Are Higher Inflation, or Even Price-level, Targets Better Than You Think?

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Abstract

Inflation targets substantially above advanced-economy norms have been suggested by some research as an approach to minimize costs associated with an effective lower bound on nominal interest rates. Alternatively, price-level targets substantially insulate the economy from the pernicious effects of the effective lower bound in "New-Keynesian" models, but policymakers have been skeptical about the sensitivity of such efficacy to the forward-looking nature of inflation in such models. This analysis re-examines the potential costs associated with an effective lower bound on nominal interest rates using a large model employed in policy analysis at the Federal Reserve. We find that that effective lower bound on nominal interest rates may bind substantially more frequently than suggested in previous quantitative analyses: For an equilibrium real interest rate in the range of some recent estimates, the nominal interest rate is constrained by the effective lower bound nearly one-third (and in some cases more) of the time under a commonly-used policy rule. The severe constraint imposed by the lower bound implies that the possible benefits of a higher inflation or a price-level target may be sizable, even when inflation is backward looking. The key mechanism generating a role for a price-level target is forward-looking behavior in financial markets, which allow monetary policy strategies to shape asset prices and hence aggregate demand.
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1 Introduction

Many of the workhorse dynamic-stochastic-general-equilibrium (DSGE) models used for monetary policy analysis suggest that, under appropriate monetary policy strategies, the lower bound on nominal interest rates is not a serious impediment to good macroeconomic performance. In particular, such models appear (at least in the well-known cases) to suggest infrequent and short spells at the lower bound on nominal interest rates.[1] Moreover, forward guidance regarding the path of nominal interest rates is a powerful substitute for near-term policy accommodation in many DSGE models, implying that nearly optimal outcomes can be replicated under policy strategies that include a role for a (flexible) price-level target.[2]

Many economists and policymakers question the degree of "forward-looking" behavior in such models and the related efficacy of price-level strategies. This skepticism may reflect the notion that backward-looking rules-of-thumb better characterize the formation of expectations for some agents. Perhaps relatedly, some of this skepticism may reflect the persistence of the binding lower bound on nominal interest rates across major economies in recent years despite substantial monetary accommodation. Recent experience suggests that the lower bound on nominal interest rates may be a much more severe constraint on economic performance than estimated in earlier studies.[3]

In this analysis, the degree to which the effective lower bound may bind is reconsidered. Our investigation suggests that the lower bound on nominal interest rates may bind much more frequently that suggested in previous research under plausible approaches to monetary policy. For example, nominal interest rates are constrained by the lower bound between 25 percent and 50 percent of the time when the inflation target is 2 percent and

[1] For example, see Chung et al [2012].

[2] Eggertson and Woodford [2003] illustrate these issues in a simple model, and Woodford [2003] presents an overview of the New-Keynesian model. For examples of analogous results in larger DSGE models, see Del Negro, Giannoni, and Patterson [2012] and Chung, Herbst, and Kiley [2014].

[3] For example, Reifschneider and Williams [2000] and Williams [2009] suggest that the lower bound on nominal interest rates is unlikely to bind more than $1/5th$ of the time, and do not find very large costs (at least relative to those found herein) associated with the lower bound.

the equilibrium real interest rate is in the range of 0-to-1 percent estimated by Laubach and Williams [2003] and Kiley [2015].[4]

The large costs associated with such a severe lower bound constraint may suggest some benefits from a higher target inflation rate, although such benefits need to be balanced against the potential costs of higher inflation (which may be sizable, e.g., Woodford [2009]).[5] In light of these costs and the possibly severe constraint on monetary policy imposed by the effective-lower bound, the analysis reconsiders conditions under which price-level targets may be valuable. In particular, central-bank communications appear capable of affecting asset prices directly, perhaps reflecting a greater degree of forward-looking behavior among important participants in financial markets than among households or non-financial businesses.[6] Moreover, even models in which household or firm spending decisions are importantly backward-looking, such as the Federal Reserve's FRB/US model used herein, include important influences on spending (and hence, indirectly, inflation) from asset prices through "wealth effects" and other channels. This mix of channels and views on the nature of expectations formation naturally leads to the question of the degree to which strategies with a price-level target could stabilize inflation and economic activity when the effective lower bound on nominal interest rates binds and asset prices are forward-looking.

To explore the importance of forward-looking elements to both wage/price setting and asset price channels, we consider both a simple model, akin to that in Fuhrer and Rudebusch [2004] and Kiley [2014], and the Federal Reserve's FRB/US model. These models are less micro-founded than DSGE models – but the absence of tight restrictions from micro-foundations is a benefit in our analysis, as it allows a flexible decomposition of the effects of forward-looking inflation dynamics and financial-market channels. The

[4]The possibility of a low equilibrium real interest rate is related to the debate on "secular stagnation" Summers [2014].

[5]A classic review of the costs in inflation is Fischer and Modigliani [1978].

[6]Afrouzi et al [2015] present evidence suggesting non-financial firms' inflation expectations do not respond directly to central bank communications.

monetary-policy transmission mechanism in the FRB/US model is similar to that in DSGE models (Boivin, Kiley, and Mishkin [2010]). However, the FRB/US model distinguishes between the inflation expectations affecting prices and wages, the inflation expectations that determine real-interest rates affecting spending by households and firms, and the expectations of financial market participants that determine nominal bond yields, equity market valuations, and other purely-financial factors. These distinctions allow an explicit breakdown of interaction between policy strategies and the ability to affect spending and inflation through direct management of household and firm expectations driving wage and product-price setting and through influences on asset prices. At the same time, the grounding of the FRB/US model in day-to-day policy analysis implies that its quantitative properties embed the insights of Federal Reserve staff, and these quantitative properties largely accord with consensus views on macroeconomic fluctuations and monetary policy transmission. (For a discussion of the properties of the FRB/US model, see Brayton, Laubach, and Reifschneider [2014].)

The analysis suggests five conclusions

- Model simulations demonstrate that the effective lower bound on nominal interest rates may bind one-third of the time at recently estimated values of the equilibrium real interest rate and an inflation target of 2 percent.

- In the presence of an effective lower bound on nominal interest rates, economic stability under inflation-targeting regimes can deteriorate substantially if the equilibrium interest rate is low.

- In addition, average economic performance deteriorates as well, with inflation and resource utilization typically averaging below desired levels when the equilibrium interest rate is low.[7]

- In the absence of alternatives to inflation targeting, these result points to potential

[7] For similar results in the New-Keynesian model, see Hills, Nakata, and Schmidt [2016].

benefits from an inflation target above 2 percent.

- Price-level targets mitigate substantially the risks to economic performance created by the interaction of a low equilibrium real interest rate and an effective lower bound on the nominal interest rate. Price-level targets enhance economic performance substantially–even with a large backward-looking component to inflation–as long as asset prices are forward looking and affect economic activity.

The possible benefits of a price-level target despite largely backward-looking price-setting behavior contrasts sharply with discussions in previous work, reflecting two factors. First, much previous work used very simple models, and hence abstracted from the possible effects of a price-level strategy on asset prices. Second, the lower bound on nominal interest rates is found to be much more binding and costly in the analysis herein.

The next section discusses the evolution of thinking within the economics profession and among policymakers in recent decades, emphasizing both the simple nature of models used in some earlier work on price-level targeting and the shift in views regarding possible values of the equilibrium real interest rate. Section 3 lays out some of the analytical issues in a simple model. Section 4 illustrates the properties of the FRB/US. Section 5 discusses the frequency with which the effective lower bound may bind under inflation targeting and policy strategies with a price-level element and the consequences of the binding lower bound for economic performance, under both forward-looking and backward-looking inflation dynamics. This discussion also compares results herein to those in previous work. Section 6 suggests some areas for future research.

2 Relationship to Previous Work and Policy Discussions

The role of expectations in shaping the stabilization effects of inflation and price-level targeting have a long intellectual history, but our review of related literature and policy discussions focuses on the evolution of views since the advent of inflation targeting in the early 1990s.

The dominant view in policy circles regarding inflation and price-level targeting developed in the early 1990s. At that time, DSGE models of the type now commonly used at central banks were not yet developed. As a result, macroeconomic models employed equations inspired by economic theory and with important roles for expectations – but in a manner much less closely tied to a specific microeconomic optimization problem than modern DSGE models (as exemplified by Taylor [1993]). The FRB/US model, the current incarnation of which is used herein, grew out of this tradition (as discussed in Brayton and Tinsley [1996]).

At roughly the same time, research was exploring the relative merits of specifying a nominal anchor in terms of the inflation rate or price-level path. In these analyses, inflation targeting generally was found to be superior because inflation expectations were modeled as backward-looking, at least in part. In the presence of a substantial backward-looking element to inflation expectations, returning the economy to a price-level path after unexpectedly high (low) inflation tended to require policymakers to pursue excess slack (overheating) in output and the labor market, leading to greater output variability; moreover, inflation could be more volatile under such conditions, reflecting the need to oscillate between high and low inflation periods to return the economy to a desired price-level path. (For analyses demonstrating these results, see Fillion and Tetlow [1994] and Lebow, Roberts, and Stockton [1992].) As a result, a consensus emerged that a price-level target exacerbated economic volatility, at least when behavior was importantly backward-looking (e.g., Fischer [1994]). This view has persisted in more recent analyses using similar models and assumptions regarding expectations (e.g., Reifschneider and Roberts [2006]).

Following this early-1990s literature, empirical work began to more clearly suggest an important role for forward-looking expectations in inflation dynamics (e.g., Kiley [2007] and Smets and Wouters [2007]), and theoretical work on monetary policy strategy became more firmly embedded in the New-Keynesian paradigm. These developments led to a reconsideration of the merits of price-level targets (e.g., Svensson [1999] and Kiley [1998]). Moreover, the persistence of nominal interest rates near their effective lower bound (of about zero) in Japan led researchers to suggest that price-level targets may be an important element of mitigating risks associated with the effective-lower bound on nominal interest rates.[8] Eggertson and Woodford [2003] described how a commitment to raise inflation in the future following a period of low inflation and nominal interest rates stuck at zero, such as embedded in a price-level target, raises current inflation and demand (through the forward-looking elements of the Phillips and IS curves, respectively) and thereby mitigates the effects of the zero-lower bound. A large literature has demonstrated that this result holds across many classes of estimated DSGE models. (For an analysis of the sensitivity of these results to the nature of the Phillips curve and related references, see Chung, Herbst, and Kiley [2014].)

Since the onset of the global financial crisis, economists and policymakers have taken note of these results: For example, Erceg, Kiley, and Levin [2008], sent to the Federal Open Market Committee in December 2008, discussed the possible advantages of price-level targeting. But central banks have not embraced a price-level target as a strategy to mitigate the risks to economic activity posed by the effective-lower bound on interest rates. The idea that inflation expectations may not respond to a price-level target because of backward-looking elements has been an important reason cited in such decisions. For example, the Bank of Canada renewed its inflation-targeting approach in November 2011, stating

"..it is the Banks view that realizing the theoretical net benefits of PLT would likely be challenging in practice. Recent research has shown that modest, but economically signifi-

[8] Krugman [1998] emphasized such an approach, highlighting the need to commit to a permanent expansion in nominal aggregate demand beyond the period over which the effective lower bound is expected to bind.

cant, potential gains from PLT can be found in the most favourable model simulations, with these gains prospectively enhanced once the costs and risks of the ZLB are incorporated. However, these models assume that agents are forward-looking, fully conversant with the implications of PLT and trust policy-makers to live up to their commitments. While positive, albeit smaller, net gains from PLT may still be available if these conditions are not fully satisfied, it is not presently clear that they would be sufficiently satisfied in the real world for the Bank to have confidence that PLT could improve on the current inflation-targeting framework." Bank of Canada [2011], page 14.

In the minutes of their September 2010 meeting, the Federal Open Market Committee noted a related concern regarding the ability of price-level targeting to influence inflation expectations, suggesting that communications regarding a price-level target may be difficult to calibrate in a manner that successfully steers such expectations:

"Participants noted a number of possible strategies for affecting short-term inflation expectations, including providing more detailed information about the rates of inflation the Committee considered consistent with its dual mandate, targeting a path for the price level rather than the rate of inflation, and targeting a path for the level of nominal GDP. As a general matter, participants felt that any needed policy accommodation would be most effective if enacted within a framework that was clearly communicated to the public." Federal Open Market Committee [2010], page 7.

In reviewing these reactions from central banks, two features are striking.

First, the emphasis is on how price-level targeting manages inflation expectations. While this emphasis is both appropriate and closely tied to the New-Keynesian tradition, it does not encompass the possible broader channels through asset prices emphasized in the introduction. For example, it is reasonable to question the degree to which the statements and strategy of a central bank actively manage inflation expectations – as highlighted in recent research by Afrouzi et al [2015]. Nonetheless, financial market participants appear attuned to central bank communications, and central banks such as the Federal Reserve appear to be able to manage expectations for future interest-rate settings among such participants to some degree. This ability suggests some possibility for price-level targeting to stabilize economic activity and inflation through an asset-price channel, even in the absence of a direct effect on the inflation expectations of wage and price setters.

Second, these policy institutions emphasize that the possible efficacy of price-level targeting is an empirical question, and that changes in the economy may affect the relative efficacy of price-level targeting; this perspective is explicitly stated by the Bank of Canada (which emphasizes it is "not presently clear" that price-level targeting would be advantageous). The empirical nature of the question at hand motivates the analysis herein in two ways. First, we consider price-level targeting in a model used for policy analysis (the FRB/US model) and in comparison to a benchmark (inflation-targeting) rule that has been suggested as both a "good" rule and as one reminiscent of FOMC behavior – a version of the rules in Taylor [1993] and Taylor [1999], perhaps with some allowances for inertia in interest-rate adjustment.[9]. Second, we emphasize how recent empirical analyses of the long-run equilibrium real interest rate may substantially enhance the desirability of price-level targeting. For example, Hamilton, Harris, Hatzius, and West [2015], Johanssen and Mertens [2015], Kiley [2015], and Laubach and Williams [2003] suggest that the long-run equilibrium short-term real interest rate may be notably below its historical average going forward. A lower equilibrium real interest rate raises the likelihood that stabilization efforts of the central bank will be impeded by the effective lower bound on nominal interest rates, and therefore increases the possible benefits associated with monetary policy strategies that manage effective-lower bound risks.

[9]For recent discussion of the possibility such rules are potentially good guideposts, under some circumstances, see Yellen [2012, 2013], English, Lopez-Salido, and Tetlow [2013], and Reifschneider, Wascher, and Wilcox [2013]; as emphasized in these studies these approaches, like all simple rules, may not be appropriate under all circumstances

3 Illustrating the issues in a stylized model

Our discussion of the analytical issues begins with a sketch of the issues in a stylized model of inflation and aggregate-demand determination, consisting of simple inflation (Phillips curve) and output (IS-curve) equations. We choose specific parameter values that yield a model in which the response to monetary-policy shocks are reminiscent of those in the FRB/US model with backward-looking inflation expectations.

The simple Phillips curve is

$$\Delta p_t = 0.3\Delta p_{t-1} + 0.7E_{t-1}\Delta p_{t-1}^{LR} + 0.15y_t + e_t \tag{1}$$

where Δp is inflation, $E_{t-1}\Delta p_{t-1}^{LR}$ is a measure of long-run inflation expectations, y is the output gap, and e is a cost-push shock. This equation links inflation with resource utilization and inflation expectations, as well as lagged inflation, and hence has connections to, but is more *ad hoc*, than the New-Keynesian Phillips curve. We assume that long-run inflation expectations are backward-looking, to link our illustrations to the literature emphasizing such behavior in the costs and benefits of price-level targeting:

$$E_t\Delta p_t^{LR} = 0.975E_{t-1}\Delta p_{t-1}^{LR} + 0.025\sum_{i=1}^{4}\frac{\Delta p_{t-i}}{4} + e_t \tag{2}$$

Turning to output, the IS-curve has the form

$$y_t = -.5\sum_{i=0}^{T}\frac{\mathbb{E}_{t-1}[r_{t+i}] - E_{t-1}\Delta p_{t+1+i}}{40} + 1.4y_{t-1} - 0.5y_{t-2} + v_t. \tag{3}$$

Equation 3 links the output gap to a long-term interest rate (e.g., a 10-year or 40-quarter rate) and its own lags, as in Fuhrer and Rudebusch [2004] and Kiley [2014]; each of these references discusses the links between such an equation and the standard New-Keynesian IS curve.

In equations 1 and 3, the expectations operators ($\mathbb{E}$ and E) are allowed to differ across expectations for financial variables – in this case, the long-term interest rate – and inflation. This separation allows two distinct channels through which alternative monetary policy strategies such as price-level targeting may stabilize demand. First, monetary policy communications that raise asset values, through communication of plans for future nominal interest rates, can directly stimulate demand. To the extent that expectations regarding asset valuations can be managed more easily – as would be the case if the "marginal investor" was attuned to central bank actions. Second, monetary policy actions that directly affect inflation expectations can influence spending and inflation through the roles of inflation expectations in the IS curve and Phillips curve. As highlighted above, much of the literature on price-level targets has emphasized this second channel, some policymakers have appeared to question the power of this channel, and some empirical work, such as Afrouzi et al [2015], suggests limited support for this channel. Because much recent work emphasizes the case with forward-looking inflation, our consideration of a simple model will not examine this case.

The model is highly stylized, but can nonetheless illustrate the basic issues that have been raised in the literature. For the inflation-targeting case, the policy rule is given by

$$r_t = 0.85 r_{t-1} + 0.15(1.5\Delta p_t + y_t) + w_t \tag{4}$$

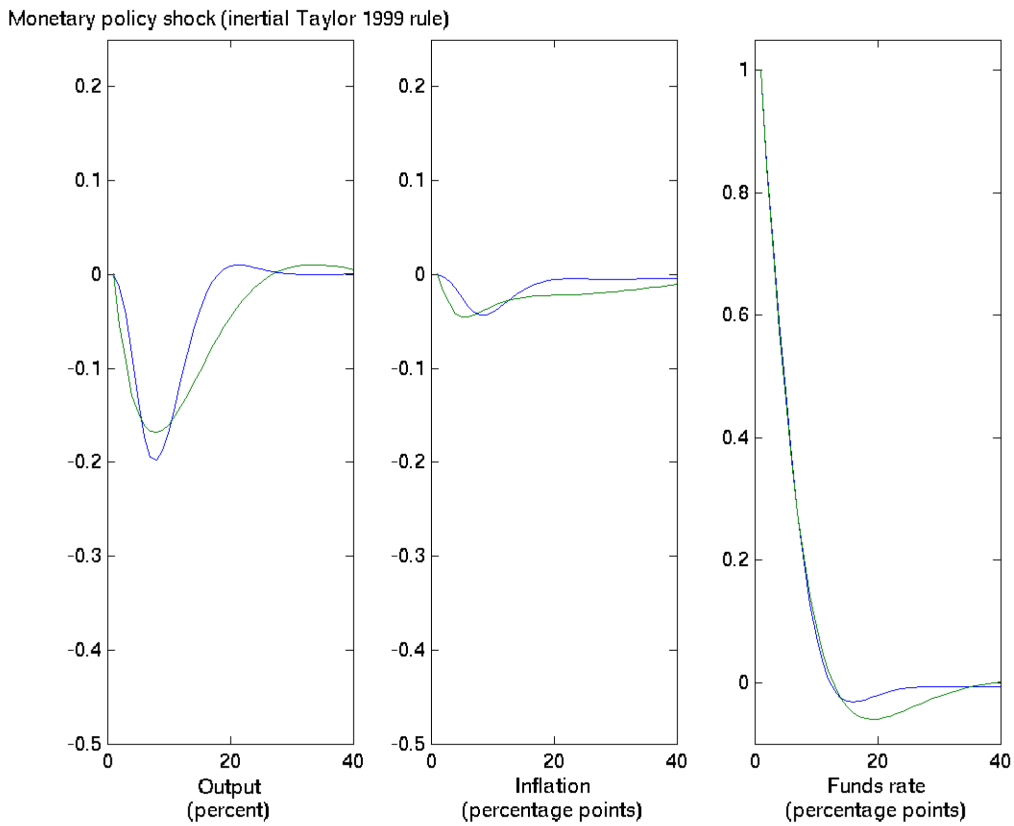
where w_t is the shock to the interest rate rule. For a strategy with a price-level element, we consider

$$r_t = 1.5\Delta p_t + y_t + .5 p_t + w_t \tag{5}$$

Note that the price-level approach implies a great deal of inertia in the nominal interest rate and hence the lagged interest rate is deleted from this rule.

Figure 1 presents the responses of output, inflation, and the nominal interest rate in

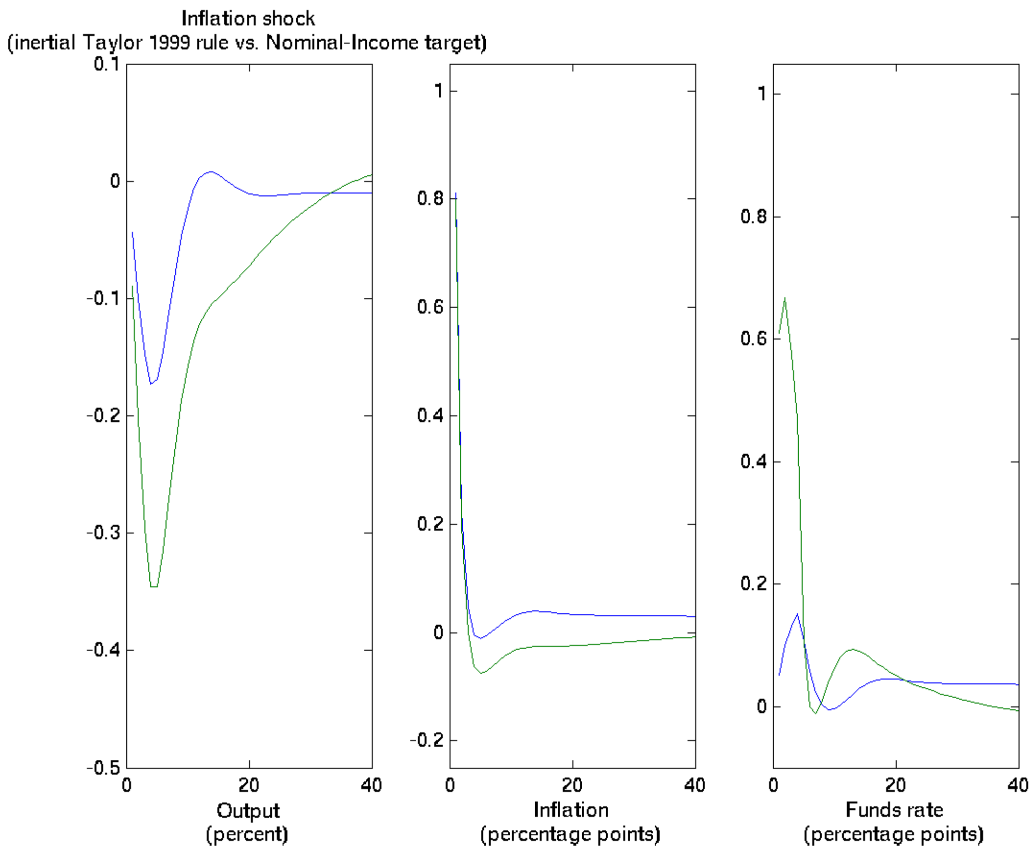
Figure 1: Response to Monetary Policy Shock in Simple Model (blue line) and Large (FRB/US) Model (green line)



the simple model and the larger FRB/US model (discussed further below) following a 100 basis point shock to the nominal interest rate under the assumed inflation-targeting rule. The responses in the models are quite similar, especially in light of the simple nature of the stylized model.

Turning to the costs and benefits of price-level targets, the costs can be well illustrated through a presentation of the effects of a shock to the Phillips curve that temporarily raises inflation with backward-looking long-run inflation expectations (figure 2). Under the inflation-targeting approach, monetary policy tightens with the increase in inflation but quickly returns the policy interest rate to baseline, and output declines only modestly (the blue lines). Results under a rule that brings the price level back to a baseline path are presented in the green lines. Because an inflation shock increases the price level,

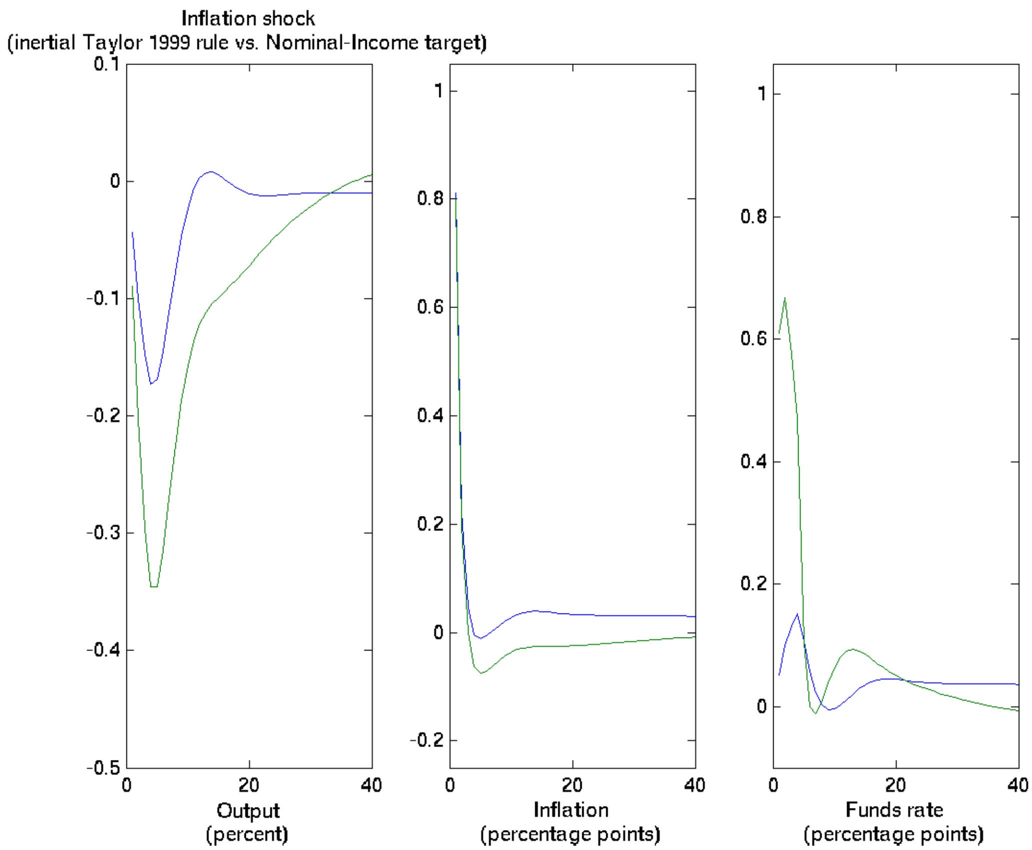
Figure 2: Cost of Price-level Target (green line) (Relative to Inflation Target (blue line)) Following Inflation Shock



monetary policy must be relatively "tight" following the shock, pushing output lower (and thereby eventually returning the price level to its baseline path). These dynamics imply that price-level targeting is costly in terms of excess output volatility under backward-looking inflation expectations, as emphasized in the literature. If one thinks of economic welfare, or the policymaker loss function, as being a function of squared deviations of output and inflation from their baseline levels (as in the New-Keynesian and monetary policy literatures), it is clear that price-level targeting is costly.

Nonetheless, there may be benefits to a price-level target when interest rates are constrained by the effective lower bound. Consider an economy in which the (non-stochastic) steady-state nominal interest rate is 2 percent - as would occur if the inflation target were 2 percent and the steady-state real interest rate were zero (as estimated by Laubach and

Figure 3: Benefit of Price-level Target (green line) (Relative to Inflation Target (blue line)) Following Adverse Aggregate Demand Shock



Williams [2003]). Figure 3 shows responses for the output gap, inflation, and the nominal interest rate following a sequence of large, negative shocks to the IS curve that would lower output in the presence of this lower bound on nominal interest rates under the inflation-targeting approach (the green lines) by more than 15 percent. A price-level targeting strategy (the blue lines) leads to a somewhat smaller decline in output and a faster return of inflation to its objective, with some overshooting of the target. This requires output to rise persistently above trend to push the price level back to its baseline path. The stabilizing effect of the price-level approach arises through the asset-price channel – that is, from long-term nominal interest rates. All told, the squared deviations of output and inflation from their steady-state values are smaller under the price-level strategy – although this owes importantly to the fact that the very large initial decline in output has a sizable effect on the sum of squared output gap deviations.[10] As a result, this impulse response analysis points to a benefit from price-level targeting even when inflation expectations are backward looking. (While not emphasized, the impulse response analysis of an adverse aggregate demand shock in Reifschneider and Roberts [2006] showed a similar result.)

Overall, this discussion highlights the key issues in previous work and the focus herein on asset-price transmission channels. Price-level targets may add to volatility in inflation and output if inflation shocks are important, in contrast to the emphasis in some New-Keynesian work. Nonetheless, the ability of monetary policy to influence demand through asset prices can make a price-level target valuable if the effective lower bound on nominal interest rates is binding.

In light of these considerations, an evaluation of price-level targets requires a model with several elements. First, the role of monetary policy actions in the determination of asset prices must be modeled. Second, the model should contain an empirical description of the importance of shocks to aggregate demand and aggregate supply, including shocks to the Phillips curve, in order to quantitatively evaluate the costs and benefits of a price-level target. Third, the model should be able to entertain the possibility of forward- or backward-looking behavior in the determination of inflation. Finally, the degree to which the effective lower bound may bind is central; as a result, the model must be quantitative, and any assessment should confront the evolving evidence on the possible value for the long-run steady-state real interest rate.

[10] The sum of absolute deviations of the output gap from zero is larger under the price-level strategy. Even so, mainstream thinking and models would point to smaller losses in the price-level target case: In particular, negative deviations of output from steady state are more costly than positive deviations because output is already inefficiently low owing to product and labor-market imperfections, suggesting that trimming the deep loss in output would have a larger benefit than the costs associated with modest degrees of output above its steady-state level.

4 The FRB/US Model

The FRB/US model can meet the criteria laid out at the end of the previous section. As described in Brayton, Laubach, and Reifschneider [2014], the FRB/US is one of several used by the Federal Reserve. It is a large-scale model, consisting of hundreds of equations, and its size and structure allow analysis of the effects of a broad range of policies and shocks. Household spending is determined by current income and life-time wealth, reflecting the assumption of some degree of "liquidity-constrained" households in conjunction with permanent-income considerations. Business investment is governed by (an empirically-determined) mix of user cost and accelerator factors. A large number of financial prices influence spending – nominal mortgage rates, interest rates on consumer durable-goods loans, corporate bond yields, equity prices, house prices, and the exchange value of the dollar are among the most important.

In addition, the FRB/US model allows for alternative assumptions regarding the expectations formation of different agents. For example, Afrouzi et al [2015] find that households and non-financial businesses do not pay much attention to central bank communications and suggest such expectations are largely backward-looking. In the FRB/US model, such backward-looking expectations, such as expectations for next-period's inflation (or income, or other factor), are specified through a regression of the variable on a set of lagged variables.[11] Alternatively, expectations can be modeled as consistent with the structure of the model, including the monetary policy regime, which allows for management of expectations (subject to the constraint that such managed expectations are model-consistent or "rational".)

In our simulations of the FRB/US model, we employ a linearized version and incorporate the non-linearity associated with an effective-lower bound on nominal interest rates using the algorithm outlined in the next subsection. This approach makes simulations for

[11] As such, these backward-looking expectations are not purely extrapolative – but are immune to direct management through changes in policy strategy.

many periods, and hence more accurate computation of moments under alternative monetary policy strategies, feasible; the nonlinear model in Brayton, Laubach, and Reifschneider [2014] is not amenable to such computations.[12] A comparison (not shown) of the impulse responses for a set of shocks in the linearized version of the model used herein with those from the non-linear version presented in Brayton, Laubach, and Reifschneider [2014], demonstrated that the models are similar along the quantitative dimensions emphasized in earlier work.

4.1 Basic intuition in the FRB/US model

With this qualitative discussion as background, our analysis turns to a discussion of quantitative properties of the FRB/US model and how we analyze the implications of alternative policy strategies for macroeconomic performance under different assumptions regarding the equilibrium real interest rate.

In light of our discussion of the role of expectations in the monetary-transmission mechanism and its effects on the possible merits of a price-level target, we emphasize two cases:

- **Rational asset pricing and wage/price determination**: Expectations for nominal interest rates and inflation are model-consistent in the equations determining long-term interest rates, asset valuations, and in the wage and price Phillips curves within the model. Expectations for inflation and other factors (e.g., expected income) are backward looking in spending equations.

- **Rational asset pricing**: Expectations are model-consistent in the equations determining long-term nominal interest rates and asset valuations. Expectations in wage and price Phillips curves and spending equations are backward looking.

In the first case, the management of inflation expectations directly affects inflation performance through the effects emphasized in the New-Keynesian literature. In the second

[12]Programs to replicate all simulation results are available upon request following the completion of a final version of this working paper.

case, these effects are absent, and the only variables that "jump" in response to monetary policy strategies are financial-market variables. Both of these cases are emphasized in the public version of FRB/US presented in Brayton, Laubach, and Reifschneider [2014].

These cases are able to capture the key elements linking strategies and expectations emphasized in previous work, as illustrated in impulse responses under the following policy strategies:

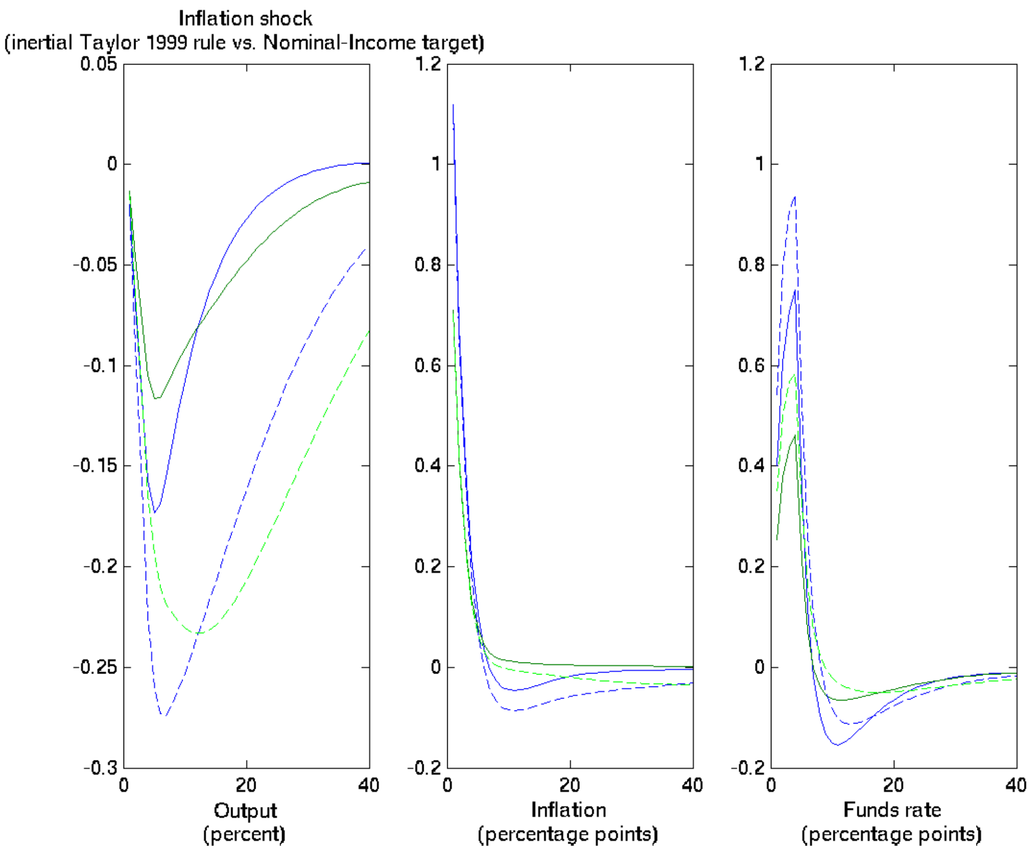
- Taylor [1999] rule: $r_t = r^* + \pi_t + .5(\pi_t - \pi^*) + y_t$;
- Taylor [1993] rule with nominal income: $r_t = r^* + \pi_t + .5(\pi_t - \pi^*) + .5y_t + .5 * (y_t + p_t)$;

The first rule is one benchmark in the literature and is regularly presented to the FOMC.[13] The second takes the classic Taylor [1993] rule and appends a "nominal income" term (the sum of the output gap and a price level), with a coefficient equal to that on the inflation and output gaps in Taylor [1993]; note that this is equivalent to appending a price-level term to the Taylor [1999] rule with a coefficient equal to that on the inflation gap. In each case, inflation is measured by the four-quarter change in the personal consumption expenditures price index, excluding food and energy, and the price-level term is given by the same index.

Our quantitative illustrations begin with the issues depicted earlier with the simple model – that is, the dynamics following an inflation shock and following a severe aggregate demand contraction in which the effective-lower bound binds. Results under both forward-looking wage and price expectations (the blue lines) and backward-looking wage-and-price dynamics (the green lines) are presented in figure 4. The results under inflation targeting are presented as solid lines, and those under a price-level target are presented as dashed lines. Overall, the results echo those in the simple model: A price-level target requires monetary policy to depress demand following an inflation shock, and this effect implies that output movements are exacerbated following an inflation shock relative to the

[13] See the most recent publicly available discussion of monetary policy strategies presented to the FOMC at http://www.federalreserve.gov/monetarypolicy/files/FOMC20091216bluebook20091210.pdf.

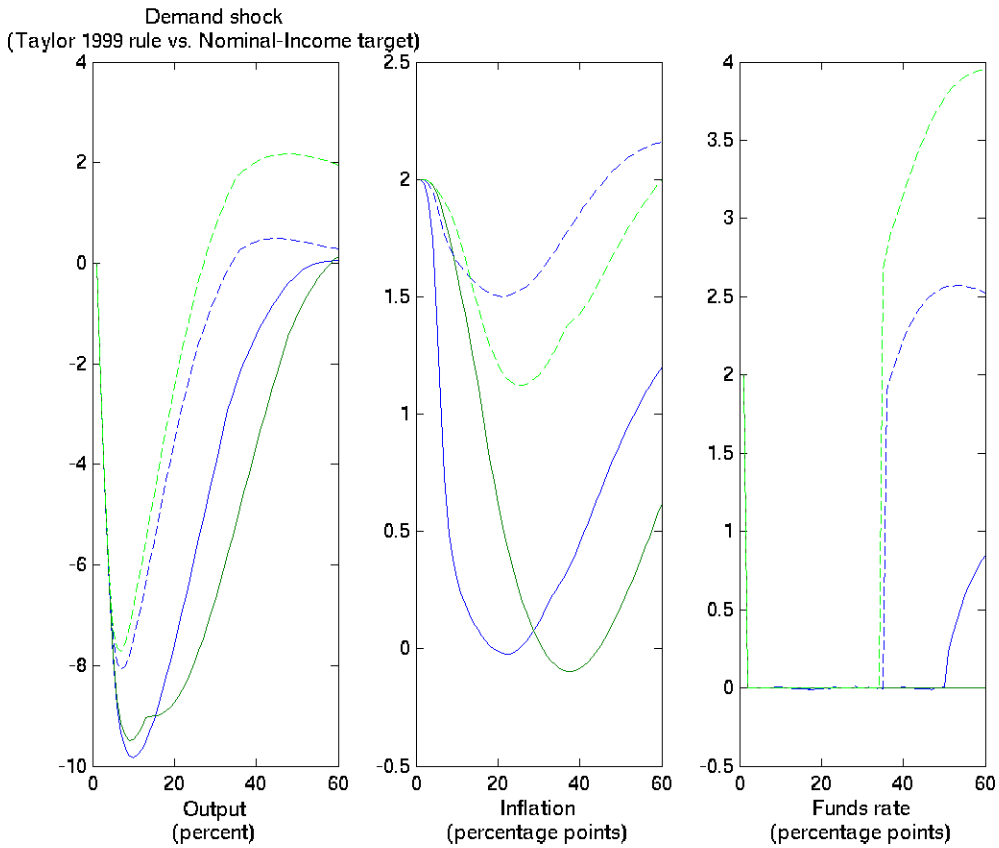
Figure 4: Cost of Price-level Target (dashed lines) (Relative to Inflation Target (solid line)) Following Inflation Shock in FRB/US Model
(Blue: forward-looking inflation; Green: backward-looking inflation)



inflation-targeting case. As in the simple model, the quantitative differences are relatively small for a one-standard deviation inflation shock, as can be seen by examining the scale of the graphs (where the differences in output movements are on the order of tenths of a percentage point).

Figure 5 presents impulse responses following a large sequence of adverse aggregate demand shocks, analogous to those from the simple model presented in figure 3. As in figure 4, the results under inflation targeting are presented as solid lines, and those under a price-level target are presented as dashed lines. In both cases, price-level targeting substantially mitigates the effects of the aggregate demand contraction – the similarity across expectations assumptions makes it clear that the important expectations channel in

Figure 5: Benefits of Price-level Target (dashed lines) (Relative to Inflation Target (solid line)) Following Adverse Aggregate Demand Shock in FRB/US Model
(Blue: forward-looking inflation; Green: backward-looking inflation)



the FRB/US model, for these issues, are expectations embedded in asset prices. Overall, the benefit of a price-level target are much more clear in this large-scale, estimated model than in the simple model presented earlier.

4.2 Stochastic simulations in the absence of an effective lower bound

While the impulses responses in the previous subsection highlight how the FRB/US model can capture the intuition driving previous results in the literature on price-level targets, they are only a first step. In particular, price-level targets within a model similar to the FRB/US model is not the "free lunch" that arises in some DSGE models (e.g., Chung, Herbst, and Kiley [2014]), and has both benefits and costs. If the factors that would raise costs, such as a great deal of instability in the price level owing to shocks to the Phillips curve, are large relative to those that may make a price-level target desirable, such as a very significant role for "aggregate demand" shocks, then the possible benefits may not outweigh the costs.

As a first step to gauging these trade-offs and a complementary exercise to aid in understanding of the FRB/US model, we present a variance decomposition of the sources of economic fluctuations in the FRB/US model in the absence of the effective lower bound on nominal interest rates. This decomposition sorts the 63 shocks in the FRB/US model into four broad categories:

- **Financial shocks**: Shocks to equity and house prices, corporate bond spreads, Treasury yields and mortgage rates, the exchange value of the dollar, and similar factors.
- **IS-curve shocks**: Shocks to the spending equations for categories of personal consumption expenditures, residential and nonresidential investment categories, government expenditures, exports, and imports.
- **Potential-output shocks**: Shocks to productivity and labor supply.
- **Phillips-curve shocks**: Shocks to the wage and price Phillips curves, energy- and food-price shocks, import-price shocks, other relative price shocks, and shocks to energy consumption or production.

In the FRB/US model, these shocks are not orthogonal, and hence there is a residual category reflecting the covariance across shocks. Table 1 presents the variance decomposition, ignoring the effective-lower bound constraint. A few results are clear. First, most fluctuations in the output gap are attributed to aggregate demand shocks, and most fluctuations in inflation are attributed to inflation shocks. Second, the importance of aggregate demand shocks is higher for prices than is the importance of price shocks for the output gap. Third, the output gap is much more variable than is inflation – which, under a strategy such as Taylor [1999] with a sizable role for the output gap in determination of the

Table 1: Various Decomposition of Output and PCE Price Inflation in the FRB/US Model
(forward-looking version)

	Output gap	Inflation
Variance	5.55	3.02
	Percent explained by	
Financial shocks	42.4	19.1
IS-curve shocks	57.4	20.7
Price shocks	5.2	75.3
Potential shocks	0.1	12.9
Residual covariance effects	-5.1	-27.9

nominal interest rate – suggests that aggregate demand may be the dominant factor in the tradeoffs affecting the merits of price-level targeting at the effective-lower bound on nominal interest rates that have been illustrated in the impulse responses shown so far. The next section turns to stochastic simulations with an effective-lower bound to assess this possibility.

5 Results

5.1 Simulations with an effective lower bound on nominal interest rates

The remainder of our analysis considers outcomes across large numbers of simulations in the presence of an effective lower bound on nominal interest rates. While a great deal of progress has been made in simulating models with an effective lower bound on nominal interest rates (e.g., Guerrieri and Iacoviello [2015]), such approaches encounter numerical challenges in simulations with a large model such as the FRB/US model. As a result, we develop a simulation approach well-suited to the challenges associated with the FRB/US model. Our simulations consist of the following approach:

1. Solve for the moving average representation of the model under each policy strategy

in the absence of an effective lower bound on interest rates.[14]

2. Draw a sample of shocks from the FRB/US model's shock distribution of 200 quarters; this step is repeated 50 times.

3. For each draw of shocks and assumed equilibrium real interest rate, compute the evolution of the economy from period 0 to period t. If the effective lower bound on nominal interest rates binds, compute anticipated shocks to impose the bound and the horizon over the bound holds, up to N quarters. The horizon N is chosen to be sufficiently large so as to not bind in any simulations.[15]

4. Go to the next period, and check if expectations for the duration of the effective lower bound have changed, recomputing shocks as appropriate.

The algorithm produces results that match those produced by the algorithm of Guerrieri and Iacoviello [2015] for cases in which the Guerrieri and Iacoviello [2015] algorithm converges; an appendix provides an illustration. However, the algorithm herein always converges – subject to the limitation that it is possible that the limit imposed in step 3 that lower bound episodes are expected to be at most 60 quarters may be violated – whereas that of Guerrieri and Iacoviello [2015] fails to converge frequently.[16] Moreover, the algorithm succeeds in imposing the lower bound in (the rare) cases where the approach in Williams [2009] fails; that said, a comparison of simulations herein with analogous exercises using the approach of Williams [2009] suggests similar results (as also discussed in an appendix).[17]

[14]The moving average representation is found through inversion of the vector-autoregressive representation produced by the Dynare algorithm of Adjemian et al [2011].

[15]In practice, a horizon of 60 quarters is sufficient for a steady-state nominal interest rate of 3 percent or greater. For a steady-state nominal interest rate of 2 percent, a horizon of 80 quarters was used. Note that in both of these cases, the algorithms allow expectations for very prolonged periods at the lower bound on nominal interest rates (e.g., up to 20 years for an inflation target of 2 percent and an equilibrium real interest rate of 0 percent); these episodes are ruled out in earlier work imposing expectations that only a few years at the lower bound are expected, as discussed in the appendix comparing results to earlier work.

[16] citeHolden discusses this issue.

[17]Williams [2009] also uses the FRB/US model. His approach builds on the algorithm of Anderson and Moore [1985].

5.2 Quantitative importance of the effective-lower bound

We now turn to the main simulation results. The inflation target is set at 2 percent. The steady-state real short-term (federal funds) rate is assumed to lie between 0 percent (near estimates from Laubach and Williams [2003]) and 3 percent (a figure arguably characteristic of the 1980s or the period around 2000). These assumptions imply a steady-state nominal rate of interest from 2 percent to 5 percent. The effective lower bound on nominal interest rates is set to zero.

Results under forward-looking asset prices and Phillips curves are presented first. Statistics for the root-mean-square of the output gap and inflation (where steady-state inflation is 2 percent) are reported in table 2 for each possible steady-state nominal interest rate. The table also includes the frequency with which the effective lower bound is binding. With forward-looking Phillips curves, price-level targeting results in similar (or better) outcomes for output and inflation to other strategies as measured by the root-mean square and the mean outcome relative to objective– as in DSGE models, price-level targeting is not costly. For low values of the equilibrium interest rate, price-level targeting does an excellent job at stabilizing the economy. The other strategies do relatively poorly. In addition, the FRB/US model implies that the deterioration in economic performance as the equilibrium interest rate falls is manifest first in changes in output volatility; only at very low equilibrium interest rates does inflation performance change significantly. This behavior contrasts with that in many DSGE models. Finally, interest rates are very often stuck at their effective lower bound for low equilibrium real interest rates. For an equilibrium real interest rate in the 0-to-1 percent range estimated in Kiley [2015] and Laubach and Williams [2003], the lower bound binds between from approximately 20 percent to more than 40 percent of the time.

It is also interesting that the Taylor [1999] rule with inertia leads to poor performance more quickly as the equilibrium rate falls, with output volatility increasing markedly under this approach for an equilibrium interest rate of 3 percent or less. This occurs because inertia slows the response of monetary policy when activity deteriorates, which worsens outcomes (Reifschneider and Williams [2000]). This is the flip side of why inertia works when the economy is emerging from an effective lower bound (ELB) episode, which promotes recovery as emphasized by Yellen [2012, 2013], English, Lopez-Salido, and Tetlow [2013], and Reifschneider, Wascher, and Wilcox [2013].

Results for backward-looking Phillips curves and forward-looking asset prices are contained in table 3. When the equilibrium real interest rate is high, a price-level element in the monetary-policy strategy exacerbates the volatility of economic activity, as is clear from the cases in which the nominal equilibrium rate is 4 or 5 percent. In this respect, our analysis echoes the conclusion in earlier work about possible costs of a price-level target. However, these effects are modest. In contrast, these types of costs are clearly outweighed by the benefits of a price-level strategy if the equilibrium interest rate is 3 percent or below. Strategies without a price-level target perform very poorly once the equilibrium rate falls to a low level – such as the levels recently estimated (e.g., Kiley [2015], Johanssen and Mertens [2015], and Laubach and Williams [2003]). In this sense, the costs of a price-level target are modest in the cases where such a target detracts from economic performance, but the benefits are very sizable in those cases where the equilibrium real interest rate is low. Finally, the lower bound is binding up to approximately one-third of the time for low values of the equilibrium real interest rate.

Looking across results, it is clear that forward-looking nominal wages are prices are not necessary for price-level targeting to dominate inflation targeting. Rather, forward-looking financial markets are most important in delivering a role for price-level targeting.

5.3 Why is the frequency of lower bound episodes so high?

Some readers, familiar with analyses in Reifschneider and Williams [2000] or Williams [2009], may be surprised at the frequency with which the lower bound binds and ask why results appear different than in these earlier analyses.

Table 2: Outcomes Under Forward-looking Asset Prices and Phillips Curve

	Root-mean square		**ELB frequency**	**Mean**	
	Output gap	**Inflation**	**(percent)**	**Output gap**	**Inflation**
	Steady State Nominal Interest Rate equals 5 percent				
Taylor [1999]	2.5	2.6	12.9	-0.3	1.9
Inertial Taylor [1999]	2.8	2.6	8.2	-0.3	1.9
Taylor [1993] with nominal income	2.5	2.4	8.8	-0.1	2.0
	Steady State Nominal Interest Rate equals 4 percent				
Taylor [1999]	2.9	2.6	20.3	-0.5	1.8
Inertial Taylor [1999]	3.2	2.6	13.9	-0.5	1.8
Taylor [1993] with nominal income	2.6	2.4	14.2	-0.2	2.0
	Steady State Nominal Interest Rate equals 3 percent				
Taylor [1999]	3.8	2.6	30.6	-0.9	1.7
Inertial Taylor [1999]	5.5	2.7	25.3	-1.4	1.5
Taylor [1993] with nominal income	2.8	2.4	22.2	-0.3	2.0
	Steady State Nominal Interest Rate equals 2 percent				
Taylor [1999]	39.1	14.9	42.8	-6.7	-1.2
Inertial Taylor [1999]	263.3	87.8	40.1	-27.0	-8.9
Taylor [1993] with nominal income	3.2	2.4	33.8	-0.5	2.0

Table 3: Outcomes Under Forward-looking Asset Prices (only)

	Root-mean square		**ELB frequency**	**Mean**	
	Output gap	**Inflation**	**(percent)**	**Output gap**	**Inflation**
	Steady State Nominal Interest Rate equals 5 percent				
Taylor [1999]	2.9	2.2	9.7	-0.2	1.9
Inertial Taylor [1999]	3.0	2.2	6.9	-0.2	1.9
Taylor [1993] with nominal income	3.9	2.3	11.7	0.2	2.0
	Steady State Nominal Interest Rate equals 4 percent				
Taylor [1999]	3.3	2.2	16.7	-0.3	1.8
Inertial Taylor [1999]	3.4	2.2	13.2	-0.4	1.8
Taylor [1993] with nominal income	3.9	2.2	17.0	0.3	1.9
	Steady State Nominal Interest Rate equals 3 percent				
Taylor [1999]	11.0	3.6	28.5	-2.1	1.1
Inertial Taylor [1999]	7.1	2.6	25.2	-1.5	1.4
Taylor [1993] with nominal income	4.0	2.2	22.5	0.4	1.9
	Steady State Nominal Interest Rate equals 2 percent				
Taylor [1999]	30.1	11.7	33.6	-3.3	-0.5
Inertial Taylor [1999]	46.0	14.8	31.4	-5.9	-0.8
Taylor [1993] with nominal income	4.2	2.2	28.9	0.7	1.9

Table 4: Frequency of Binding ELB under Alternative Approaches

Steady State Nominal Interest rate	Our approach	Algorithm of Williams [2009]
5 percent	12.9	9.8
4 percent	20.3	13.3
3 percent	30.6	24.1
4 percent	42.8	44.7

While the version of the FRB/US model used herein differs from that in, for example, Williams [2009] and the solution algorithm is somewhat different, neither of these factors contributes importantly to the differences. Rather, Reifschneider and Williams [2000] and Williams [2009] both assume that the central bank automatically raises its inflation target in a rule such as the Taylor [1999] rule so as to eliminate the downward bias in inflation associated with low equilibrium real interest rates. That is, this studies assume that the central bank , in the absence of shocks, will pursue a rate of inflation on the order of 4 percent per year if it wants to ave an average inflation rate of 2 percent per year, given the size of the biases in inflation for an inflation target of 2 percent per year reported in table 2.

Table 4 demonstrates that this is a key source of differences. The table reports the frequency of the lower bound on nominal interest rates for equilibrium real interest rates between 0 and 3 percent for an inflation target of 2 percent when monetary policy is set according to the Taylor [1999] rule, under the approach herein and using the code from Williams [2009] without assuming any increase in the inflation target.[18] If the equilibrium real interest rate is as low of 0 percent, as in Laubach and Williams [2003] and implying a steady-state nominal interest rate of 2 percent, the lower bound binds more than 40 percent of the time under either algorithm.

These results highlight how one approach to lowering the adverse effects of a lower bound on nominal interest rates is to pursue a higher inflation target.

[18]At low levels of the equilibrium real interest rate, the algorithm of Williams [2009] faces numerical difficulties; an appendix discusses this issue.

5.4 A price-level target or higher inflation target

While the challenges of an effective lower bound on nominal interest rates naturally suggest the possibility of raising the inflation target, a long-literature suggests that there are costs to a higher inflation target[19] In the New-Keynesian literature, such costs are captured by a loss function of the form

$$L = E_t[\Delta p_t^2 + \lambda y_t^2]. \tag{6}$$

This expression includes a loss from both the level and volatility of inflation. Increases in the inflation target – for example, from 2 to 3 – immediately raise losses from a minimum of 4 to a minimum of 9, assuming the target is met. As was demonstrated in the previous section, a monetary policy strategy consistent with inflation targeting must aim for an inflation rate above its true goal when the equilibrium real interest rate is low because of the substantial downward bias in inflation outcomes in those circumstances. Nonetheless, the direct effect of average inflation on welfare suggests that it may be preferable to adopt a price-level target rather than raise the inflation target.

An in-depth analysis of this issue requires a much more careful examination of the costs of inflation. However, the results in tables 2 and 3 indicate the following for the case when λ equals one:

- Under backward-looking price setting, a price-level target (holding the inflation target at 2 percent) leads to lower loss than an inflation target of 3 percent only if the equilibrium real interest rate is 2 percent.

- Under forward-looking price setting, a price-level target dominates raising the inflation target for all equilibrium real interest rates.

While only suggestive, these results point to the possibility that price-level targets may be

[19]Fischer and Modigliani [1978] reviews a large literature. The New-Keynesian model emphasizes costs of non-zero inflation (Woodford [2009]). Shiller [1997] reviews the public's strong dislike of inflation.

superior to a higher inflation target under some conditions.

6 Areas for further exploration

We have re-examined the frequency with which the lower bound on nominal interest rates may bind, the costs of this lower bound in terms of the stabilization objectives of a central bank, and the role of the level of the inflation target or a price-level target in shaping these outcomes. Our analysis suggest several conclusions.

- Model simulations demonstrate that the effective lower bound on nominal interest rates may bind nearly one-third of the time at recently estimated values of the equilibrium real interest rate and an inflation target of 2 percent.
- In the presence of an effective lower bound on nominal interest rates, economic stability under inflation-targeting regimes can deteriorate substantially if the equilibrium interest rate is low.
- In addition, average economic performance deteriorates as well, with inflation and resource utilization typically averaging below desired levels when the equilibrium interest rate is low.
- In the absence of alternatives to inflation targeting, this result points to potential benefits from an inflation target above 2 percent.
- Price-level targets mitigate substantially the risks to economic performance created by the interaction of a low equilibrium real interest rate and an effective lower bound on the nominal interest rate. Price-level targets enhance economic performance substantially–even with a large backward-looking component to inflation–as long as asset prices are forward looking and affect economic activity.

These results suggest several areas for further analysis. First, the exploration herein has focused on simple rules (or small modifications thereof) that policymakers and policy institutions have discussed as reasonable approximations to the broad contours of monetary policy. This approach makes the results herein relevant for policy discussions, but begs the question of what approaches are "optimal" to deal with the question we analyze. Second, the analysis discussed the central role that an evaluation of the costs of steady-state inflation in an assessment of a higher inflation target, but did not investigate these costs in detail. Finally, our modeling approach has been somewhat *ad hoc*, and it may be interesting to explore micro-founded models distinguishing between asset price and inflation transmission channels as in this work.

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A Appendix: Solution methods

As discussed in the main text, the solution method used in stochastic simulations imposing the zero-lower bound involves the following steps.

1. Solve for the moving average representation of the model under each policy strategy in the absence of an effective lower bound on interest rates. The moving average representation is found through inversion of the vector-autoregressive representation produced by the Dynare algorithm of Adjemian et al [2011].

2. Draw a sample of shocks from the FRB/US model's shock distribution of 200 quarters; this step is repeated 50 times.

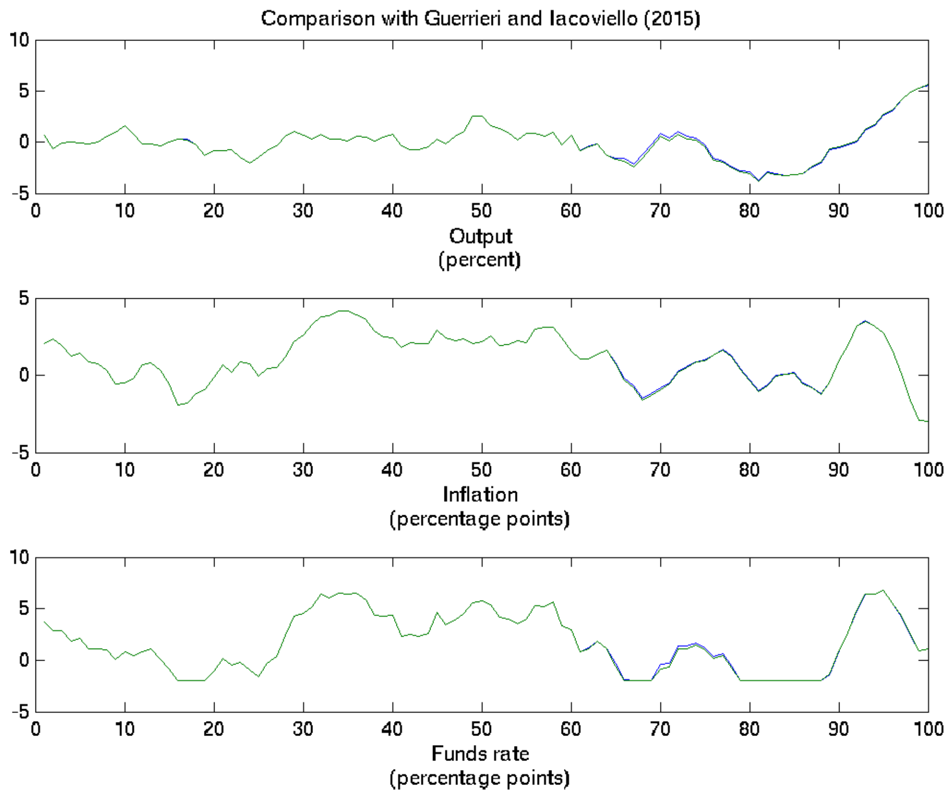
3. For each draw of shocks and assumed equilibrium real interest rate, compute the evolution of the economy from period 0 to period t. If the effective lower bound on nominal interest rates binds, compute anticipated shocks to impose the bound and the horizon over the bound holds, up to N quarters. The horizon N is chosen to be sufficiently large so as to not bind in any simulations. In practice, a horizon of 60 quarters is sufficient for a steady-state nominal interest rate of 3 percent or greater. For a steady-state nominal interest rate of 2 percent, a horizon of 80 quarters was used. Note that in both of these cases, the algorithms allow expectations for very prolonged periods at the lower bound on nominal interest rates (e.g., up to 20 years for an inflation target of 2 percent and an equilibrium real interest rate of 0 percent); these episodes are ruled out in earlier work imposing expectations that only a few years at the lower bound are expected, as discussed in the appendix comparing results to earlier work.

4. Go to the next period, and check if expectations for the duration of the effective lower bound have changed, recomputing shocks as appropriate.

Alternative algorithms, using the vector-autoregressive representation and a non-linear minimization routine to impose the lower bound on nominal interest rates, have often been used in analogous applications, as in Guerrieri and Iacoviello [2015], Reifschneider and Williams [2000], and Williams [2009]. As discussed in Holden [2016], such approaches are not guaranteed to converge. The lack of convergence can reflect a number of factors, including the possibility that no solution exists, the existence of multiple solutions, or an inability of the numerical optimization routine to find the solution path. In our applications, at least one solution always exists (the one we find), but we cannot rule out the possibility of other solution paths.

Guerrieri and Iacoviello [2015] develop an algorithm, to be applied to any linear model subject to occasionally binding constraints, which efficiently computes a large number of stochastic simulations using the Dynare package (Adjemian et al [2011]). As emphasized by Guerrieri and Iacoviello [2015] and Holden [2016], this algorithm is not guaranteed to converge to a solution – and non-convergence was the norm in the simulations conducted using this algorithm for the analysis herein. That said, our approach should generate the same outcomes as those in Guerrieri and Iacoviello [2015] when their algorithm does converge. This property is illustrated in figure 6, which presents the solution form the

Figure 6: Simulation of Alternative Algorithms
(blue line, herein) (green line, Guerrieri and Iacoviello [2015])



algorithm herein for a simulation of 100 periods in which the approach of Guerrieri and Iacoviello [2015] converges. As is apparent from the fact that the lines lie on top of each other, outcomes are nearly identical.

Williams [2009] uses an approach very similar to that in citeGI (albeit based on the algorithm of Anderson and Moore [1985]). A key difference is that the approach in Williams does not stall when it fails to find a path that imposes the lower bound on nominal interest rates – rather, the algorithm of Williams [2009] simply allows the nominal interest rate to fall below its lower bound. In the analysis in Williams [2009], this issue was not encountered, as it considered equilibrium real interest rates above those analyzed herein and raised the inflation target to as to avoid any bias in realized inflation relative to the central bank's objective. Herein, the problem was encountered, albeit rarely. Nonetheless, the approach in Williams [2009] yields very similar conclusions, as presented in the main text in table 4.