Monetary Policy in a Low Interest Rate World

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ABSTRACT

Nominal interest rates may remain substantially below the averages of the last half-century, as central bank's inflation objectives lie below the average level of inflation and estimates of the real interest rate likely to prevail over the long run fall notably short of the average real interest rate experienced over this period. Persistently low nominal interest rates may lead to more frequent and costly episodes at the effective lower bound (ELB) on nominal interest rates. We revisit the frequency and potential costs of such episodes in a low-interest-rate world in a dynamic-stochastic-general-equilibrium (DSGE) model and large-scale econometric model, the FRB/US model. Several conclusions emerge. First, monetary policy strategies based on traditional policy rules lead to poor economic performance when the equilibrium interest rate is low, with economic activity and inflation more volatile and systematically falling short of desirable levels. Moreover, the frequency and length of ELB episodes under such policy approaches is significantly higher than in previous studies. Second, a risk-adjustment to a simple rule in which monetary policymakers are more accommodative, on average, than prescribed by the rule ensures that inflation achieves its 2 percent objective and requires that policymakers aim at inflation near 3 percent when the ELB is not binding. Third, commitment strategies in which monetary accommodation is not removed until either inflation or economic activity overshoot their long-run objectives are very effective in both the DSGE and FRB/US model. Finally, our results suggest that the adverse effects associated with the ELB may be substantial at inflation targets near 2 percent if r* is low and monetary policy follows a traditional policy approach. Whether such adverse effects could justify a higher inflation target depends on whether monetary policy strategies substantially different from traditional approaches are feasible and an assessment of the effects of the inflation target on economic welfare.

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During the low inflation period of recent decades, the effective lower bound (ELB) across Europe, Japan, and the United States has been binding a large fraction of the time, impeding macroeconomic performance. ELB episodes may be more frequent and costly in the future, as nominal interest rates may remain substantially below the norms of the last fifty years.

Heightening this concern is the possibility that structural factors have depressed, and will continue to depress for some time, the level of the (short-term) real interest rate consistent with price stability and economic activity at its potential level. This level of the real interest rate, often termed the *equilibrium real interest rate r**, may have fallen for many reasons, including a slower rate of technological progress; the demographic transitions associated with the aging of the Baby Boom, increased longevity, and changes in the dependency ratio; the overhang from an excessive buildup of household debt through the mid-2000s; and shifts in the demand for safe and liquid assets.[2] A number of empirical studies document a decline in *r**: While there is considerable uncertainty about the current level and its future trajectory, many studies— including Del Negro et al. (2017), presented at this conference—suggest that *r** may be near 1 percent (or lower) at an annual rate, 1 to 2 percentage points below that average real interest rate in the period since the middle of the last century.

The potential decline in the equilibrium real interest rate has been accompanied by a decline in the level of inflation expected to prevail over the longer run—a decline owing, in large part, to the shift in central bank's objectives toward targeting a level of inflation near 2 percent. Figure 1 graphs the evolution of the nominal effective federal funds rate, inflation, and a survey measure of long-term inflation expectations. The downward drift in nominal rates and inflation is striking, and points to the possibility that nominal interest rates may remain persistently below the averages of the past half-century.

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[2] In addition to Del Negro et al (2017), discussions of factors that may contribute to a lower r* include Hamilton et al (2015), Gagnon, Johanssen, and Lopez-Salido (2016), and Eggertsson, Mehrotra, and Robbins (2017).

Figure 1: The Nominal Federal Funds Rate, Inflation, and Long-run Inflation Expectations
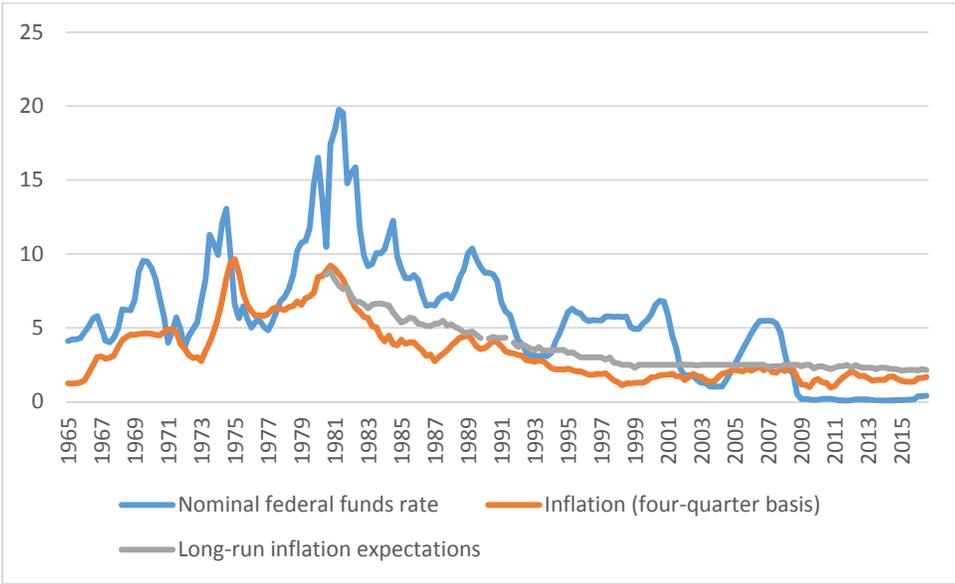

A simple thought experiment highlights the potential importance of persistently lower interest rates for the frequency of the ELB. Over the period from 1960 to 2007, the nominal federal funds rate averaged about 6 percent, with a standard deviation of 3¼ percent. Figure 2 presents the probability density function of a variable with this mean and standard deviation, assuming a normal distribution, as the black-solid line. As can be seen at the intersection of the shaded region that begins at zero and the density function, this distribution implies that an observer might expect an effective-lower bound of zero to bind rarely (less than 5 percent of the time): Over the 48 years from 1960 to 2007, this expected event—about two years of the nominal interest rate below zero—did not occur, but was realized soon thereafter.

The other density function maintains the standard deviation of the nominal interest rate, but assumes that its mean is lower at 3 percent. Such lower values could stem from an inflation target below the mean of inflation from 1960 to 2007, as core PCE price inflation averaged a bit more than 3½ percent over that period and most target rates of inflation in advanced economies are notably below this level. Alternatively, a lower steady-state nominal interest rate could reflect the decline in the equilibrium real interest rate. Whatever the cause, a decline in the steady-state nominal interest rate implies a sharply rising incidence of the ELB. For example, a steady-state nominal interest rate of 3 percent is consistent with an inflation target of 2 percent and $r*$ equal to 1 percent, and, according to the corresponding density function presented in the

red line, would imply nominal interest rates below zero 18 percent of the time. A binding ELB of this magnitude would lead to a deterioration in economic activity and inflation—and thereby amplify the costs and frequency of the ELB. For example, as we discuss in detail below, one possible consequence is the inflation target of 2 percent not being met consistently.

Figure 2: Probability Density Functions for Alternative Steady-State Nominal Interest Rates under Assumption of Normality
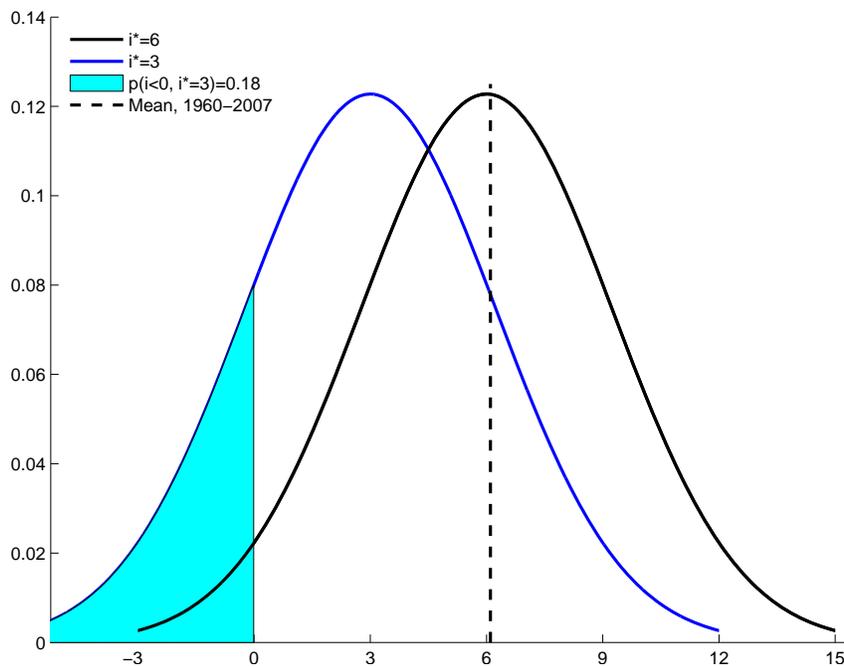
To quantify the magnitude of this amplification and to assess strategies to address it, we employ simulations of macroeconomic models. Alternative macroeconomic models may have different implications for the degree to which the ELB may affect economic and price stability. We use two models—the Federal Reserve Board staff's FRB/US model and a dynamic-stochastic-general-equilibrium (DSGE) model. As emphasized in Brayton, Laubach, and Reifschneider (2014) and Laforte and Roberts (2014), the FRB/US model is extensively used in monetary-policy analysis at the Federal Reserve and captures features of the economy that reflect consensus views across macroeconomists, but is not strictly "micro-founded" in the manner used in many academic analyses. The DSGE model we use, from Lindé, Smets, and Wouters (2016), is much smaller than FRB/US, but also shares a number of features with FRB/US, including

similar contours of the effects of monetary policy on economic activity and inflation.[3]   In spite of these similarities, the DSGE model also features substantially greater amplification of shocks at the ELB and a more powerful role for forward guidance regarding monetary policy to affect outcomes. These differences will allow us to examine the robustness of certain model predictions and policy strategies related to the effects of the ELB, and hence provide insights beyond studies using either the FRB/US model or a DSGE model in isolation.

Our simulations suggest that an economy in which the steady-state nominal interest rate equals 6 percent, about the average value for the nominal federal funds rate from 1960 to 2007, will rarely encounter an ELB of zero under a policy rule estimated on U.S. data or under a simple benchmark rule, which takes the form of the rule in Taylor (1993).[4]   As noted in earlier work with the FRB/US model (Reifschneider and Williams, 2000; Williams, 2009), performance under an estimated rule or the simple rule deteriorates sharply in FRB/US for steady-state nominal interest rates of 4 percent or less, as would be implied by an inflation target of 2 percent and values of $r*$ of 2 percent or less. In such circumstances, the ELB binds often and inflation falls systematically short of the 2 percent objective; in addition, output is, on average, below its potential level.

Quantitatively, we find that the incidence and severity of ELB episodes is notably larger than in previous work. Consider first previous work with the FRB/US model. In our analysis, output falls 1 percent below potential, on average, and the ELB binds two-fifths of the time when the long-run nominal interest rate is 3 percent; this estimate of ELB incidence compares to an estimate of 16 percent under the simple rule and "worst case" assumption in Williams (2009). Earlier work with DSGE models had also been quite sanguine about the consequences of the

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[3] Boivin, Kiley, and Mishkin (2010) highlight the similarities and differences in the monetary-policy transmission mechanism across models like the FRB.US model and DSGE models.

[4] As we discuss more thoroughly below, we employ a simple rule that responds more forcefully to the output gap than the initial Taylor (1993) rule, as considered in Taylor (1999) and suggested in Bernanke (2015a). Yellen (2017) labeled this rule the "balanced approach." It is among the rules that began to be regularly reported to the FOMC starting in 2004; see
https://www.federalreserve.gov/monetarypolicy/fomchistorical2004.htm). Bernanke (2015a) reported that, in his experience, the Federal Open Market Committee paid more attention to rules such as the balanced rule than to other related rules. The specific coefficient on the output gap is not central to our qualitative or quantitative conclusions.

ELB for macroeconomic performance—see, for example, Coibion, Gorodnichenko, and Wieland (2012).

As we discuss in more detail below, there are several reasons we find more frequent and severe ELB episodes than earlier analyses using FRB/US or DSGE models. One is that we consider lower values of the equilibrium federal funds rate than some earlier studies. More importantly, these earlier studies often assumed policy rules that differ in important ways from the canonical simple rules, including implicit channels generating commitments or forward guidance. For example, the rules considered by Williams included a fallback mechanism for providing the accommodation precluded by an ELB that substantially mitigates the adverse effects of the ELB. Similarly, Coibion, Gorodnichenko, and Wieland (2012) construct a "shadow" interest rate that keeps track of accommodation foregone because of the ELB and commits to make up some of this foregone accommodation. Commitments are effective in both the FRB/US and DSGE models, and hence a good part of the sanguine assessment of the effects of the ELB in previous analyses owe to their commitment assumptions.

To address the sizable consequences of the ELB, the first strategy we consider is a risk adjustment to the policy rule, in which the short-term nominal interest rate is set, on average, at a level below the value prescribed by a traditional simple rule in order to ensure that inflation equals, on average, an assumed inflation target of 2 percent. Earlier work, including Reifschneider and Williams (1999), Williams (2009), and Nakata and Schmidt (2016), considered a similar adjustment. We find moderate risk adjustments on the order of ½ to 1 percentage point ensure that inflation averages 2 percent when $r*$ is as low as 1 percent and the inflation target is 2 percent. Such risk adjustments imply that, in periods when the ELB is not binding, inflation averages more than 2 percent. Thus, the efficacy of such policies in achieving an inflation target of 2 percent hinges on policymakers pursuing inflation levels that are notably above 2 percent—in our model simulations, near 3 percent—during periods when the ELB does not bind.

While the risk-adjusted simple rule allows the central bank to achieve its inflation target, the economy nonetheless encounters the ELB with greater frequency at lower levels of average interest rates, and economic performance is worse. One response to these challenges, voiced by Blanchard et al (2010), Ball (2014), and Ball, Gagnon, Honohan, and Krogstrup (2016), is for a

central bank to consider a higher target for inflation. Such a shift would likely lower the frequency of ELB episodes and their undesirable effects. At the same time, a higher inflation target, if achieved, would be accompanied by the costs of higher average inflation. There is a great deal of controversy about the importance of these costs. Our analysis has little insight to provide about such costs, but our simulations illustrate the benefits of different monetary-policy strategies, in the two models we examine, in terms of reduced volatility and skewness of economic outcomes. To illustrate how an assessment of the benefits and costs associated with a higher inflation target depend on the effects of the ELB on economic stabilization, we posit an *ad hoc* loss function typical of the literature and explore alternative assumptions about the costs of inflation and output deviations from socially-optimal levels in such a framework. Overall, our simulation results suggest that the adverse effects on economic and price stability associated with the ELB may be substantial at inflation targets near 2 percent if $r*$ is low and monetary policy follows a traditional approach (as embedded in rules of the Taylor, 1993, form). Whether such adverse effects could justify a higher inflation target depends upon the degree to which monetary policy strategies substantially different from such traditional approaches are feasible and an assessment of a broader array of effects of the inflation target on economic welfare.

In light of the potential problems associated with either a risk adjustment to a simple rule or a higher inflation target assuming a simple rule, we also consider policy strategies that imply substantial changes in the manner in which accommodation is delivered and which include a role for commitments by the central bank, akin to forward guidance of the Odyssean type described by Campbell, Evans, Fisher, and Justiniano (2012), to make up any accommodation precluded by the ELB. A strategy we consider is a policy rule in which *changes* in (rather than the level of) the nominal interest rate are linked to deviations of inflation and output from objective. Such an approach implies that nominal interest rates are not raised from the ELB (once it is reached) until either inflation or output overshoot their objectives. Such a policy improves outcomes, but still shows sizable deterioration in economic performance in an environment of low steady-state nominal interest rates. The addition of a commitment to track a shadow rate, which captures the accumulated stock of foregone accommodation induced by the ELB, essentially eliminates the costs of an ELB. These results highlight how commitments to maintain accommodation until inflation or economic activity overshoot their objectives may not be sufficient to eliminate the adverse consequences of an ELB; rather, such policies may need to be accompanied by

additional commitments to remain accommodative for an even longer period (akin to the make-up policies suggested by Reifschneider and Williams, 2000). We note the close relationship between such a change rule and price-level/nominal income approaches.

The efficacy of commitment strategies implies that the need to consider alternatives such as a higher inflation target is greatly reduced, if such an approach is credible with the public and shift expectations in the manner predicted by the models. A crucial question, then, is whether a central bank can follow through on commitments that are not time-consistent. The experience with inflation targeting—another policy that is not time consistent (Barro and Gordon, 1983)—suggests that central banks can keep certain commitments, but the degree to which such successes imply that commitment strategies of the type we consider are feasible is uncertain.

We do not directly consider the potential for negative interest rates or quantitative easing aimed at lowering long-term interest rates. Our reading of related work suggests that these policies would provide stimulus to economic activity and hence are among plausible tools to combat the deterioration in economic performance from an ELB. Nonetheless, the literature also suggests that such policies may have limits (either in potential scope or efficacy) and that a focus on traditional approaches and commitment strategies is useful. As former Federal Reserve Chairman Bernanke noted, "…our unconventional policy tools, such as quantitative easing, involved costs and risks as well as benefits. It made sense to use unconventional tools less aggressively than more conventional tools like interest rate cuts." (Bernanke, 2015b, p. 529) Notably, the size of quantitative easing needed to achieve even modest improvements in macroeconomic outcomes is very large. Reifschneider (2016) provides illustrative simulations in which policymakers confronted by a severe U.S. recession act to combat the economic downturn by augmenting a conventional response (akin to the simple rule we consider) through a combination of forward guidance and quantitative easing (QE). These simulations suggest roles for forward guidance—which we analyze in our discussion of commitments—and quantitative easing. Reifschneider's simulations suggest that even in the case where the total increase in the central bank's balance sheet owing to QE equals $4 trillion, the stabilization gain is small relative to the size of the recession. Moreover, these moderate benefits arise in the FRB/US

model, where the effects of QE are large relative to those in some DSGE models.[5] Finally, the

efficacy of QE as a regular component of a central bank's policy toolkit depends both on the

effects of increasing balance sheets (as in Reifschneider, 2016) and on the strategy for unwinding

the balance sheet, as repeated doses of QE absent unwinding would lead to an ever-increasing

balance sheet. Nonetheless, a more thorough set of simulations across a broad range of

conditions, as in the stochastic simulation approach we adopt in our analysis of interest rate

strategies, is required for an assessment of QE's ability to improve performance and remains an

important topic for future research.[6]

I.   Previous contributions and how our analysis differs

The potential for the ELB to bind and impede economic performance, as well as policy strategies

to ameliorate such effects, has been analyzed extensively since concerns regarding its effects

were raised in Summers (1991). Prior to the Great Recession, research suggested ELB episodes

would be infrequent; have modest effects on economic performance; and could be mitigated by

appropriate strategies. For example, Orphanides and Wieland (1998), Reifschneider and

Williams (2000), and Coenen, Orphanides, and Wieland (2004) considered the effects of the

ELB in structural and semi-structural models, including the FRB/US model. The results in

Reifschneider and Williams (2000) are illustrative of those in this literature: These authors

estimated that an ELB of zero would bind less than 15 percent of the time and that such episodes

would average less than 1½ years under the Taylor (1993) rule if the equilibrium short-term

nominal interest rate r^* equals 3 percent.[7] In contrast, our simulations suggest that the ELB will

bind about 40 percent of the time and will last, on average, 2½ years under such conditions (with

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[5] See Kiley (2014) for an argument that movements in long-term interest rates stemming from changes in terms premiums may be less effective at stimulating economic activity than changes stemming from traditional monetary policy.

[6] Kiley (2014) reviews related work up to that point and provides estimates of a small DSGE model in which the estimated effect of a flattening in the yield curve (as in quantitative easing) on economic activity is much smaller than the effect of a decline at both the short and long end of the yield curve (conditional on the same-sized decline in yields at the long end).

[7] These earlier studies reached these conclusions, in part, because the models used implied a fairly stable economy: For example, the models in Orphanides and Wieland 1998) and Coenen, Orphanides, and Wieland (2004) implied that the standard deviation of the output gap would equal about 1 percent absent an ELB. In contrast, the Congressional Budget Office's output gap has a standard deviation closer to 2½ percent. In the models we consider, economic activity is fundamentally more volatile than in these earlier assessments.

the distribution of the length of ELB episodes strongly skewed to the upside, implying a high probability of episodes of substantially longer duration). That said, our analysis using the FRB/US model builds closely on Reifschneider and Williams (2000), and our emphasis on the need for a risk-adjustment to simple policy rules and commitments to make up foregone accommodation following and ELB episode draws directly from their insights.

The New-Keynesian literature explored similar issues in more stylized models (e.g., Wolman, 1998, Eggertsson and Woodford, 2003, and Adam and Billi, 2006)—with Eggertsson and Woodford (2003) emphasizing how changes in the policy strategy, involving commitments akin to price-level targeting, can substantially mitigate these already modest effects of the ELB. Summarizing this range of pre-crisis work, Kiley, Mauskopf, and Wilcox (2007)—in a memo sent to the FOMC in 2007, 2009, and 2010—characterized the literature as suggesting the risks from the ELB to macroeconomic stability were "de minimis."

Williams (2009) revisits many of the same issues as Reifschneider and Williams (2000), again using the FRB/US model.[8] Despite drawing shocks from the 1968-1983 period only, a more volatile period, the incidence of the ELB estimated by Williams (2009) for a steady-state nominal interest rate of 3 percent is only 16 percent, whereas we estimate that ELB episodes are likely to be substantially more frequent under traditional policy rules, occurring nearly 40 percent of the time. We discuss the factors that lead to a more binding ELB in our analysis, including the removal of a feature that implied extraordinary accommodation relative to a simple rule following an ELB period and the maximum assumed duration of ELB episodes at the end of section III.

Despite the significantly larger constraint implied by the ELB in our analysis, the broad message regarding how to ameliorate these effects in our work is similar to that of Reifschneider and Williams (2000) and Williams (2009): When the equilibrium real interest rate is low, a sizable risk-adjustment to traditional rules, on the order of ½ to 1 percentage point, is required to achieve an inflation target of 2 percent; such an adjustment implies that inflation must average closer to 3 percent outside of ELB periods. In addition, policies that accumulate the foregone

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[8] Chung et al (2012) focus on developments following the Great Recession and suggest that macroeconomic models, including FRB/US and standard DSGE models, may understate ELB risks. However, their analysis does not consider the possible frequency of ELB episodes in the future.

accommodation induced by the ELB and provide that accommodation after the conditions generating an ELB episode dissipate mitigate the most severe adverse effects of the ELB. A key contribution of our work is to show that these features are more important than previous work suggested, because the ELB may bind more frequently. As well, we demonstrate that these approaches behave similarly in both the FRB/US and DSGE models we employ.

We undertake the same analysis in the DSGE model as we do in FRB/US. This approach departs from that in most DSGE work. Previous analyses with DSGE models have typically not employed the quantitative approach used herein and have focused more on illustrative cases using impulse response analysis and steady-state comparisons (e.g., Wolman, 1998, and Eggertsson and Woodford, 2003). The general result in these investigations and related work is that New-Keynesian models imply that steady-state inflation is very costly because of its effects on price dispersion and commitment strategies are very effective at ameliorating the adverse effects of the ELB. As a result, the optimal level of inflation is typically quite low in this literature and the ELB is not a large problem under appropriate monetary policy strategies (for example, Schmitt-Grohé and Uribe, 2010). An analysis using DSGE models that is closer in spirit to ours is that of Coibion, Gorodnichenko, and Wieland (2012), who revisit the optimal inflation rate in the context of a DSGE model using the welfare function implied by their DSGE model. They conclude, using a model calibrated to capture features of the data spanning 1947 to 2011, that the optimal rate of inflation in their preferred specification is about 1½ percent, not far from the 2 percent target of the Federal Reserve and many other central banks. Importantly, they assume an equilibrium real federal funds rate of 2½ percent in their baseline case, far above recent estimates. Moreover, the costs of inflation are tightly linked to their model of price adjustment, which implies that price dispersion rises materially as inflation increases. Finally, their baseline case uses an approach in which policymakers commit to keeping track of foregone accommodation and make up some of this accommodation after the conditions generating the ELB end; such commitments are well known to generate good performance in DSGE models, and we emphasize both this commitment case and outcomes under traditional rules of the Taylor (1993) form.

II. Our approach

Relative to earlier work, our analysis builds on the recent literature emphasizing the possibility that the equilibrium real interest rate will remain persistently below earlier norms and compares results from two empirical models of the U.S. economy.

II.A. Estimates of the equilibrium real interest rate

Looking back over the past 50 years, there appears to be a trend decline in the real interest rate (e.g., Hamilton et al, 2015). Laubach and Williams (2003) present a semi-structural model that attempts to extract the long-run value of the short-term policy interest rate from a model with an IS-curve and a Phillips curve. Extending this analysis through more recent data (e.g., Laubach and Williams, 2016, Holston, Laubach, and Williams, 2016), estimates of the likely long-run value of the short-term nominal interest rate—the equilibrium real interest rate r^*—have fallen to quite low levels.[9] Del Negro et al. (2017), also presented at this conference, review related literature and present estimates from both time-series approaches and structural models.

While the economic forces behind a possible decline in r^* are outside the scope of our analysis, a number of factors may be at play. A slower pace of potential output growth may depress r^* by altering the balance between investment in productive capacity and savings; demographic shifts—both slower population growth and changes in age composition—may add to such trends (e.g., Gagnon, Johanssen, and Lopez-Salido, 2016). Another strand of literature emphasizes shifts in the demand for safe and liquid assets: For example, Bernanke (2005) pointed to a "global savings glut" combined with strong demand for U.S. assets as putting downward pressure on yields on safe U.S. securities; Del Negro et al (2017) review an array of factors that suggest changes in the safety/liquidity premium (or convenience yield) contribute to the low level of interest rates.[10]

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[9] It is, however, worth bearing in mind that some research has highlighted that the data are not strongly informative about the decline (Kiley, 2015).

[10] A striking feature of this literature is that each contribution tends to find that the factors emphasized in their study can completely account for the decline in the equilibrium real interest rate: Gagnon, Johanssen, and Lopez-Salido, 2016 and Eggertsson, Mehrotra, and Robbins (2017) attribute all (or more than all) of the decline in the equilibrium real interest rate to demographic and productivity factors, whereas Del Negro et al (2017) emphasize safety/liquidity premiums as the only sizable driver.

In terms of magnitudes, most estimates suggest that, going forward, *r** is likely to remain considerably lower than the 2½ percent average for the real interest rate experienced over the 1960-2007 period. Figure 3 presents the evolution of the real federal funds rate since 1960 along with the estimates of *r** from the models of Laubach and Williams (2003), Kiley (2015), and Del Negro et al (2017). According to the model of Laubach and Williams (2003), *r** exceeded 3 percent from the 1960s through the 1980s and may have been as low as 0 percent in the 2010s; in contrast, the models of Kiley (2015) and Del Negro et al (2017) point to a somewhat higher value recently, of about 1 percent (and both studies point to smaller shifts in *r** over time than the model of Laubach and Williams, 2003). Much of our analysis will emphasize the higher value of 1 percent—and any effects of the ELB we identify would be larger if *r** lies closer to zero.

Figure 3: The Real Federal Funds Rate and Estimates of r*
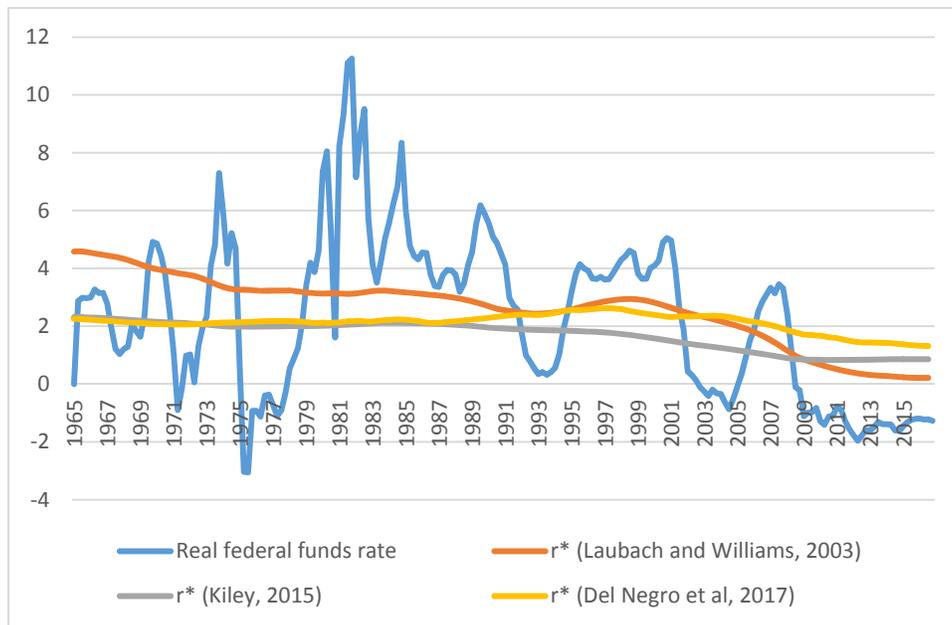
II.B. Alternative macroeconomic models

Our analysis uses two models of the U.S. economy—the DSGE model from Lindé, Smets, and Wouters (2016) and the FRB/US model of maintained by the Federal Reserve Board staff.

The DSGE model follows in the tradition associated with Smets and Wouters (2007) and now employed at many central banks: It is based on optimizing behavior by a representative household and firms; it is tied to the New-Keynesian literature in emphasizing staggered nominal price and wage setting as key frictions governing the tradeoff between activity and inflation stabilization and the effects of monetary policy; it is estimated as a system using Bayesian methods.[11] Relative to earlier models, a key advantage of the Lindé, Smets, and Wouters (2016) is that it was developed after the Great Recession to incorporate the outsized movements in economic activity witnessed over that period and to consider the length and effects of ELB episodes.[12]

As emphasized in Brayton, Laubach, and Reifschneider (2014), the FRB/US model of the U.S. economy is one of several that Federal Reserve Board staff consults for forecasting and the analysis of macroeconomic issues, including both monetary and fiscal policy. The model is large relative to DSGE models, and its equations are linked to core macroeconomic frameworks, such as the permanent-income model of consumption and the neoclassical user-cost model of investment, but are not closely tied to representative-agent optimization problems as in DSGE models. Importantly, the FRB/US model includes inertial behavior in many of its spending, as well as price and wage, equations—through inclusion of adjustments costs that introduce a longer lag structure into the dynamic specification of the model than in smaller DSGE models. In addition, a number of key frictions are incorporated in the empirical specification, including a role for liquidity-constrained households, disaggregated equations for firms' investments in durable equipment, intellectual property, and nonresidential structures that include *ad hoc* accelerator terms that may capture the effects of sales on liquidity-constrained firms' ability to invest. Finally, a variety of interest rates, including yields on Treasury securities, corporate bond yields, and residential mortgage rates, are determined as the expected average value of the federal funds rate over the appropriate holding period plus endogenous term/risk premiums, equity prices equal the present discounted value of corporate earnings based on an estimated

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[11] Examples of such models in use at central banks include the EDO and Sigma models at the Federal Reserve Board of Governors (Chung et al, 2010, and Erceg et al, 2005, respectively) and the New Area-Wide Model at the European Central Bank (Christoffel et al, 2008).

[12] Earlier contributions, such as Edge, Laforte, and Kiley (2008) focused on the period after the early 1980s and before the Great Recession, yielding models that predict relative modest cyclical fluctuations—a potential problem we earlier identified with contributions to the ELB debate such as Orphanides and Wieland (1998), Reifschneider and Williams (2000), and Coenen, Orphanides, and Wieland (2004).

require return to equity, and monetary policy is modeled as a simple rule for the federal funds rate subject to the zero lower bound on nominal interest rates.

To illustrate the properties of both the DSGE and FRB/US models that will be important when examining the effects of the ELB, we consider the effects of alternative monetary policy actions. Panel A of figure 4 presents the response of each model to a 100 basis point shock to the monetary policy rule. In each case, inflation (the green line) responds very little, as both models feature fairly flat Phillips curves. Output (the blue line) falls modestly. The decline is somewhat larger and more immediate in the DSGE model, with the maximum decline in output slightly exceeding ½ percent. While the differences across models are noticeable, the more prominent takeaway from these responses is the relative similarity of the models.

Panel B illustrates the relative power of forward guidance in each model. It considers a 100 basis point decline in the policy interest rate 12 quarters in the future, holding the nominal interest rate fixed at baseline prior to the 12th quarter and reverting to the policy rule thereafter. The power of forward guidance in DSGE models has been highlighted by a number of authors, including Chung, Laforte, and Kiley (2015); McKay, Nakamura, and Steinsson (2015); and Kiley (2016). The scale in the figure is held constant across the FRB/US and DSGE models to highlight the differences in the results. As is clear from the bottom panel, forward guidance is very powerful in the DSGE model, with output rising nearly 2½ percent in response to the shock. In contrast, the power of forward guidance is much more limited in FRB/US. These results suggest that the DSGE and FRB/US models differ importantly along this dimension.

The force of forward guidance in the DSGE model points to the possibility that monetary policy may be more effective in mitigating any adverse effects of an ELB on economic performance. However, it is also important to keep in mind that the power of forward guidance is simply an illustration of the amplification of shocks in the DSGE model absent the cushioning effect on output and inflation that comes from monetary policy adjustments. To see this, figure 5 shows the effects of a severe shock to aggregate demand in the DSGE and FRB/US models; in the DSGE model, the downturn is caused by an exogenous sequence of shocks to the model's risk-premium shock, and the FRB/US results reflect an exogenous sequence of negative shocks to the consumption equation. The top and bottom panels shows FRB/US and DSGE results, respectively, with the solid lines illustrating the effects in the absence of the ELB and the dashed

Figure 4

**A. Impulse response to a contemporaneous monetary policy shock
(Blue line—output; green line—inflation; red line—short-term interest rate)**

FRB/US

Linde–Smets–Wouters (2016)
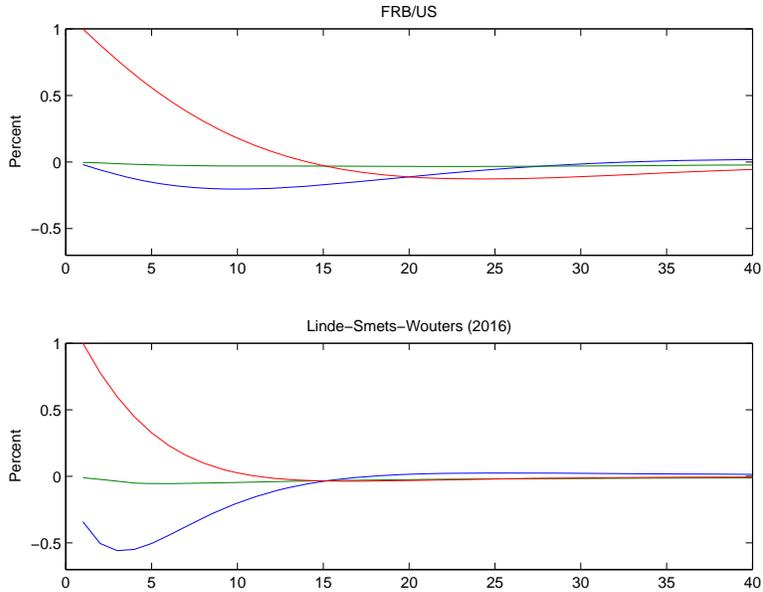
B. Impulse response to a monetary policy shock 12 quarters in the future

(Blue line—output; green line—inflation; red line—short-term interest rate)

FRB/US

Linde–Smets–Wouters (2016)
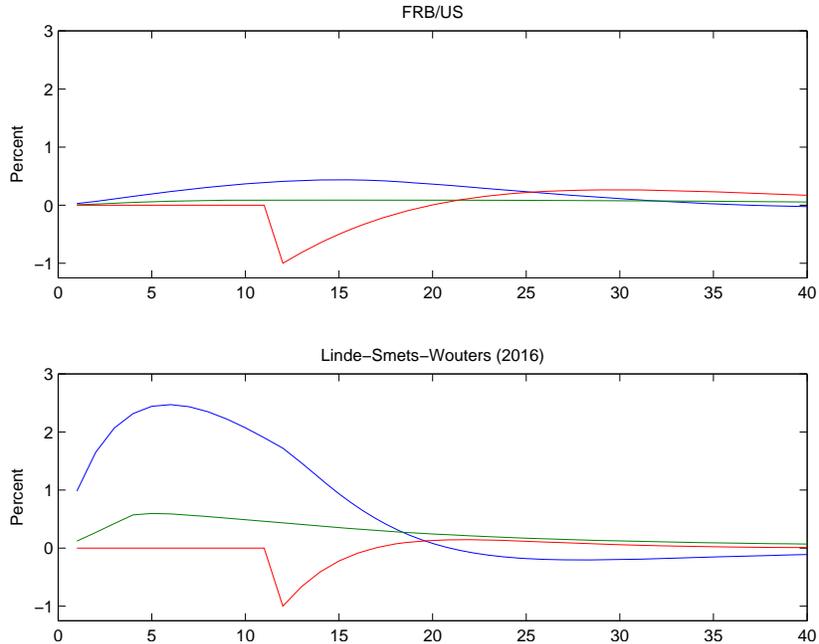
lines illustrating outcomes in the presence of an ELB 3 percentage points below steady state—
that is, assuming a steady-state nominal interest rate of 3 percent. In both panels, when not
constrained, the federal funds rate is set according to the estimated policy rule. As can be seen,

the ELB greatly magnifies the consequences of the shock in the DSGE model, with the trough value of the output gap declining from about 7 percent in the absence of the ELB to nearly 10 percent in the presence of the ELB. In the constrained case, the funds rate is at its effective bound for about three years. While the ELB binds for a similar period in the FRB/US simulation, amplification of the recession by the ELB is modest.

Figure 5: Amplification of Recessionary Shock by ELB

(Blue line—output; green line—inflation; red line—short-term interest rate
Solid—no ELB; dashed—ELB imposed)

FRB/US

Linde−Smets−Wouters (2016)
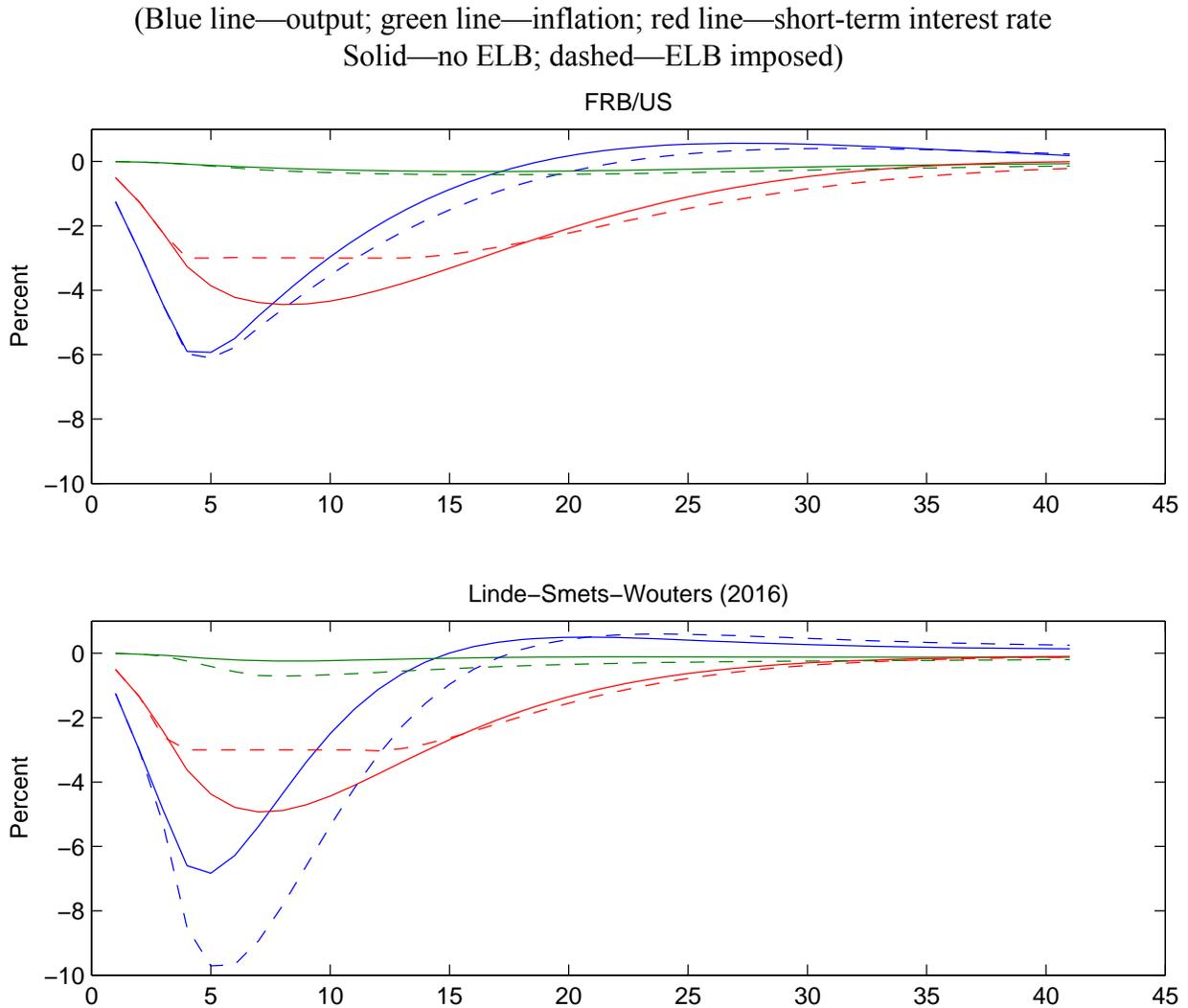
II.C. Our simulation approach

Much of the remainder of our analysis will involve computation of moments from simulations of the models. In computing these simulations, we:

- Generate 500 simulated samples of 200 periods (e.g., 40 years), initializing the simulations at the models' non-stochastic steady state.

- Impose the ELB appropriately under alternative assumptions about the steady-state nominal interest rate. For example, we most often consider steady-state nominal interest rates of 5, 4, or 3 percent, which would be consistent with a 2 percent inflation target and r^* values equal to 3 (consistent with the r^* estimates from the Laubach and Williams, 2003, model through 2000), 2 (a common pre-crisis value), or 1 percent (approximately the most recent estimated value from the models of Kiley, 2014, and Del Negro et al., 2017).

- Draw shocks from the period 1970 to 2015 for the FRB/US (via a bootstrap of the residuals from the model) and from the estimated variance-covariance matrix of shocks for the DSGE model. In each case, we assume no shocks to monetary policy—monetary policy strictly follows the rules we posit below.

- Our algorithm imposes the ELB in a manner similar to that in Williams (2009) and Guerrieri and Iacoviello (2015). We assume that agents never expect the ELB to bind for more than 15 years. In contrast, Williams (2009) assumed that the ELB only strictly binds (in expectation) for up to 4 years.

- We include an emergency fiscal stimulus package that is enacted when the output gap is lower than -10 percent. This fiscal package is implemented as an expansion of government purchases, and prevents the emergence of extremely adverse outcomes. A similar approach is followed in Reifschneider and Williams (2000) and Williams (2009). In the FRB/US model, the fiscal stimulus package is rarely invoked and results would largely be the same without this assumption. The fiscal stimulus package is more important in the DSGE model, particularly for some monetary policy strategies that fail to counteract the effects of the ELB effectively. This importance is consistent with the property of this model highlighted above: Once the ELB binds in the DSGE model, amplification of shocks can become large, and this can necessitate extraordinary measures to rescue the economy. While the specific quantitative results we present for the DSGE model depend on the nature of the fiscal package, the policy lessons do not.

- In both FRB/US and the DSGE model, we assume that agents have model-consistent expectations. As a consequence, households and firms fully understand the policy regime

that is in place. Thus, our analysis is helpful for assessing how the economy would behave once the policy regime has been in place for some time. Our analysis may not be as useful for an assessment of how the economy might behave in the immediate aftermath of the announcement or adoption of such a policy. Understanding the steady-state benefits are clearly of first-order importance in assessing whether to adopt any particular policy; if the steady-state behavior is not desirable, then it is clearly not worthwhile assessing the transition. For a detailed discussion of transition issues using the FRB/US model, see Reifschneider and Roberts (2006).[13]

An important element of the stochastic simulations we perform is that they admit the possibility of back-to-back recessions, as indeed the United States experienced in the early 1980s. There is no requirement that the economy will have fully recovered from one recessionary episode before additional adverse shocks arrive (as in the more illustrative simulation approach of Eggertsson and Woodford, 2003; Reifschneider and Roberts, 2006; and Reifschneider, 2016); rather, the shocks are simply drawn from the unconditional distribution. To the extent that our models, including their shocks, are realistic, this approach will give the simulations a reasonable chance of encountering challenging situations and thus "testing the mettle" of the various policy strategies. This advantage is important for assessing likely behavior across the business cycle and over time.

III. Economic performance under traditional approaches

III.A. Performance from 1960-2007

Our analysis begins with the properties of the DSGE model and the FRB/US model under an estimated policy rule. Table 1 presents historical statistics for the output gap (as measured by 100 times the natural logarithm of real GDP divided by the CBO's estimate of potential), core

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[13] Reifschneider and Roberts (2006) examine the ability of rules similar to the ones we explore here to mitigate the effects of the ELB using the FRB/US model. Importantly, they examine the performance of the rules under both fully model-consistent expectations and assuming that only financial-market participants have model-consistent expectations, while other agents form expectations using the FRB/US model's option of VAR-based expectations. The use of VAR-based expectations effectively means that agents form expectations assuming the historical policy regime remains in place.

PCE inflation (measured on a four-quarter basis), and the nominal federal funds rate, along with statistics from stochastic simulations of the DSGE model and the FRB/US model assuming that the steady-state nominal interest rate equals 6 percent (the 1960-2007 average) and the effective lower bound is zero. In each model, the federal funds rate is set according to the rule,

$$i(t) = .9i(t-1) + .2\pi^4(t) + .15y(t) + .25\Delta y(t) \qquad \text{(1)}$$

where i is the nominal interest rate (measured at an annual rate), y is the output gap, and π^4 is the four-quarter change in the natural logarithm of core PCE prices (throughout, we use quarterly data). This rule was estimated for the 1988-2007 period using data from the CBO on the output gap; constants are suppressed in the expression of the rule.

Table 1: Standard Deviations of the Output Gap, Core Inflation,

and the Federal Funds Rate

	Standard deviations of variables		
	Output gap	Core inflation	Nominal federal funds rate
Maximum History	2.5	2.2	NA
1960-2007	2.3	2.2	3.3
1984-2007	1.4	1.0	2.4
Models under estimated rule and steady-state nominal interest rate of 6 percent			
FRB/US	2.2	1.5	2.8
Lindé-Smets-Wouters (2016)	2.4	2.4	2.6
FREQUENCY OF ELB IN MODEL SIMULATIONS			
FRB/US	2.0 percent		
Lindé-Smets-Wouters (2016)	1.1 percent		

As can be seen by comparing the standard deviations of output, inflation, and the nominal funds rate from the DSGE model to the estimates based on data from 1960 to 2007, the DSGE model replicates the sample moments very closely, which is unsurprising given that the estimation sample for this model corresponds, roughly, to this period. The exception is the nominal federal funds rate, where the standard deviation from model simulations is less than the sample standard deviation over the entire 1960-2007 period and lies closer to the value seen over the 1984-2007; this may reflect the fact that the model simulations assume no exogenous

disturbances to the policy rule and such systematic behavior of monetary policy may be a better characterization of monetary policy actions after the Volcker disinflation. The statistics from the FRB/US model are also broadly similar to their sample counterparts—although inflation is slightly less volatile (with a standard deviation of 1.5 percentage points, whereas the sample counterpart from 1960-2007 equals 2.2 percentage points). As just noted, the ELB rarely binds in either model for a steady-state nominal interest rate of 6 percent.

III.B. Economic performance under lower steady-state nominal interest rates

We now consider the implications of a lower steady state nominal interest rate for economic performance in the models we consider. Our analysis begins with performance under each model's estimated policy rule and then turns to behavior under a simple Taylor (1993)-type policy rule, under the parameter values suggested in, for example, Yellen (2017). These rules are useful benchmarks because they are simple ways to capture the behavior of inflation targeting central banks. In all cases, we assume that the inflation target is 2 percent and equilibrium real interest rates $r*$ is between 1 and 3 percent, consistent with the evidence reviewed above. As a result, our discussion will focus on the steady-state nominal interest rates from 3 to 5 percent. While outside the main focus of our analysis, we will also consider higher and lower values of the steady-state nominal interest rate in some cases, to compare to the historical average nominal interest rate of 6 percent or to consider the implications of an equilibrium real interest rate $r*$ as low as 0 percent, as in the estimates from the model of Laubach and Williams (2003) presented in figure 2.

III.B.1. Performance under the estimated rule

Table 2 presents stochastic simulations of each model for alternative values of the steady-state nominal interest rate under the estimated rule, incorporating the ELB. In the DSGE model, there is some modest deterioration in macroeconomic performance owing to the ELB for a steady-state nominal interest rate of 4 percent. For a steady-state nominal interest rate of 3 percent (or lower), the impact on economic performance is more sizable: Inflation systematically falls short of target, averaging less than 1 percent, and output is below potential, on average. Note that these adverse effects arise even though the ELB is binding only 17 percent of the time.

Significant effects of the ELB also arise in the FRB/US model. As shown in the first row of the bottom panel, the effects of the ELB are modest for a steady-state nominal interest rate of 5 percent: The ELB is expected to bind about 10 percent of the time and output and inflation volatility are little different from the case shown in table 1. Economic performance is worse for a steady-state nominal interest rate of 4 percent, with inflation falling ¼ percentage point below target and output averaging nearly ½ percent below potential. As with the DSGE model, for steady-state nominal interest rates of 3 percent, performance deteriorates sharply, with inflation falling substantially short of the target (with an average across simulations of 1.2 percent) and output averaging more than 1 percent below potential. The ELB binds about 1/3 of the time.

Table 2: Performance under Estimated Rule in Alternative Models and for Alternative Values of the Steady-State Nominal Interest Rate

	ELB frequency	Mean duration of ELB	mean(y)	mean(π) (π*=2)	RMSD(y)	RMSD(π)
DSGE Model						
5	3.2	5.1	-0.1	2.0	2.5	2.5
4	7.8	6.5	-0.4	1.7	3.4	3
3	17.4	8.8	-1.3	0.9	5.7	4.6
FRB/US Model						
5	5.1	5.8	-0.1	1.9	2.4	1.5
4	12.8	8.3	-0.4	1.7	2.7	1.7
3	31.7	9.2	-1.3	1.2	3.7	2.1

One reason for the poor performance of the estimated rule is its sizable response to the change in the output gap; such a response implies that accommodation is removed as soon as a recovery begins (rather than waiting until the level of activity has recovered)—a response that short-circuits a recovery as emphasized by Billi (2011).

III.B.2. A simple rule

An alternative to the estimated rules is a rule in the simpler class suggested by Taylor (1993, 1999) in which the nominal interest rate responds to inflation and the output gap only. Such a rule has a number of desirable features for our analysis: It relates the current level of the nominal interest rate to the deviations of inflation from target and output from potential, and therefore captures both goals of a dual-mandate central bank; it has been shown to produce

reasonable economic performance abstracting from the effective-lower bound (e.g., Taylor and Williams, 2010); and it is a benchmark often consulted within the Federal Reserve, including through regular presentations in the discussion of monetary policy alternatives in material produced for the FOMC (e.g., Tealbook B) and as represented by calculators available at Federal Reserve Banks.[14]

Table 3 presents statistics for the version of the rule under a 2 percent inflation target,

$$i(t) = r^* + 2 + 1.5(\pi^4(t) - 2) + y(t) \tag{2}$$

Table 3: Performance under Simple Rule in Alternative Models and for Alternative Values of the Steady-State Nominal Interest Rate

	ELB frequency	Mean duration of ELB	mean(y)	mean(π) (π*=2)	RMSD(y)	RMSD(π)
DSGE Model						
6	0	NA	0	2	2.3	3
5	12.9	7.4	-0.5	1.7	3.7	3.8
4	21.1	8.9	-1.2	1	5.4	4.8
3	32.6	12.0	-2.3	0.1	7.3	6.1
FRB/US Model						
6	5.3	4.5	-0.1	2.0	2.3	1.6
5	10.0	5.5	-0.1	1.9	2.4	1.6
4	20.2	7.8	-0.4	1.7	2.8	1.8
3	38.3	9.8	-1.1	1.2	3.4	2.2

Overall, the results suggest that this policy rule is as ineffective at addressing the challenges that arise if the steady-state nominal interest rate lies below 4 percent as the estimated policy rule. In the FRB/US model, inflation and output systematically fall short of their objectives to a degree similar to that under the estimated rule when the steady-state nominal interest rate equals 3 percent. Moreover, the ELB binds nearly 2/5th of the time and the mean

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[14] Materials prepared by staff for the Federal Open Market Committee began regularly reporting the prescriptions from this rule in advance of decisions in January 2004 and have continued to report these prescriptions through the most recent publicly available materials (in the "Bluebook" and "Tealbook B"; see https://www.federalreserve.gov/monetarypolicy/fomchistorical2004.htm). The Taylor-rule utility at the Federal Reserve Bank of Atlanta can be found at https://www.frbatlanta.org/cqer/research/taylor-rule.aspx?panel=1; the Taylor-rule utility at the Federal Reserve Bank of Cleveland can be found at https://www.clevelandfed.org/en/our-research/indicators-and-data/simple-monetary-policy-rules/about.aspx.

duration of ELB episodes is 2½ years (and the duration of episodes is highly positively skewed, implying some episodes are much longer). In the DSGE model, the deterioration in performance under a simple Taylor rule is worse than under the estimated rule, with inflation averaging about 0 percent when the steady-state nominal interest rate equals 3 percent. More generally, the simple rule performs relatively poorly even at much higher steady-state interest rates, suggesting that the simple rule is far from optimal in this model. [15] This poor performance relative to the estimated rule arises because the inertia in the estimated rule has a significant stabilizing effect away from the ELB in the DSGE model: The path of interest rates is very important in this class of models, as suggested by the forward-guidance simulations presented earlier, and the persistence in the path for the nominal interest rate induced by the presence of the lagged interest rate in the estimated policy rule stabilizes inflation and activity away from the ELB in the DSGE model; the Taylor rule does not have this feature, and output and especially inflation are more volatile as a result (as can be seen in the row for a steady-state nominal interest rate of 5 percent)—which leads to a more binding ELB, with larger adverse effects, in the DSGE model under the Taylor rule. Note that this result echoes those for a Taylor (1993) rule in Coibion, Gorodnichenko, and Wieland (2012).

Given the changes in the mean and standard deviations of inflation under alternative values of the steady-state nominal interest rate, it is instructive to examine the entire distribution of outcomes from the simulations in each model. Figure 6 presents the probability density functions and cumulative distribution functions for output, inflation, and the nominal federal funds rate for an inflation target of 2 percent and equilibrium real interest rates from 0 to 4 percent. When the steady-state nominal interest rate equals 6 percent, as over the 1960-2007 period, simulated outcomes for inflation and output are symmetric around their target values. But lower values of the steady-state nominal interest rate, in interaction with the ELB, induce notable asymmetries in outcomes: Output averages below potential and inflation averages below target because their downside tails are larger than their upside tails. This asymmetry is important to keep in mind both when thinking about policy strategies and in thinking about the implications

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[15] This feature is not unique to the DSGE model. For example, Williams (2003) shows that simple rules of this type are far from optimal in the FRB/US model.

for economic welfare, as the costs of above/below target inflation and output may be asymmetric.

Figure 6: Distributions of Outcomes under Simple Rule

A. DSGE Model
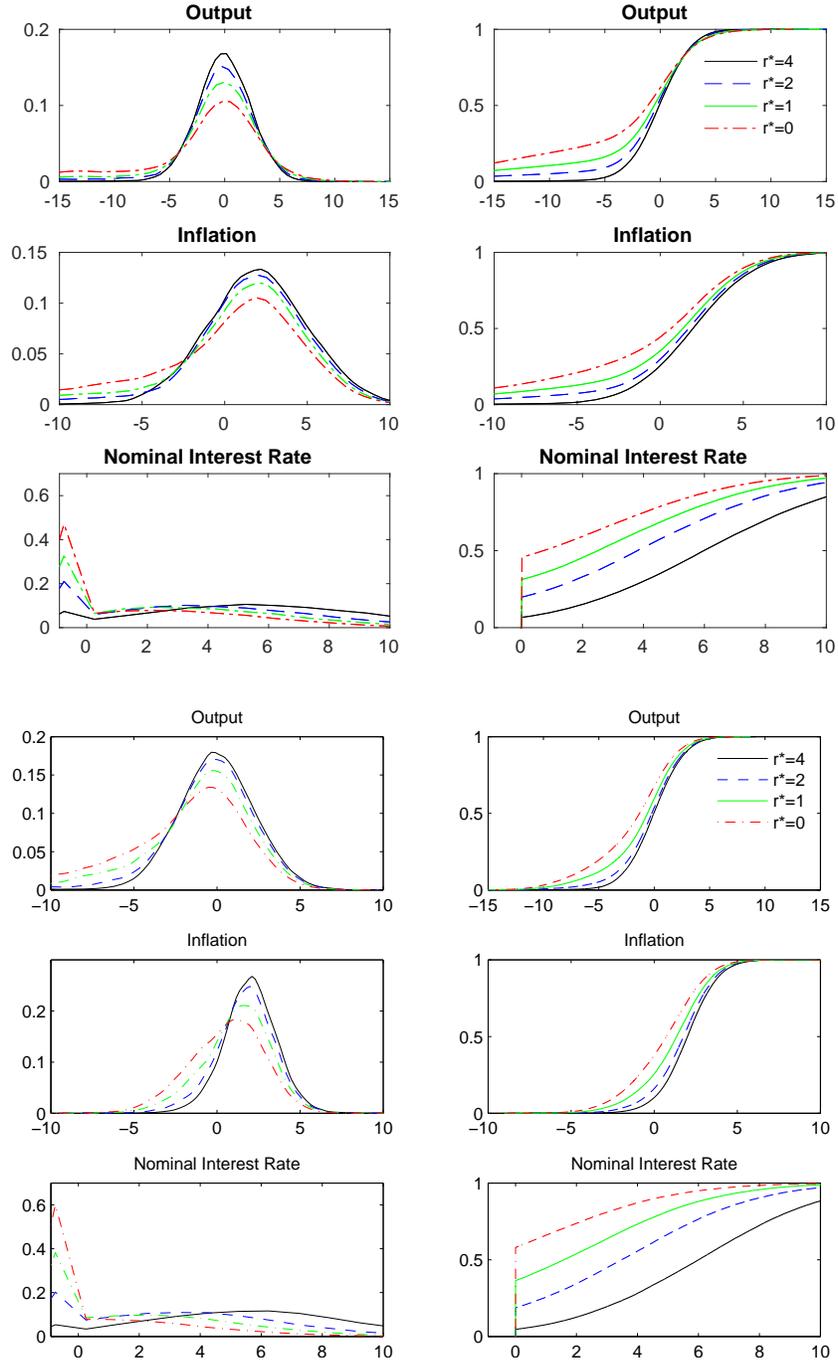
III.C. Comparison to earlier analyses

The frequency with which the ELB binds and the magnitude of the adverse effects on economic performance may be surprising in light of earlier literature. In particular, Reifschneider and Williams (2001) and Williams (2009) find that the ELB will bind less than 1/5th of the time for an equilibrium real interest rate of 1 percent and an inflation target of 2 percent, and do not find the sizable negative skewness in economic activity reported above using the FRB/US model. Similarly, Coibion, Gorodnichenko, and Wieland (2012) report important effects of the ELB, but the impression from their discussion is that the ELB is not an extraordinary impediment to economic performance, at least in the DSGE model they consider. Other DSGE analyses (e.g., Schmitt- Grohé and Uribe, 2011) leave a similar impression.

An obvious candidate explanation is changes in the structure of the models used and in the magnitude of exogenous "shocks" hitting the models. While there have been changes in the structure and estimated coefficients of the FRB/US model (e.g., a flatter Phillips curve in recent vintages), these changes do not account for the different assessment from FRB/US.

Rather, the key drivers of the different perspective are twofold. First, we abstract from adjustments from the simple policy rule (of the Taylor, 1993, form) that add accommodation beyond that prescribed by the base form of the rule. In contrast, Williams (2009) and the main case emphasized in Coibion, Gorodnichenko and Wieland (2012) include features that amount to commitments to making up accommodation foregone because of the ELB.

Concretely, Williams (2009) reports simulation results for the same simple rule as in the previous subsection. In those simulations, the rule is adjusted to provide additional accommodation when the output gap or inflation deviate from objective values. For example, under Williams's parameterization, an output gap of -5 percent for a two-year period results in a setting for the federal funds rate approximately 1¾ percentage points below the prescription of the simple rule, and this accommodation decays at a rate of 0.05 per quarter. This feature yields substantial additional accommodation beyond the prescription of the simple rule following an ELB episode. In addition, Williams (2009) only strictly enforces the ELB for up to 4 years, whereas we strictly enforce the ELB for up to 15 years. Figure 7 presents the implications of these assumptions for the frequency with which the ELB binds and the average deviation of output from potential across simulations for an equilibrium real interest rate of 1 percent (and

Figure 7: Comparison of Results to Williams (2009) for Steady-State Nominal Interest Rate of 3 percent

A.
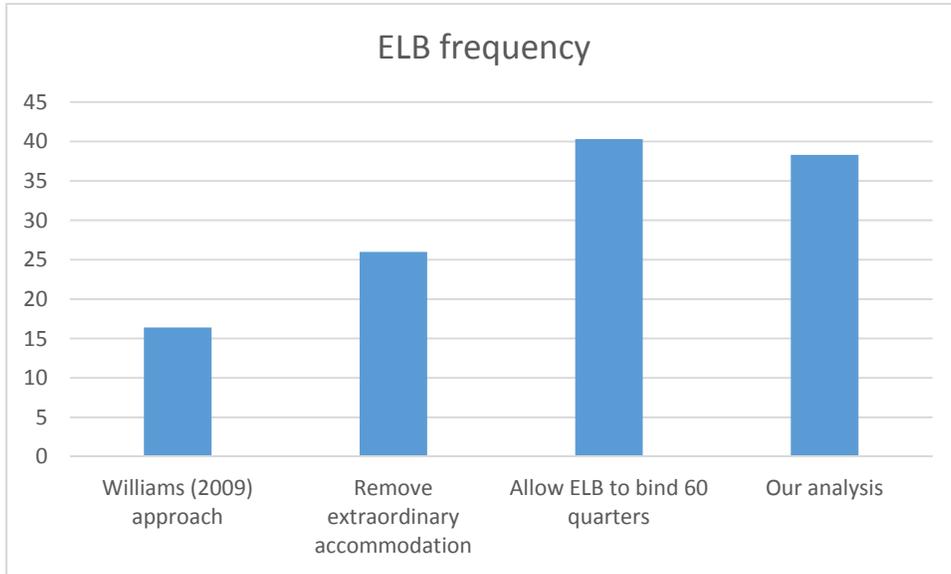
B.
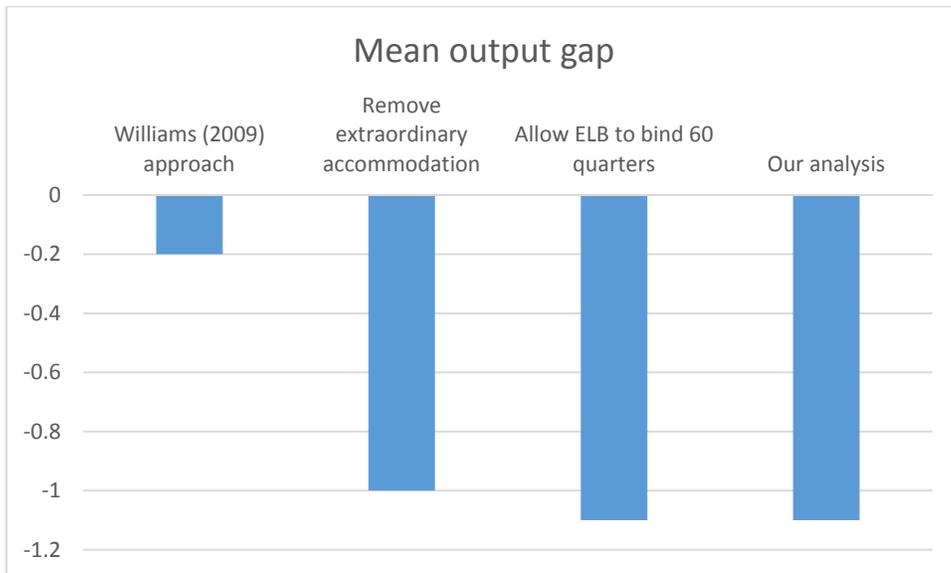
hence a non-stochastic steady-state interest rate of 3 percent). In these simulations, the version of FRB/US used is the same as that in Williams (2009). Under the approach in Williams (2009), the ELB binds 16.4 percent of the time and output falls 0.2 percent below potential, on average. Removing the adjustment to the simple rule that provides additional accommodation raises the frequency with which the ELB binds to 26 percent and brings the shortfall in output relative to

potential to 1 percent, on average. Allowing the ELB to bind for up to 60 quarters increases the frequency with which the ELB binds to 40.3 percent. Comparing these values to those reported in table 3 (and reported as the last bar in each figure) shows that the frequency with which the ELB binds and the effect on output are essentially identical in the version of FRB/US used herein and that from Williams (2009), under common assumptions.

An investigation of differences between our results and those from previous DSGE model investigations suggests that similar factors explain why we find more severe constraints from the ELB. In particular, Coibion, Wieland, and Gorodnichenko (2016) present results for an estimated rule that includes lagged interest rates, similar to that above. In their simulations, they keep track of the (negative) values that the policy rate would obtain absent the ELB, setting the actual nominal interest rate equal to this shadow rate when the shadow rate is non-negative. As we discuss in section VI, this feature implies a commitment to deliver accommodation long after the ELB would otherwise bind. Removing this assumption from their analysis implies the ELB is substantially more problematic than the authors report.[16] Indeed, economic performance is poor for the simple Taylor (1993) rule they analyze, as herein.

IV. Achieving the inflation target—A risk-adjustment strategy

The strategies considered above involve a policy rule in which inflation is guided back to 2 percent, over the long run, in the absence of shocks. However, shocks to the economy and the inability to provide accommodation in certain circumstances imply that inflation averages less than 2 percent and output systematically falls short of potential when r^* is at a moderate-to-low level. As emphasized by Reifschneider and Williams (2000), Williams (2009), and Nakata and Schmidt (2016), a *risk adjustment* assumes that policy is more accommodative, on average, than the simple Taylor-type rules would imply, and can bring average inflation back to 2 percent. To examine this idea, we consider the following rule:

$$i(t) = r^* - risk\ adjustment + 2 + 1.5(\pi^4(t) - 2) + y(t) \qquad \textbf{(3)}$$

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[16] Strictly speaking, their code cannot find a solution under this case for a steady-state nominal interest rate of 3 percent, presumably because outcomes diverge uncontrollably.

Note that, in the absence of shocks, this rule would be expected to bring inflation to a level of 2 percent plus 2 times the risk adjustment. One interpretation of this observation is that policymakers systematically aim to achieve inflation somewhat above the long-run target of 2 percent, when they can, so as to achieve the assumed 2-percent objective, as their strategy takes into account the average drag on inflation imposed by the ELB.

The upper panel of figure 8 presents results regarding the magnitude of the necessary risk adjustment in the DSGE model. As was shown in table 3, the approach without a risk adjustment leads to inflation below its objective for low r^*, and the top panel of the figure illustrates this shortfall. To compensate for this shortfall, a risk adjustment that yields more accommodative policy is needed to bring inflation to a 2 percent target. Given the large shortfall of inflation relative to objective when r* is low, sizable adjustments—on the order of 100 basis points for an r^* of 1 percent—are required to achieve inflation of 2 percent on average, as shown in the middle panel. Nonetheless, these adjustments still leave output performance subpar—for r* equal to 1 percent, the output gap across simulations falls short of potential by ½ percent, on average, as illustrated in the lower left panel. Overall, these results point to the ability of a risk adjustment to ensure that a 2 percent inflation objective is achieved, on average.

Panel B of figure 8 presents analogous results in the FRB/US model. Average inflation performance under a Taylor-type strategy falls short of the 2 percent by a more moderate amount than in the DSGE model for r^* of 1 percent, as can be seen by comparing the rows in table 3 for non-stochastic steady-state nominal interest rates of 3 percent for each model. And a risk adjustment of approximately 50 basis points brings inflation to the 2 percent objective, on average, in the FRB/US model, as shown in the middle panel of the figure. As in the DSGE model, output remains notably below potential, on average, with the risk-adjusted policy, as shown in the lower-left panel.

Figure 8:

A. Risk Adjustments to the Simple Rule in the DSGE Model

Average Inflation without risk adjustment

Risk adjustment to achieve inflation of 2 percent

Average shortfall of output from potential with risk adjustment

Average inflation when interest rate exceeds ELB
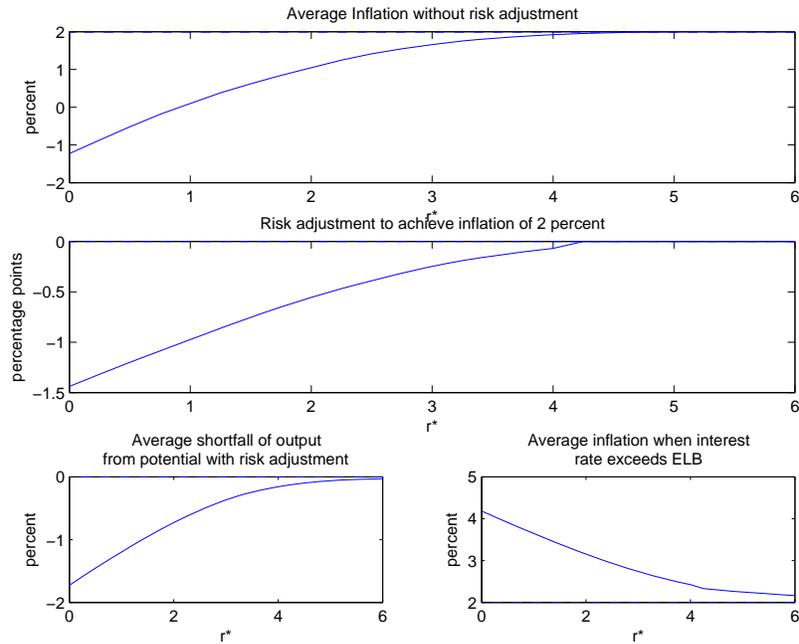
B.   Risk Adjustments to the Simple Rule in the FRB/US Model

Average Inflation without risk adjustment

Risk adjustment to achieve inflation of 2 percent

Average shortfall of output from potential with risk adjustment

Average inflation when interest rate exceeds ELB
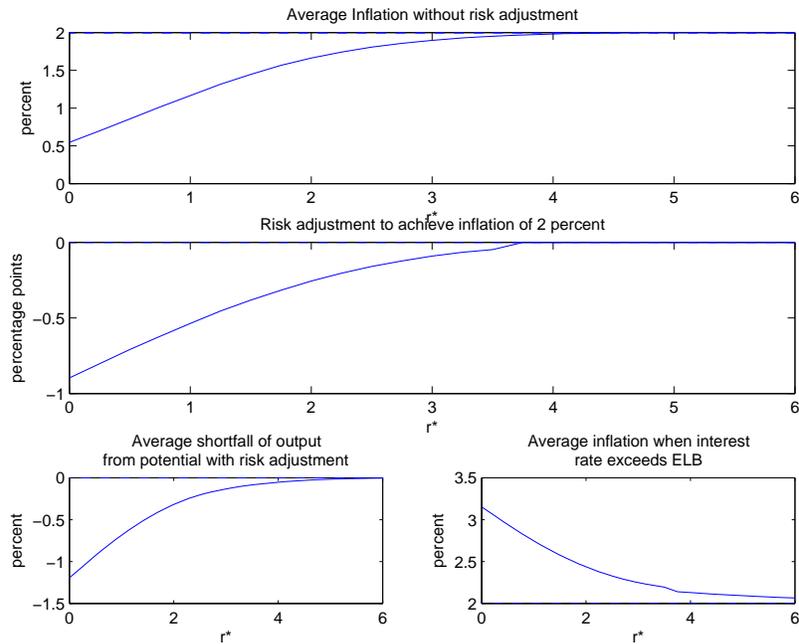
In both models, the risk-adjusted strategy (for *r** near 1 percent) is consistent with inflation near 3 percent in the absence of shocks. With shocks buffeting the economy and interacting with the ELB, inflation averages 2 percent, below the implied non-stochastic level

consistent with the model. Because inflation and the level of output relative to potential are linked in the models through a Phillips curve relationship, inflation below the implied steady-state level must be accompanied by output below potential, on average. It is important to note that this relationship essentially amounts to a long-run tradeoff between inflation and output, and the presence of such a tradeoff hinges importantly on the anchoring of long-run inflation expectations that we have assumed in our simulations. A level of activity below potential, on average, could risk an unanchoring of inflation expectations from policymakers' assumed objective of 2 percent. We will return to this potential challenge—and related challenges associated with other strategies we discuss—in the concluding section.

All told, a key takeaway is that the risk-adjustment strategy can be effective in bringing inflation to a given objective (such as 2 percent), but may be less effective in addressing the deterioration in the level and volatility of economic activity.

V. A higher inflation target—benefits and costs

If a low value of the equilibrium real interest rate causes the economy to encounter the ELB more often, a natural reaction might be to boost the inflation target: According to the Fisher equation, higher average inflation would imply a higher average value of nominal interest rates, and so the ELB would be encountered less frequently. A number of authors have proposed such a change in policy, notably Blanchard et al (2010), Ball (2014), and Ball, Gagnon, Honohan, and Krogstrup (2016).

While an increase in the inflation target would have the benefit of reducing the frequency of encountering the ELB, higher average inflation would come with its own set of costs. There is an extensive literature on the implications of higher average inflation for economic welfare. This literature considers a broad range of mechanisms, and these are, for the most part, not directly considered in our simulations, and may be inadequately captured in the models we consider: For example, Feldstein (1997) and Abel (1997) suggest that taxation of nominal capital income imply substantial effects of changes in the inflation target on the long-run productive capacity of the economy. Another example is the cost of money holdings that underlie the optimality of the Friedman (1969) rule in some models. The New-Keynesian

literature has emphasized the effects of steady-state inflation on price dispersion; such effects are not present in FRB/US and are not the focus in our analysis of the DSGE model, which we employ largely for its empirical predictions regarding output, inflation, and interest rates.[17] Kiley, Mauskopf, and Wilcox (2007) review various strands of literature on the costs of inflation.[18]

The importance of these costs remains controversial. As discussed in Coibion, Gorodnichenko, and Wieland (2012), in New Keynesian models, most of the costs associated with inflation arise from steady-state inflation, rather than inflation fluctuations. Indexation or alternative notions of nominal rigidity may alter the relative weight on these factors in economic welfare. For example, Nakamura, Steinsson, Sun, and Villar (2016) note that the commonly used Calvo specification implies costs of price dispersion that are an order of magnitude larger than plausible other models.[19] They then present empirical evidence that suggest the link between inflation and price dispersion may be more muted than in the earlier literature. An overall assessment would require more work pulling together a range of effects, as was done by Fischer (1981) and Kiley, Mauskopf, and Wilcox (2007), including the effects on price dispersion emphasized in the New-Keynesian literature, the interaction of the nominal tax code with the trend rate of inflation, and a re-assessment of the costs associated with money holdings given changes in transaction technologies and the legal authority to pay interest on bank reserves.

In light of the uncertainty and debate surrounding the costs associated with higher trend inflation, we take a pragmatic approach to assessing economic welfare of the outcomes from the various models and monetary-policy strategies we consider. We assume an *ad hoc* loss function that is similar to one commonly used in central bank analysis.[20] We view such a specification as being the closest possible to current "conventional wisdom;" we will return at the end of the discussion to a consideration of the limitations of this approach.

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[17] Woodford (2003) is the classic reference. Schmitt- Grohé and Uribe (2011) review much of the related literature.
[18] Their analysis builds on Fischer (1981).
[19] This insight is closely related to the discussion in Kiley (2002) of the magnification of price dispersion in Calvo (1983) models relative to similar models of price stickiness. Nakamura and others (2016) go beyond this point in their empirical and calibration exercises.
[20] See, for example, the speech by Yellen (2012).

In particular, suppose that economic welfare can be approximated by the loss function,

$$E\left\{\left(\pi(t) - \pi^{optimal}\right)^2 + \gamma\left(y(t) - y^{optimal}\right)^2\right\}. \tag{4}$$

In this formulation, economic losses equal the expected value of squared deviations of inflation and output from their optimal values, and γ is the weight on output gaps relative to that on inflation gaps.[21] With this loss function, we can use the distributions of simulated outcomes under alternative values of the inflation target to estimates economic losses. We consider three cases

- **Case 1**: In this case, the optimal inflation rate is assumed to be 2 percent and the optimal level of output is consistent with an output gap of zero. In addition, γ equals 0.25, a value consistent with a relative weight on deviations of the unemployment rate from its natural rate of 1 and an Okun's law coefficient linking the unemployment gap to the output gap of ½.[22]

- **Case 2:** Parameters the same as case 1, except the weight on output γ is raised to 1. Such a weight is substantially higher than in most work, including work deriving γ from micro-foundations.

- **Case 3:** Parameters the same as case 2, but the optimal inflation rate equals zero.

These cases span economically important ones. First, the general form of the loss function echoes that often used in the New-Keynesian literature.[23] Second, cases 1 and 2 yield an optimal inflation rate of 2 percent abstracting from the ELB, and hence can provide a sense of how much a binding ELB may shift the desirable rate of inflation away from a level that was chosen by a number of inflation-targeting central banks prior to recent ELB experience. Finally, case 3—in which the optimal inflation rate is zero when the ELB is not a consideration—is most consistent with typical discussions of the potential costs of inflation.[24] Nonetheless, important

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[21] Coibion, Gorodnichenko, and Wieland (2012) undertake a similar assessment of the optimal rate of inflation. A key difference is that they derive their loss function from the underlying welfare problem in their model, whereas we posit an ad hoc loss function.
[22] In Yellen (2012), there are equal weights on inflation and unemployment gaps, and an Okun's law coefficient of ½ (that is, unemployment gaps are ½ as large as output gaps).
[23] See, for example, Woodford (2003).
[24] See, for example, Coibion, Gorodnichenko, and Wieland (2012).

cases also fall outside these assumptions: In particular, these cases do not include one in which the socially optimal level of output exceeds the productive capacity of the economy (because distortions lead economic activity to fall short of an optimal level).

Panel A of figure 9 presents losses as a function of the average level of inflation (the inflation target) from the FRB/US model simulations for values of the equilibrium real interest rate from 1 to 3 percent. As illustrated by the left panel, r^* equal to 3 percent leads to an optimal inflation level very close to 2 percent when the welfare function assumes zero losses at 2 percent inflation and the weight on output is ¼. Because optimal inflation in the stochastic case is close to the point at which the loss function achieves its minimum absent shocks, we can infer that the ELB has little effect on the optimal inflation rate. By contrast, in case 3 (a loss function in which zero inflation is desirable absent shocks), the optimal inflation rate is close to 1 percent when r* is 3 percent. As r* falls, the optimal inflation rate rises as the effects of the ELB become more pronounced. For example, in case 1, the optimal inflation rate when r^* equals 1 percent approaches 2½ percent. In case 3, the optimal inflation rate is about 2 percent when r* equals 1. Here, the effect at the margin of a lower r* is somewhat great, but the implied value of optimal inflation is nonetheless consistent with current inflation targets.

Panel B presents optimal inflation results for the DSGE model. The overall message is similar—the asymmetries in risk implied by the ELB can, under some loss function assumptions, point to an optimal level of inflation above 2 percent. In some of the cases presented, the optimal level of inflation is notably higher than 2 percent, with optimal inflation clustered around 4 percent when r* equals 1. One reason optimal inflation is so high in the DSGE model is that under the simple policy rule the ELB implies particularly adverse outcomes in this model, echoing the results for that rule in Coibion, Gorodnichenko, and Wieland (2012). As we will see below, other policy strategies lead to notably better outcomes near the ELB in the DSGE model.

Figure 9: Alternative Views on Losses at Different Levels of Inflation Target

A. FRB/US Model
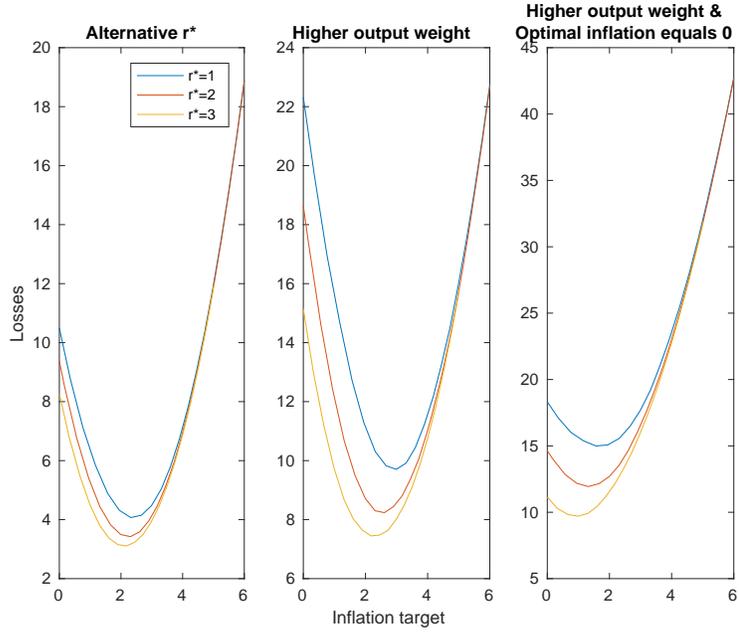
B. DSGE Model
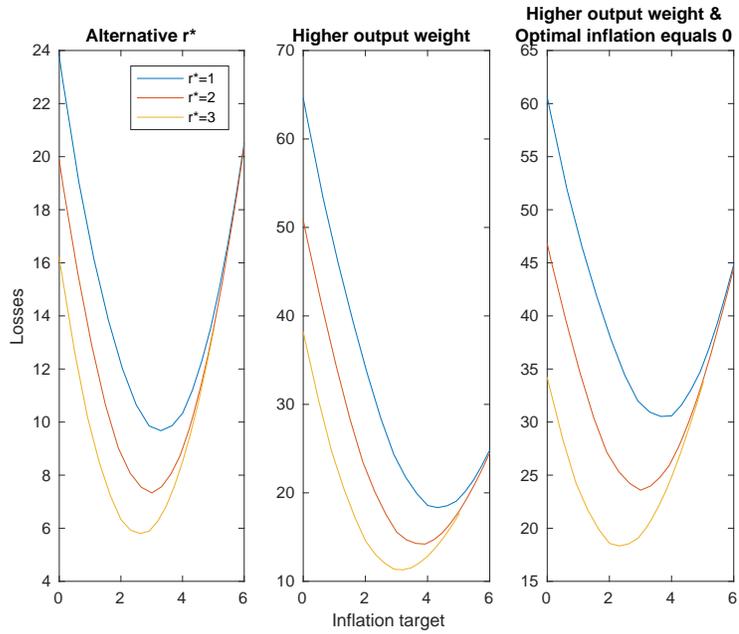
These calculations and our earlier results point to several key questions that are likely to determine the desirable level of the inflation target in an environment where monetary policy is constrained to follow a simple strategy akin to a Taylor-style rule.

- What are the costs associated with steady-state inflation vs. inflation volatility? If a steady trend rate of inflation is very costly, as in much of the literature, the optimal level of inflation would be much lower than if the primary costs associated with inflation stem from volatility/uncertainty.

- What is the relative weight that should be placed on fluctuations in economic activity? A relatively modest weight often emerges from the "micro-foundations" of DSGE models – which typically assume, for example, perfect insurance across individuals regarding consumption and labor-market fluctuations. More recent work (see, for example, Ravn and Sterk, 2017) allows for heterogeneity across households and imperfect insurance, and related approaches may lead to different conclusions about the relative costs of fluctuations in economic activity.

- How large are distortions that imply that the level of economic activity is below its optimal level? On the one hand, distortions that imply the socially-optimal level of output exceeds productive potential would imply that the shortfalls in output relative to potential associated with the interaction of a low inflation target and the ELB are more costly than in our illustrations. On the other hand, the work of Barro and Gordon (1983) (and its descendants) argued that such distortions would make it difficult for a central bank to maintain low and stable inflation.

A satisfactory analysis of this range of questions is left to future work.

VI. Commitment strategies

VI.A. A rule with commitment

We now move beyond the traditional simple rule approaches toward an approach that better captures the New-Keynesian literature's emphasis on commitments to maintain policy accommodation for a longer period—that is, forward guidance of the Odyssean variety in the lexicon of Campbell, Evans, Fisher, and Justiniano (2012)—as a means to lowering the adverse

effects of an ELB. In particular, we consider a policy rule in which the change in the nominal interest rate responds to the deviation of inflation from an inflation objective of 2 percent and the output gap:

$$\Delta i(t) = .125[(\pi^4(t) - 2) + y(t)].\ ^{25}\tag{5}$$

We consider two ways in which this rule could be followed. We refer to the first as a "naïve" implementation of the rule. In this implementation, we assume policymakers take the lagged value of the nominal interest rate entering the rule to be equal to the actual lagged value. This assumption implies that the short-term interest rate is increased from the ELB as soon as the weighted average of inflation and the output gap in the rule exceed their objectives. It also implies that the ELB is not accompanied by any commitment to extraordinary accommodation beyond that prescribed by the rule. One might nonetheless interpret the rule as implying extraordinary accommodation relative to a Taylor (1993, 1999) rule, as it embeds a commitment not to raise the interest rate until the average of inflation and output exceed their objectives.

In the second implementation of the rule, we introduce a commitment to remain more accommodative than the naïve implementation of the rule following a period in which the ELB binds. The idea is to keep track of the "shadow" rate of interest—that is, the interest rate that would have prevailed had the ELB not applied—and not raise interest rates until the shadow rate rises above the effective lower bound. Algebraically, we can define the shadow rate, i^*, as:

$$i^*(t) = .125(\pi^4(t) - 2) + .125y(t) + i^*(t - 1)\tag{6}$$

The policy rate is then set equal to the maximum of this shadow rate and the ELB:

$$i(t) = \max(i^*(t), i^{ELB})\tag{7}$$

Under this rule, the shadow rate will continue to fall if output and inflation fall below objective during an ELB episode, and the nominal interest rate will not rise above the ELB until the shadow rate rises above the ELB—which will not occur until sometime after the average of

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[25] In equation 5, the nominal interest rate is expressed at an annual rate and that the four-quarter rate of inflation, $\pi^4(t)$, equals the average of inflation in the current and previous 3 quarters: ($\sum_{i=0}^3 \pi(t - i) = \sum_{i=0}^3 (1 - L)p(t - i)$, where L is the lag operator).

inflation and output rise above objective. This mechanism is related to the one proposed by Reifschneider and Williams (2000), who suggested that policymakers keep track of the foregone decline in interest rates implied by an ELB and commit not to raise the short-term policy rate above the ELB until this stock of forgone cuts in interest rates has been exhausted. As we noted above, Coibion, Gorodnichenko, and Wieland (2012) employ a similar shadow rate adjustment, and this commitment assumption is central to their finding that the ELB is only mildly binding in their DSGE model.

There are several reasons to consider such rules. First of all, like the empirical rule (Section III.A), both versions of this rule include an important weight on the lagged nominal interest rate—indeed, our change rule goes further than the empirical rule and assumes a coefficient of one. There is a long literature discussing why introducing lags of the policy rate into a policy rule improve its performance away from the ELB—see Woodford (2003) for a summary. Intuitively, adding the lagged value of the funds rate tends to make the rule more effective because doing so makes changes in the funds rate more persistent. Greater persistence will mean that any given change in interest rates will have a larger impact on long-term interest rates, and in most macroeconomic models—including FRB/US and our DSGE model—it is long-term interest rates that are most relevant for spending. As a comparison of tables 2 and 3 indicates, the empirical rule performs somewhat better than the simple rule, especially in the DSGE model, and the presence of lagged inflation is one reason why.

Second, the naïve version of the rule implies that the nominal interest rate will remain at its ELB until either inflation rises above the 2 percent target or output rises above potential once the ELB has been reached. As a result, the equation captures risk-management considerations emphasized in recent discussions: Campbell, Evans, Fisher, and Justiniano (2012) consider the role of thresholds for economic activity or inflation in determining exit from the ELB in their discussion of Odyssean forward guidance and risk management, and the rule implies thresholds of output equal to potential (or, equivalently, an unemployment rate threshold at the natural rate). In addition, Evans, Fisher, Gourio, and Krane (2015) argue that the risks associated with a return to the ELB point to a need for policymakers to allow some overshooting of either inflation or output relative to their long-run objectives before removing policy accommodation once an ELB

episode has begun—and a rule that does not remove accommodation until at least one of the goal variables overshoots guarantees such behavior.

Third, a small literature has suggested that a rule of this form is a good description of policymaker behavior over certain historical periods (Fuhrer and Moore, 1995; Kiley, 2014) and that such a policy may be nearly optimal in simple rules with some features reminiscent of modern macroeconomic models (Fuhrer and Moore, 1995). Moreover, the optimal simple rules in Reifschneider and Williams (2000) and Williams (2003) have parameter values fairly close to those in the proposed rule. The near-optimality of a rule in which the first difference of the nominal interest rate responds to inflation and the output gap is also consistent with the New-Keynesian literature on optimal inertia (e.g., Woodford, 1999). This connection stems, in part, from the fact that the proposed rule has a price-level element absent the ELB, as we discuss next.

Finally, the shadow-rate version of the rule can also be interpreted as a type of flexible price-level targeting, connecting our discussion of a commitment approach to that literature. Integrating backward, the rule can be rewritten as:[26]

$$i(t) = .125\left\{\sum_{i=0}^{3}(p(t-i) - .5t) + \sum_{j=0}^{\infty}y(t-j)\right\} \quad \text{(8)}$$

Here, the rule responds to the average of the price-level over the most recent four quarters relative to a trend that increases at a 2 percent (annual rate) per period, as well as to the entire history of deviations of output from potential. A simple version of the first component of the rule (e.g., the current price level) is shared with price-level targeting and nominal-income targeting rules. The second component would not be present in a pure price-level rule; in a nominal-income targeting rule, only the current value of the output gap would be present, not the entire history of output gaps. Rules that include a price-level element, as in the shadow-rate version of our rule, have been shown to be quite valuable in stabilizing the economy and have been discussed as a potential commitment approach, especially in discussions of the effective lower bound (Woodford, 2003).

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[26] It is instructive to walk through the steps delivering the price-level terms. The inflation terms above are $\sum_{i=0}^{3}\pi(t-i) - 2$, which equals $\sum_{i=0}^{3}\left((1-L)p(t-i) - .5\right)$. Multiplying by the inverse of (1-L) yields $\sum_{i=0}^{3}(p(t-i) - .5t)$.

VI.B. Outcomes

Table 5 presents, in the upper half of the relevant panel, results for the DSGE and FRB/US models under the naive version of the rule. As can be seen on the first line of each table, the rule delivers good economic performance when the steady-state nominal interest rate is relatively high, with the standard deviations of both inflation and the output gap below the values achieved under either the estimated rule or the simple rule in both models. Performance remains very good under this rule in both models for a steady-state nominal interest rate as low as 4 percent, but deteriorates for lower values of the steady-state nominal interest rate.

Table 5: Performance of Difference Rule with and without Shadow Rate Adjustment

	ELB frequency	Mean duration of ELB	mean(y)	mean(π) (π*=2)	RMSD(y)	RMSD(π)
DSGE Model						
Without Shadow Rate Adjustment						
5	0.8	4.9	0	2	2.4	2.1
4	3.4	6.2	-0.1	2	2.5	2.1
3	10.4	9	-0.5	1.6	3.4	2.8
With Shadow Rate Adjustment						
5	0.9	6.1	0	2	2.4	2.1
4	3.6	7.7	0	2	2.5	2.1
3	9.6	9.3	0	2	2.5	2.1
FRB/US Model						
	ELB frequency	Mean duration of ELB	mean(y)	mean(π) (π*=2)	RMSD(y)	RMSD(π)
Without Shadow Rate Adjustment						
5	5.3	7.2	-0.1	2	2.3	1.4
4	12.4	8	-0.4	1.9	2.7	1.5
3	29.7	10.8	-1.4	1.5	3.8	1.8
With Shadow Rate Adjustment						
5	6.1	9.6	0	2	2.3	1.4
4	12.0	11.1	0	2	2.3	1.4
3	22.0	13.8	-0.1	2	2.5	1.4

The structure of the rule contributes to the limited gains in performance achieved relative to our earlier, non-commitment rules. In particular, the rule continues tightening policy for as long as inflation and/or output exceed objective, which can be quite restrictive. At low values of the steady-state nominal interest rate, this latter property dominates the stimulative properties

that accompany continued loosening in policy when inflation and output fall short of objectives because the ELB limits accommodation and the period after an ELB episode is followed by a pronounced tightening in the monetary stance.

Overall, these results suggest that a policy approach in which the nominal interest rate is not increased until either inflation or output sufficiently exceed their long-run objective—that is, thresholds for exiting the ELB equal to the inflation target and the natural rate of unemployment, respectively—may capture part of the risk-management approach suggested by Evans, Fisher, Gourio, and Krane (2015). However, the very aggressive tightening in policy implied by a difference rule of this type may be too restrictive to promote recovery absent an additional element.

The bottom panel of table 5 presents results under this shadow-rate implementation for both the DSGE and FRB/US model. In both models, such a commitment effectively eliminates any deterioration in economic performance associated with an ELB. This result is reminiscent of a core result from simple New-Keynesian models: Policymakers capable of committing to possibly very accommodative policies can essentially remove the pernicious effects of the ELB.

VI.C. Inflation targets under commitment policies

Our results in Section V suggested that lower levels of the equilibrium federal funds rate could imply some increase in the optimal rate of trend inflation, with the effects especially pronounced in the DSGE model. Those results, however, assumed that policy was set according to the simple rule. Under that rule, the ELB leads to a substantial deterioration in economic performance. A higher inflation target would lead to an improvement along this dimension, as the ELB would be encountered less often. As table 5 makes clear, macroeconomic performance is considerably better under the policy rule with the commitments we have assumed than under the simple policy rules. In particular, under the change rule that accumulates foregone accommodation in a shadow interest rate, there is hardly any deterioration in macroeconomic performance as the equilibrium real federal funds rate declines. Under commitment approaches such as these, the stabilization benefit from raising the inflation target is considerably smaller than under the simpler rules. As a consequence, the case for raising the inflation target effectively disappears under commitment approaches, regardless of one's assessment of the costs of inflation or the relative importance of output fluctuations in the social welfare function.

VI.D. Can commitments be credible?

The commitment strategies we have discussed would represent substantial changes from approaches to monetary policy based on traditional simple rules. If policy had historically been set in accordance with a simple-rule perspective—which many observers suggest may have been the case prior to 2007 (see Taylor, 1993, and Taylor and Williams, 2010)—then a switch to an approach emphasizing, for example, the change in the interest rate, or providing additional accommodation in the aftermath of an ELB episode, would mark a major change in policy. The extent to which such a major change in policy would be credible is thus an important question.

We view the credibility of a commitment policy as having two components, one concerning the credibility of the policy on announcement and the other, the credibility of the policy once it is established. A key consideration on the announcement of a new policy strategy is the degree to which expectations adapt. We do not explore that issue directly here, but it is reasonable to imagine that some period of adaptation would be necessary—see Reifschneider and Roberts (2006) for illustrative simulations and a discussion.[27]

The credibility of a commitment policy once the policy is well understood raises different questions. In particular, the commitment policies we consider here do not remove accommodation prior to inflation or activity overshooting their desired levels and may imply inflation that exceeds the central bank's 2 percent target, perhaps by a considerable margin. Such a policy may not be credible because it would not be time-consistent: Once free of the ELB, a policy maker would be tempted to tighten policy in order to bring inflation and resource utilization back to their targets. It is important to keep in mind that the credibility of commitments by monetary policymakers is not unique to the "make up" policies we discuss. For example, the risk-adjustment strategies discussed above also imply that inflation overshoots the 2 percent objective often—as we showed, inflation must average about 3 percent to reach a 2 percent target under this approach. The fact that such commitment/credibility challenges are pervasive suggests that a key question is whether economic theory and historical experience

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[27] Reifschneider and Roberts (2006) consider the effectiveness of various strategies to mitigate the effect of the ELB under model-consistent expectations and expectations that are invariant to the policy regime through a set of illustrative simulations. Kiley (2017) shows that commitment policies can be highly effective, even if households' and nonfinancial firms' expectations formation is invariant to the policy regime, so long as financial markets respond to policy communications.

indicate that a central bank could overcome the temptation to renege on its promises. This question was posed by Barro and Gordon (1983) with respect to whether a central bank would be capable of maintaining low and stable inflation. These authors showed that when equilibrium output is inefficiently low—owing, for example, to monopolistic competition—a promise to maintain low and stable inflation would not be time consistent. Barro and Gordon (1983) then worked out conditions under which commitments by a central bank could be made credible. Subsequent history suggests that central bank commitments to low and stable inflation can indeed be credible. As the review by Svensson (2010) suggests, central banks have stuck to their inflation targets over extended periods, including across turnovers in the leadership of the central bank, suggesting a role for the reputation of the institution, not just the individuals in place, in shaping the reputational forces that influence the credibility of commitments.[28] Nakata (2014) has discussed how such reputational effects may make a post-ELB commitment policy credible.

All told, it is reasonable to question whether the types of strategies we discuss could be sustained, but it is also reasonable to consider the possibility that the challenges related to commitment are manageable.

VII. Looking back at recent history: A counterfactual exercise

Up to this point, our analysis is based on simulations over many periods and is divorced from any set of specific historical conditions. To illustrate the performance of the approaches we have analyzed in a less abstract manner, we consider how the outlook for inflation and economic activity would have evolved (according to our models) if there had been a credible shift toward the approaches analyzed herein in the fall of 2013; these simulations are akin to impulse-response analyses of how conditions would have differed if policy changes were adopted at that time, based on macroeconomic conditions at that point. We chose the fall of 2013 based on several considerations: It matches the period over which Engen, Laubach, and Reifschneider (2015) considered alternative outlooks; it is sufficiently after the Great Recession to be a plausible candidate for a shift in regime, yet sufficiently far in the past so as not to conflate the general issues we discuss with issues that some readers may see as relevant for current policy

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[28] "No country has abandoned inflation targeting after adopting it (except to join the Euro Area), or even expressed any regrets." Svensson (2010, p. 1242)

debates; and it represents a period during which the outlook involved still sizable slack in labor markets and inflation below its 2 percent objective to illustrate differences across the policy strategies.

Figure 10 presents results, with the upper row of panels presenting results for the FRB/US model and the lower row those for the DSGE model. In each case, the solid blue line represents the history of a variable through 2013:Q2 and the consensus forecast thereafter, as of October 2013 as reported in Engen, Laubach, and Reifschneider (2015). We assume that this outlook is based on an equilibrium real interest rate r^* of 1.6 percent and a natural rate of unemployment of 5.6 percent, as the consensus outlook settles at these values for these variables by 2020. The FRB/US and DSGE models are matched to this history and projection, and alternative projections are derived by assuming that an alternative monetary policy approach is initiated in the first quarter of 2014.

To be clear, these simulations will assume that the new policy is immediately credible. To the extent that the policies differ substantially from policies in place historically, they would probably not be immediately credible—and thus the outcomes we present may not have been attainable circa 2013. While the performance of a new policy in the immediate aftermath of its adoption is clearly an important consideration, it is also important to assess the performance of policies in steady-state, after transition issues have been worked through.

In the consensus outlook as of October 2013, the nominal federal funds rate remains at zero until the first quarter of 2015, the output gap begins 2014 at -3 percent and closes gradually, and PCE inflation rises slowly to 2 percent.[29] Outcomes under the simple rule examined above (the solid black lines) are essentially identical to the consensus outlook, apparently because the policy approach embedded in this rule does not differ materially from that implicit in the consensus outlook according to both the FRB/US and DSGE models.

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[29] To construct the output gap implicit in the consensus outlook, we subtract the unemployment rate from the assumed natural rate of unemployment of 5.6 percent and multiply the resulting unemployment gap by -2.

Figure 10: Changes in the Economic Outlook under Alternative Approaches
(Blue line: October 2013 Consensus Outlook; Black line; Outcomes under simple rule;
Black dashed-dotted line: With risk adjustment; Red dashed line: Outcomes under change rule with shadow rate)
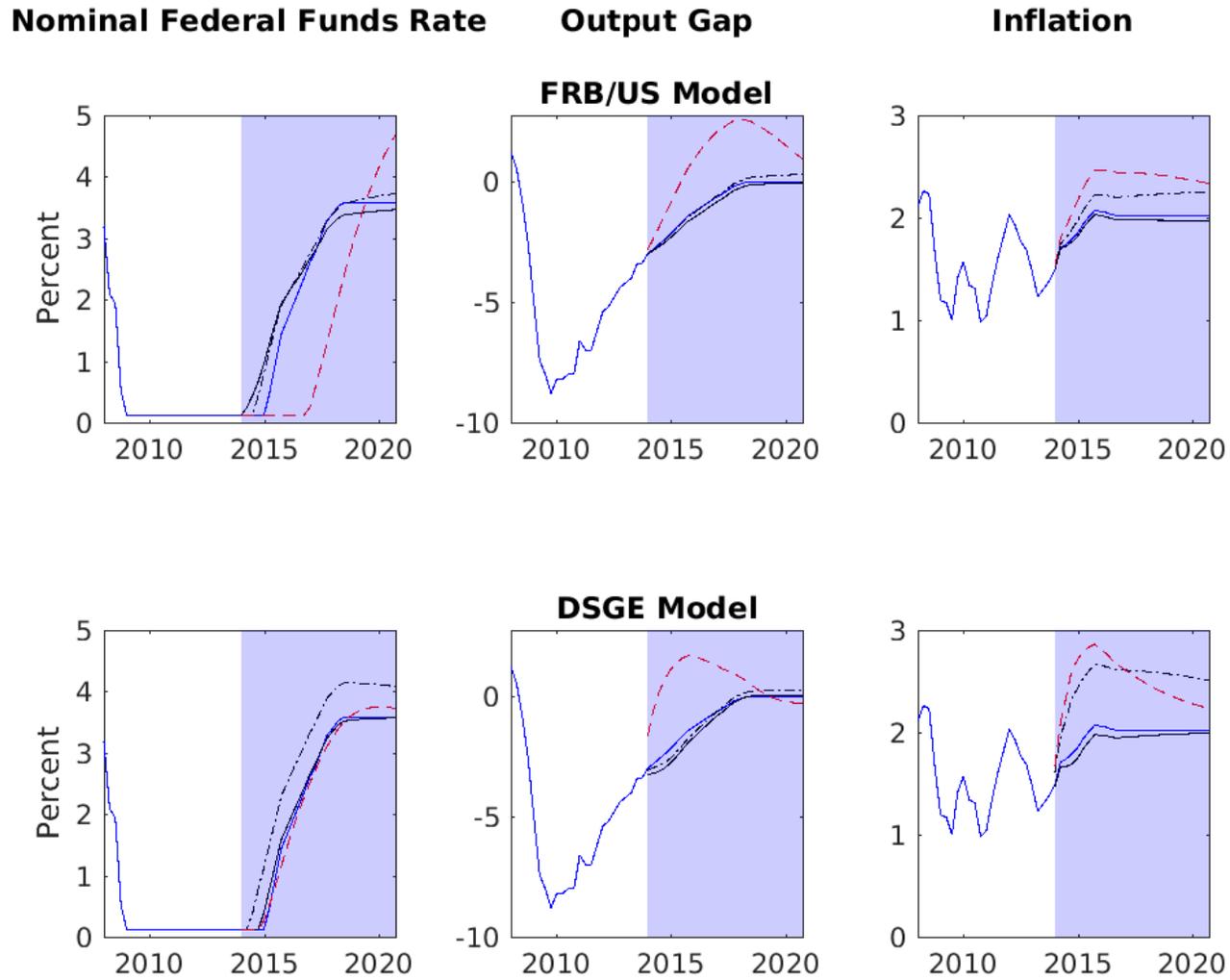
Implementing a 50 basis-point risk adjustment to the simple rule (the black dashed-dotted lines) leads to somewhat higher inflation and little change in output in both models. The more accommodative policy approach alters the outlook for the nominal interest rate very little in FRB/US, and actually leads to a more rapid increase in nominal interest rates in the DSGE model, as inflation rises quickly in response to the credible commitment to pursue inflation above 2 percent under the risk-adjusted strategy. All told, the stimulus associated with the risk-adjusted strategy leads to inflation between 2 percent and 2½ percent after 2015 in both models.

The change rule with shadow-rate adjustment commits to not raising the federal funds rate until the cumulated shortfall in inflation and output from their objectives from 2014 onward is unwound; it is shown in the red dashed lines. In the FRB/US model, this commitment leads to a considerably longer period over which the nominal interest rate is at its ELB, with the output gap rising to above 2 percent and inflation near 2½ percent by the late 2010s. In the DSGE model, activity and inflation jump immediately, and the path for the nominal federal funds rate is little different from the consensus outlook.

The overshooting that attends the risk-adjustment and commitment strategies raises possible areas of concern. One is whether the shifts in expectations and consequent changes in economic performance associated with the alternative rules would be realized: The shifts depend on the idea that the model's equations fairly capture structural relationships and that expectations formation would shift in the manner predicted by the models. In particular, the benefits of temporary overshooting rely on forward-looking behavior that may not be a good representation of actual behavior—see, for example, McKay, Nakamura, and Steinsson (2015), Gabaix (2016), and Kiley (2016). It is reasonable, to say the least, to entertain the possibility that such shifts would not occur, as the sharp jump in activity and inflation shown under the commitment strategy in figure 10 highlight. This criticism applies to the entirety of the exercises we have considered and the overwhelming majority of related work. Notably, it also applies to proposals to increase the inflation target.

VIII. Summary and conclusions

Nominal interest rates may remain substantially below the averages of the last half-century, as central bank's inflation objectives lie below the average level of inflation and estimates of the real interest rate likely to prevail over the long run fall notably short of the average real interest rate experienced over this period. According to simulations of a recent generation (DSGE) model and the FRB/US model, monetary policy strategies based on traditional simple policy rules lead to poor economic performance when the equilibrium real interest rate is as low as 1 percent, with the ELB binding between $1/3^{rd}$ and $2/5^{th}$ of the time and both inflation and economic activity falling systematically short of desirable levels. The frequency with which the ELB binds is estimated to be significantly higher than in previous analyses.

A risk-adjustment to a traditional simple rule, in which monetary policymakers are more accommodative, on average, than prescribed by the unadjusted rule, ensures that inflation averages its 2 percent objective—and requires that policymakers systematically seek inflation near 3 percent when the ELB is not binding. Nonetheless, such an approach only moderately improves the average level and stability of economic activity.

Commitment strategies in which monetary accommodation is not removed until either inflation or economic activity overshoot their long-run objectives are very effective in both the DSGE and FRB/US model. While the commitment strategies we examine implicitly include thresholds for inflation and real activity to determine the exit from the ELB, we find that such thresholds are insufficient to achieve the full gains from commitments in the model's we analyze. Rather, such a policy must be combined with additional commitments to make up foregone accommodation. In particular, we find that under a shadow-rate policy—in which the federal funds rate is not allowed to rise above the ELB until the shadow rate has returned to the ELB—the effects of the ELB are essentially eliminated.

We also illustrated issues that arise when considering the desirable level of the inflation target. As we emphasized, the degree to which such a shift could improve economic outcomes depends on the costs of steady-state inflation vs. those associated with the ELB. The costs associated with the ELB depend, in turn, on the potential credibility of commitment policies: If commitments to overshoot can be made credibly, the costs associated with the ELB shrink

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dramatically. The current state of our knowledge on these dimensions is limited. While we view our analysis as a useful illustration of the issues involved, further work is clearly needed in this area.

There are a number of limitations to our analysis. Perhaps most importantly, other policy strategies and different analytical approaches could lead to different conclusions. As we noted at the beginning of our discussion, quantitative easing has been deployed to address ELB concerns across the advanced economies: Although some research points to clear benefits from such actions (Reifschneider, 2016), a more in-depth analysis involving stochastic simulations and a comparison to commitment approaches has not been performed, and some models suggest less efficacy than others. In addition, a complementary approach would look at historical parallels. Experience in Japan in recent decades and in Europe earlier this decade may highlight possible dangers of approaches that underweight the asymmetry in risks associated with the ELB and do not maintain accommodation until inflation rises above its target. Conversely, the factors that led to the Great Inflation of the 1970s—and in particular the root causes of an unanchoring in inflation expectations—are likely not well captured by our models, which assume that agents believe inflation will eventually revert to a central bank's target. Analysis of these issues with a model-based framework and how they interact with the ELB will require both new models and investigations of computational and related solution issues that arise from the ELB and other important nonlinearities.

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