum_{j=0}^{\infty} y_{t-j} \ , \tag{5}$$

where $\pi^{(12)}$ denotes the twelve-quarter percent change in the PCE price level (expressed at an annual rate). This type of efficient rule differs from the Taylor rule by responding to a smoother inflation measure and by responding to the *cumulative* deviations of output and inflation from their respective target levels. Such rules are frequently referred to as "first-difference" or "change" rules, because—absent the zero bound—they can be equivalently written in the form $i_t = i_{t-1} + \theta(\pi_t^{(12)} - \pi^*) + \phi y_t$. However, in the presence of the zero bound, these two representations are not the same because, with the first-difference specification, past constraints on the funds rate are perpetuated through the response to the lagged funds rate. For this reason,

Figure 9
Policy Frontiers Under Alternative Inflation Targets



it is important to focus on the form given by equation 5.

Figure 9 shows three frontiers for FRB/US using simple policy rules optimized to minimize the weighted average of the variances of inflation and output subject to the constraint the standard deviation of the funds rate does not exceed 3-1/2 percentage points. The solid line shows the performance of the frontier rules where the target rate of inflation is -1 percent, the dotted line for a target of 0 percent, and the dot-dashed line for a target of 2 percent. Frontiers for inflation targets above 2 percent are indistinguishable from that shown by the dot-dashed line. As seen in the figure, a reduction in the inflation target results in a small increase in the variability of inflation and output, with the marginal stabilization cost rising as the inflation target approaches and falls below zero. Also shown in the figure are the outcomes from the Taylor and Henderson-Mckibbin rules, adjusted to compensate for the average upward bias to interest rates, but not modified to incorporate an explicit response to past (or anticipated) deviations from the rule.

One striking result of Figure 9 is that, in relation to the Taylor or Henderson-McKibbin rules, the cost of reducing the inflation target is small for efficient policies. The effectiveness of efficient rules at stabilizing the economy even with low or negative average rates of inflation can be traced to two factors. First, the average magnitude of fluctuations is lower under efficient rules, so that the economy finds itself less frequently in a state of distress. Second, because the rules respond implicitly to all past output and inflation gaps, the current and expected future setting of policy incorporates the effects of past constraints on policy from the zero bound. Hence, as in the case of the Taylor rule modified to respond to past policy constraints, efficient rules of the form characterized by equation 5 are associated with small losses in stabilization from the zero bound. This result is related to Wolman's (1998) finding that rules that target the price level, as opposed to the inflation rate, can overcome the effects of the zero bound: Price-level targeting rules are a special case of equation 5, with $\phi = 0$ and $\pi^{(1)}$ substituted for $\pi^{(12)}$.[16] In general, rules that implicitly or explicitly build in an offset to past deviations from the rule mitigate the effects of the zero bound.

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[16] To see this, note that a price level targeting rule is normally written as $i_t = r^* + \pi_t^{(1)} + \alpha(p_t - p_t^*)$, where p_t is the log of the price level and p_t^* is its deterministic trend. Substitution of $p_t = p_0 + \sum_{j=0}^{t} \pi_j^{(1)}$, with p_0 normalized to zero, converts the rule into a special case of the inflation targeting rule described by equation 5. It is worth noting that, in the FRB/US model, efficient price-level targeting rules are nearly as efficient at stabilizing output and inflation as rules that target inflation (Williams (1999)).

7 Conclusion

We draw three broad conclusions from previous research and our investigation. First, during particularly severe contractions, standard open-market operations alone may be insufficient to restore macroeconomic equilibrium; fiscal policy or some other stimulus may be needed. However, our results suggest that such episodes are fairly rare, even in a low inflation environment—about once every 100 years if the target rate of inflation is around zero, given the sorts of shocks that have characterized the U.S. economy over the past 30 years.

Second, in very low inflation environments where policy follows the Taylor rule, the zero bound could prove to be a significant constraint on policy. For example, our simulations indicate that under such conditions the nominal funds rate could be stuck at zero over 10 percent of the time. With the effectiveness of open-market operations diminished at times, the economy would likely experience a noticeable increase in the variability of output and employment, particularly if policymakers were to pursue an inflation target of 1 percent or below. However, our results do not suggest that the variability of inflation is greatly affected by the zero bound, even with an inflation target of zero percent.

Finally, we find that, in a world where policymakers enjoy perfect credibility augmenting the Taylor rule to incorporate a response to past constraints on policy dramatically reduces the detrimental effects of the zero bound. Interestingly, policy rules that are efficient in the absence of the zero bound—that is to say, rules that provide the best possible set of tradeoffs between output and inflation variability in moderate inflation environments—implicitly incorporate such behavior; hence, for such rules, the zero bound generates only relatively small stabilization costs. Although not formally analyzed here, incorporating a response to anticipated future constraints on policy would likely yield a further reduction in the detremental effects of the zero bound on macroeconomic stabilization.

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APPENDIX

Stochastic simulations of non-linear models under model-consistent expectations are computationally burdensome, especially on the scale conducted for this study. To make the problem computationally feasible, the FRB/US model is log-linearized around sample means, an approximation that, abstracting from the effects of the zero bound, has little effect on the relevant dynamic properties of FRB/US. Setting aside for the moment the issue of the imposition of the non-negativity constraint on interest rates, the linearized model can be written

$$E_t \sum_{j=-1}^{M} H_j x_{t+j} = G e_t \ , \tag{6}$$

where M is the maximum lead in the model, x_t is the vector of endogenous variables, and e_t is a mean-zero vector of serially uncorrelated random disturbances with finite second moments, $E(ee') = \Omega$. The information set for expectations formation differs across sectors; in general, date t expectations in the financial sector incorporate knowledge of date t variables, x_t, but expectations in the other sectors are limited to date $t-1$ variables, x_{t-1}. For a given specification of the policy rule, we solve for the saddle point rational expectations solution, if it exists, using the AIM algorithm developed by Anderson and Moore (1985). The reduced form representation of the solution is given by

$$x_t = A x_{t-1} + B e_t \ ; \tag{7}$$

from this expression generation of simulated data for randomly-selected values of e_t is straightforward.

To impose the non-negativity constraint on the model, the linear solution procedure is augmented to include additive disturbances to the levels of the funds rate for the current period and N future periods. These disturbances are set equal to zero if the unconstrained rule prescribes a funds rate setting greater than zero, and set equal to the absolute value of the unconstrained funds rate setting if the rule dictates a negative interest rate. Note that the zero bound holds in expectation only for a finite number of periods; as described below, we justify this specification on the grounds that fiscal policy can be expected to step in eventually and forestall a deflationary spiral. The results are not sensitive to the precise value of N. At each point in time, agents' expectations for future values of the policy disturbances are fully consistent with the model's predictions for future economic conditions, subject to the assumption that all future shocks to the economy (excluding the additive disturbances to the policy rule just described) are zero.