July 18, 2018

Monetary Policy Options at the Effective Lower Bound: Assessing the Current Policy Toolkit[1]

Introduction and summary

This memo quantifies some of the risks stemming from the effective lower bound (ELB) on the federal funds rate and assesses the efficacy of the Committee's options, within its current toolkit, to provide monetary policy accommodation in the event of a recession. In the first part, we estimate the probability of ELB episodes and their associated macroeconomic outcomes assuming that the federal funds rate is governed by a simple policy rule. In the second part, we explore the extent to which the FOMC can use threshold-based forward guidance and balance sheet policies of the kind used during the previous recession to mitigate ELB risks and improve macroeconomic outcomes. The policy options considered herein are consistent with the Committee's Statement on Longer-Run Goals and Monetary Policy Strategy; options that might require changes to that statement are not in scope.

Our analysis is part of prudent planning: Familiarity with policy options and their likely effects may facilitate judicious and prompt deployment if the economic outlook were to deteriorate significantly. Moreover, our analysis is motivated by estimates of a decline in the neutral rate of interest over the past decade: All else equal, a lower neutral rate reduces the scope to cut the federal funds rate in response to economic downturns, makes ELB episodes more likely to occur, makes them more severe when they do occur, and raises the need for the use of unconventional policy tools. In addition, understanding

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the capacity of the current toolkit to address ELB risks is a prerequisite for determining whether alternative policy strategies and tools should, at some point, be adopted.

Our main findings are:

- There is a material risk that the ELB will restrain policymakers' ability to support the economy in the future.
    - Simulations using the FRB/US model suggest a roughly 10 to 25 percent probability that the federal funds rate will be constrained by the ELB at some point between now and the end of 2022. That probability and the associated economic consequences are sensitive to the baseline path of the federal funds rate and the assumed volatility of economic shocks. Time-series (statistical) models suggest probabilities of an ELB episode over that horizon as high as around 35 percent.
    - Over the next decade, the simulations imply a roughly 20 to 50 percent probability that the federal funds rate will be constrained by the ELB at some point, with the per-period risk growing as the economic momentum in the current economic projection wanes.
    - These estimates of ELB risk are appreciably higher than assessed by the staff in memos sent to the FOMC about a decade ago, when participants discussed the choice of a numerical price objective and the policy framework.[2]
- The current monetary policy toolkit can offset only to some extent the effects of significant recessionary shocks.
    - During a recession, the FOMC's ability to contain the initial rise in the unemployment rate and fall in inflation is limited because of lags in the transmission of monetary policy actions.

[2] For example, in March 2007, the staff's assessment was that "the adverse effect from the zero lower bound is modest for inflation objectives at or above 1½ percent, though we recognize that 'modest' in the eye of one beholder may be either 'de minimis' or 'significant' in the eyes of others." See Kiley, Mauskopf, and Wilcox (2007), "Issues Pertaining to the Specification of a Numerical Price-Related Objective for Monetary Policy," memorandum to the FOMC, Division of Research and Statistics, March 12.

- If a recession leaves the federal funds rate constrained by the ELB, the unconventional policy tools examined in this memo can strengthen somewhat the labor market recovery and help raise inflation toward 2 percent over time.
  - Credible announcements that policymakers intend to keep the federal funds rate at the ELB until the labor market improves, inflation moves close to target, or both, put downward pressure on real long-term borrowing rates and the exchange value of the dollar, boost asset prices, and thus help stimulate economic activity.
  - Large-scale asset purchases (LSAPs) similarly can help support an economic recovery, notably by putting downward pressure on the term premium components of longer-term rates and easing financial conditions more broadly.
  - By contrast, resuming full reinvestment of principal payments on the Federal Reserve's security holdings or implementing a maturity extension program (MEP)—two measures that leave the size of the balance sheet unchanged—would provide only limited additional policy accommodation.
- Given that the transmission of monetary policies is subject to long lags, policymakers should deploy such policies rapidly in the event of an incipient recession.
- Overall, our analysis is consistent with the preponderance of empirical studies suggesting that the forward guidance and balance sheet policies deployed by the FOMC in the aftermath of the global financial crisis lowered the unemployment rate and raised inflation notably. However, there is considerable uncertainty around empirical estimates—even studies that find notable effects of balance sheet policies on Treasury yields can differ substantially

in the transmission of such effects to broader financial conditions and economic activity.[3] Moreover, the efficacy of these policies in our model is predicated on the FOMC making credible multi-year commitments to maintain accommodative financial conditions as well as on the public understanding those commitments and their effects.

Part I: How likely is the policy rate to be constrained by the ELB in the future? How severe would the consequences be?

Modeling approach

The federal funds rate could be constrained by the ELB in the future if adverse shocks were to cause inflation and economic activity to deteriorate sufficiently. The latest economic projections of FOMC participants are consistent with the federal funds rate settling between 2¼ and 3½ percent over the longer run. This range is lower than the cumulative rate cuts implemented by the FOMC in each of the past three recessions—roughly 5 percentage points—and thus suggests a material risk that the federal funds rate will be constrained by the ELB in the next economic downturn.

To estimate the frequency, duration, and severity of ELB episodes, we simulate the FRB/US model using historical shocks of the kind and size experienced by the U.S. economy over the past several decades.[4] Our stochastic simulations start in the third quarter of 2018 and extend several decades into the future. To establish a benchmark, we abstract for the moment from active use of unconventional monetary policies, assuming instead that the federal funds rate is set by a simple policy rule and that the term premium

[3] The staff's approach to estimating the effect of balance sheet policies on term premiums is described in Ihrig and co-authors (2012), itself building on Li and Wei (2013). As described in the former paper, in the main staff framework, these term premium effects transmit to macroeconomic variables via the conventional channels linking the term structure of interest rates to economic activity and inflation. Alternative structural models of balance sheet policies, featuring a distinctive transmission mechanism for asset purchase programs, include Andrés and co-authors (2004), Gertler and Karadi (2011, 2013), D'Amico and co-authors (2012), Chen and co-authors (2012), and Kiley (2014, 2018).

[4] Our approach is similar to that employed by Reifschneider and Williams (2000), Williams (2009) and Kiley and Roberts (2017), though, as we discuss later on, the details of our implementation differ along a number of dimensions.

effects (TPEs) of the Federal Reserve's existing asset holdings gradually dissipate as assumed under the staff's baseline projection.[5] We impose an ELB of 12.5 basis points, a value equal to the mid-point of the lowest range for the federal fund rate implemented by the FOMC during the global financial crisis. See Appendix I for a summary of our modeling assumptions.

The risks of an ELB episode depend on a number of factors, three of which we emphasize in our analysis:

- The baseline economic projection. We simulate the FRB/US model around an economic projection consistent with the medians of the June 2018 Summary of Economic Projections (SEP). For comparison, we also report statistics based on simulations around the June 2018 Tealbook baseline in Appendix II. The Tealbook baseline implies a higher path for the federal funds rate in coming years—and thus lower ELB risk—than the SEP-consistent baseline.
- The conduct of monetary policy. We assume that the federal funds rate is set according to either the inertial Taylor (1999) rule, which the staff uses to construct the Tealbook baseline, or an "asymmetric" version of that rule that calls for quicker cuts in the federal funds rate when the labor market is deteriorating. The inertial Taylor (1999) rule is given by:

$$R_t = 0.85R_{t-1} + 0.15(r^{LR} + \pi_t + 0.5(\pi_t - 2) + ygap_t),$$

where R_t is the federal funds rate, r^{LR} is the real federal funds rate in the longer run, π_t is four-quarter core PCE inflation, and $ygap_t$ is the output gap. The asymmetric version of that rule includes an extra term that calls for lowering the federal funds rate more rapidly than otherwise when the

[5] In addition, we assume that the term premiums in the model are insensitive to movements in resource slack. All else equal, assuming that term premiums fall when resource slack tightens would imply that changes in the conduct of monetary policy have somewhat larger effects on real activity and inflation than suggested by our model simulations. See Appendix VIII for a discussion of this assumption.

unemployment rate is both rising and above the natural rate of unemployment, which is 4½ percent in this baseline.[6] We see the asymmetric policy rule as more consistent with the speed at which the Committee has cut policy rates in past economic downturns—and might do so in the future—than the inertial Taylor (1999) rule.

- The neutral level of the real federal funds rate in the longer run (r^{LR}). The value of r^{LR} influences the level of the federal funds rate over time and, hence, the typical room to cut before reaching the ELB. Because r^{LR} is unobserved and estimated with a high degree of uncertainty, we consider values corresponding to the median, minimum, and maximum of longer-run estimates among SEP respondents.

Main results

Table 1 reports the probability that the ELB will bind at any point between now and selected dates in the future. The simulations suggest only a modest probability of returning to the ELB by the end of 2020 under the SEP-consistent baseline, at less than 5 percent. This low probability reflects, in large part, the current strength of the economy and the time it takes for the economy to respond to shocks in the model. The ELB probability is much higher in the longer run when the economic momentum present in the first several years of the projection has dissipated and the underlying shocks have transmitted fully to the economy.[7] Another key factor for the low probabilities reported in Table 1 is the assumed gradual rise of the federal funds rate to about 3½ percent over the medium term, which leaves some room for policymakers to ease financial conditions by lowering the federal funds rate without necessarily setting that rate back to the ELB. Simulations around the June 2018 Tealbook baseline (reported in Appendix II) point to

[6] The extra term in the asymmetric rule is $-0.85(U_t - U_{t-2})\mathbb{I}\{U_t - U_{t-2} > 0\}\mathbb{I}\{U_t > U_t^*\}$, where U_t is the unemployment rate in quarter t and U_t^* is the natural rate of unemployment in that quarter. This extra term is nonzero when the unemployment rate has been rising, on net, over the past two quarters, a condition that seeks to avoid quick cuts in policy rates in response to idiosyncratic movements in U_t. The further requirement that $U_t > U_t^*$ seeks to avoid triggering the asymmetry when the unemployment rate is converging toward its natural level from below.

[7] In fact, under the asymmetric rule, the per-period ELB probability in the longer run is about 15 percent; see Table 4.

even smaller ELB risk over the next few years than simulations under the SEP-consistent baseline because the staff projection assumes a higher path for the federal funds rate and thus greater room to cut before the ELB binds.

Table 1: Probability of an ELB episode between now and selected periods based on stochastic simulations around June 2018 SEP-consistent baseline (in percent)

	2020:Q4	2022:Q4	2027:Q4
r^{LR} = 0.88 (SEP median)			
Inertial Taylor (1999) rule	2.7	10.6	28.8
Asymmetric rule	4.2	18.8	42.1
r^{LR} = 1.50 (SEP maximum)			
Inertial Taylor (1999) rule	2.4	8.2	23.0
Asymmetric rule	3.6	14.6	34.4
r^{LR} = 0.25 (SEP minimum)			
Inertial Taylor (1999) rule	3.3	14.7	36.8
Asymmetric rule	5.7	24.7	50.9
Addendum			
Survey of Primary Dealers (Median, June 2018)	20.0	n.a.	n.a.

Note: Staff calculations using 20,000 stochastic simulations of FRB/US model around the June 2018 SEP-consistent baseline, holding balance sheet policy constant.

Beyond 2020, the federal funds rate in the SEP-consistent baseline projection falls from its peak of 3½ percent to its longer-run level of 2.88 percent. As a result of this decline, policymakers are left with less scope to cut the federal funds rate in response to adverse shocks before the ELB binds and thus they face greater ELB risk in each period. Looking at the next 10 years or so, our simulations assign a 29 to 42 percent probability that the ELB will bind at some point depending on the policy rule. On a per-period basis (not shown in Table 1), the risk that the federal funds rate is constrained by the ELB rises beyond 2020 as the economic momentum embedded in the economic projection gradually wanes and as shocks and their effects cumulate. Estimates of the ELB risk at long horizons are sensitive to a number of modeling assumptions. In Appendix III, we compare our per-period ELB probabilities in the longer run to those found by Williams (2009) and Kiley and Roberts (2017) in studies that also use the FRB/US model.

Overall, the probabilities reported in Table 1 are somewhat lower at all horizons under the inertial Taylor (1999) rule than under its asymmetric version because the asymmetry leads, by design, to larger cumulative cuts in policy rates when the labor market deteriorates. Of course, the fact that the ELB binds more frequently under the asymmetric rule need not imply that macroeconomic outcomes under that rule are worse than under the inertial Taylor (1999). To the contrary, as we discuss later, prompt policy rate cuts early in economic downturns can help attenuate the effects of recessionary shocks (although doing so improves outcomes only slightly in our model simulations).

Sensitivity to longer-run neutral rate assumptions

Moderate deviations from the SEP-baseline assumption about r^{LR} have the expected effect on ELB risk: Lower (higher) r^{LR} values imply greater (lower) risk. Quantitatively, moderate deviations from baseline r^{LR} assumptions have modest effects on the ELB risk over the next few years, in part because the assumed gradualism in the conduct of monetary policy during normal times implies that changes in r^{LR} feed into the path of the federal funds rate only slowly.[8] For example, as Table 1 shows, assuming a path of the federal funds rate consistent with the lowest estimate of r^{LR} among SEP respondents (0.25 percent) is associated with a probability of returning to the ELB by the end of 2022 of 25 percent under the asymmetric rule compared with a probability of 19 percent for the median estimate of r^{LR}.[9]

Estimates from alternative models

Our conclusions about the frequency of ELB episodes are sensitive to the choice of a model to perform the analysis. Table 2 reports ELB risk estimates from three time-series models developed by Federal Reserve staff: Johannsen and Mertens (2016), Lubik and Matthes (2015), and Del Negro and co-authors (2017).[10] In contrast to the preceding

[8] To obtain an economic projection under an alternative value of r^{LR}, we simply replace the path of the federal funds rate in the SEP-consistent baseline projection with the path that is prescribed by the asymmetric rule with the alternative r^{LR} value, keeping all other elements of the baseline projection unchanged.
[9] When we posit very low r^{LR} values—say, negative 1.5 percent—and subject the model to shocks over long horizons, we sometimes encounter “death spirals” by which the policy rate response to recessionary shocks is constrained by the ELB to such an extent that the economy fails to recover after a recession. As a result, output tends to drift below its potential level by an ever increasing margin over time, causing the federal funds rate to be persistently stuck at the ELB. While such a low value is well below the range of responses in the SEP, it is encompassed in the uncertainty bands of several empirical estimates at standard levels of statistical significance.
[10] We thank the authors of these papers for providing the results reported in Table 2.

FRB/US simulations, the predictions from these models do not depend on a judgmental economic projection. In these models, the federal funds rate responds symmetrically to economic developments by construction and the degree of inertia in policy decisions is estimated to be large. Importantly, these models take into account the uncertainty attached to current estimates of r^{LR}, as opposed to postulating a specific value. To provide some idea of this uncertainty, we report in Table 2 each model's median estimate of r^{LR} for the second quarter of 2018 along with the associated 68-percent uncertainty range.

Table 2: r^{LR} estimates and probability of ELB episode between now and period shown from selected time-series models (in percent)

	r^{LR} estimate		probability of ELB episode		
	median	68-percent uncertainty range	2020:Q4	2022:Q4	2027:Q4
Johannsen and Mertens (2016)	0.7	[–0.2, 1.6]	13.5	22.2	35.3
Lubik and Matthes (2015)	1.0	[–0.6, 2.8]	10.8	18.1	29.3
Del Negro and co-authors (2017)	1.3	[1.0, 1.7]	28.5	36.8	52.0

Sources: Authors of each study.

Compared with the FRB/US simulations, the three time-series models imply a somewhat higher probability—between 22 and 37 percent—that the ELB will bind between now and the end of 2022. This higher ELB risk reflects, in large part, the weight that these models assign to the possibility that r^{LR} is currently low and will be so in the future. More generally, they suggest that occasional returns to the ELB will be a feature of policymaking in the future: Over the next decade or so, the models predict a 29 to 52 percent probability of seeing at least one ELB episode, a range high enough that the design of monetary strategies to deal with the ELB arguably warrants special attention.[11]

[11] Yet another approach to extracting estimates of ELB risk is to simulate dynamic stochastic general equilibrium (DSGE) models. In many such models, the probability of observing an ELB episode is very sensitive to the rule governing the federal funds rate. For example, Kiley and Roberts (2017) demonstrate

Macroeconomic outcomes associated with ELB episodes

ELB episodes could be a source for concern even when infrequent if they are associated with large economic losses. Conversely, ELB episodes need not have large economic consequences if the constraint binds only for short periods or if economic conditions would have called for setting the "notional" federal funds rate (that is, the rate prescribed by the policy rule in the absence of the ELB) only modestly below the ELB. To assess the negative effects on economic conditions that are attributable to the ELB, Table 3 compares outcomes for the unemployment rate and inflation when policy rates are constrained by the ELB (labeled "With ELB") to the counterfactual outcomes that would be observed in its absence (labeled "No ELB").[12] The simulations are computed under the assumption that policymakers use the asymmetric policy rule to set the federal funds rate. For comparability, the statistics are computed, for each combination of a period shown and r^{LR} value, using only the observations for which the ELB binds in that period under the "With ELB" policy.

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that a standard DSGE model implies very high ELB risk under traditional Taylor-type rules whereas more efficient strategies imply very low ELB risk. The sensitivity of results to the precise form of the interest rate rule arises, in part, because aggregate demand and inflation are more responsive to monetary policy than in the FRB/US model and can thus be stabilized through rules that adjust the expected path of short-term interest rates relatively modestly, but in a manner that is targeted to offset aggregate demand shortfalls. With regard to ELB risk over the next decade, the DSGE model of Del Negro and co-authors (2017) implies that the probability of being at the ELB at some point between now and 2020, 2022, and 2027 is 47 percent, 60 percent, and 72 percent, respectively, under the same inertial Taylor rule used in the FRB/US simulations. These probabilities are high, in part, because the authors estimate a volatile economic environment. Moreover, the model calls for a relatively low path for the policy rate in coming years to offset the effects of persistently high risk and liquidity premiums.

[12] The simulations without imposing the ELB should not be interpreted as suggesting that it is possible, in practice, to set policy rates much below zero or that the monetary transmission mechanism would be the same under negative policy rates. Rather, the simulations provide benchmarks for the shortfall in monetary policy accommodation due to the ELB and the likely effects of that shortfall on macroeconomic outcomes. Staff analysis suggests that, in the FRB/US model, being able to set interest rates about 50 basis points below the ELB assumed in the simulations for this memo would improve macroeconomic outcomes only modestly. See Hess Chung and Edward Herbst (2016), "Unconventional Policy Responses to a Recession," memorandum to the FOMC, Division of Research and Statistics and Division of Monetary Affairs, March 4. See also Sriya Anbil, Courtney Demartini, Laura Lipscomb, Patrick E. McCabe, Marcelo Rezende, Heather A. Wiggins, John P. McGowan, and Patricia Zobel (2016), "Considerations for Implementation of Negative Policy Rates in the United States," memorandum to the FOMC, Federal Reserve Board and FRBNY, March 4.

Table 3: Macroeconomic outcomes conditional on being in an ELB episode in period shown (in percent)

	2020:Q4				2022:Q4				2027:Q4			
	U_t		π_t		U_t		π_t		U_t		π_t	
	median	95th highest	median	95th lowest	median	95th highest	median	95th lowest	median	95th highest	median	95th lowest
r^{LR} = 0.875 (SEP median)												
With ELB	6.9	8.0	0.8	0.1	6.5	8.8	1.0	-0.4	6.6	9.7	0.7	-1.4
No ELB	6.4	7.3	1.0	0.4	5.9	7.8	1.2	0.1	5.9	8.1	1.0	-0.2
r^{LR} = 1.50 (SEP max.)												
With ELB	7.0	7.9	0.8	0.2	6.7	8.8	0.9	-0.3	6.9	9.6	0.7	-1.2
No ELB	6.5	7.4	1.0	0.4	6.2	7.9	1.1	0.0	6.2	8.3	0.9	-0.2
r^{LR} = 0.25 (SEP min.)												
With ELB	6.7	8.1	0.8	0.0	6.2	8.9	1.0	-0.5	6.4	9.9	0.8	-1.8
No ELB	6.1	7.3	1.1	0.4	5.7	7.6	1.3	0.2	5.7	7.9	1.1	-0.1

Notes: Staff calculations using 20,000 stochastic simulations of the FRB/US model around the June 2018 SEP-consistent baseline and under the assumption that policymakers follow the asymmetric policy rule. For comparability, simulations in which we impose the ELB (labeled “With ELB”) and in which we do not (labeled “No ELB”) are performed using identical sequences of economic shocks. For each combination of a period and r^{LR} value, all statistics are computed using the subset of observations for which the ELB binds under the “With ELB” simulations.

Overall, Table 3 shows that policymakers’ inability to lower the federal funds rate below the ELB is associated with a weaker economy than would exist otherwise. For example, the median unemployment rate across all simulations in which the ELB binds in the final quarter of 2020 is roughly ½ percentage point higher than would have been observed had the ELB not been a constraint on policy. For inflation, the median reading conditional on being at the ELB in 2020:Q4 is a couple tenths of a percentage point lower than otherwise. We find roughly similar differences in median constrained and unconstrained outcomes when we look at ELB events later in the simulation period or when we look at moderately higher or lower values of r^{LR}.[13]

[13] Because the sets of ELB observations reported in the table are specific to each period and value of r^{LR}, comparisons of statistics across r^{LR} assumptions and periods should be made with caution. For example, for a given sequence of shocks, low values of r^{LR} are typically associated with a greater deterioration in macroeconomic outcomes at the ELB than high values of r^{LR}. However, given our sampling procedure, there exists a countervailing selection effect by which ELB episodes under relatively high values of r^{LR} tend to be associated with the sampling of shocks from the most severe historical recessions.

The disruptive effects of the ELB are more readily apparent when we look at tail events for which the constraint is binding more strongly. Again conditional on being at the ELB in 2020:Q4, the 95th highest percentile of the unemployment rate is ¾ percentage point higher than in the absence of the ELB whereas the 95th lowest percentile of inflation is 0.3 percentage point lower than in the absence of the constraint; these differences are somewhat larger than the corresponding differences for the medians. Moreover, the differences between constrained and unconstrained outcomes grow in magnitude as we consider ELB events at later horizons because the accumulation of economic shocks leads to more dispersed outcomes, including several for which the ELB is a significant constraint on policy. For example, for a value of r^{LR} equal to the SEP median, the difference between constrained and unconstrained outcomes in 2027:Q4 is 1.6 percentage points for the 95th highest percentile of the unemployment rate and 1.2 percentage points for 95th lowest percentile of inflation.[14]

The above simulations are conditioned on model parameters and economic shocks that are estimated on macroeconomic data over the last five decades or so. Of course, in the future, the structure of the economy and the distribution of economic shocks may differ. For example, the experience in Japan over the past few decades suggests that ELB episodes could be more frequent and longer lasting—particularly if inflation expectations were to drift downwards substantially. Overall, the significant difference between outcomes when we impose the ELB and when we do not is revealing of the shortfall in policy accommodation due to the ELB constraint and motivates our consideration below of unconventional policy tools.

Part II: To what extent can the use of forward guidance and balance sheet policies help provide additional policy accommodation at the ELB?

We next explore how two kinds of unconventional policies used by the FOMC in response to the global financial crisis—threshold-based forward guidance about the

[14] Model estimates of the severity of the economic disruptions induced by the ELB are sensitive to a number of modeling assumptions, including the conduct of fiscal policy, the monetary policy strategy, and expectation formation. See Appendix III for a related discussion of how these factors affect long-run ELB risk in the simulations.

federal funds rate and balance sheet policies—might help stabilize the economy following adverse shocks. We first illustrate the macroeconomic effects of such policies in a stylized recession scenario in which the ELB binds for an extended period.[15] We next perform stochastic simulations of the FRB/US model to assess the overall improvement in macroeconomic outcomes and mitigation of tail risks provided by unconventional policy tools.

II.A Unconventional policies in a recession scenario

<u>Description of our recession scenario</u>

Our recession scenario is similar in severity to the 2008–2009 recession: Starting in the third quarter of 2018 (the first quarter in the simulation), a sequence of adverse spending shocks lifts the unemployment rate to 10 percent at its peak and lowers inflation to an annual rate of ¾ percent at the trough.[16] We assume that policymakers set the federal funds rate according to the asymmetric policy rule, subject to the ELB, and that balance sheet policy is completely passive; that is, full reinvestment of principal payments on the Federal Reserve's security holdings is not resumed. Instead, only principal payments on Treasury securities in excess of $30 billion per month and on agency securities in excess of $20 billion per month are reinvested, while the rest is redeemed, until the size of the balance sheet is normalized.[17] These assumptions are made for simplicity and to establish a benchmark for assessing the effects of alternative monetary policies later on. As shown in Figure 1, economic conditions in this scenario deteriorate sufficiently that the ELB binds for nearly five years. In the absence of the ELB constraint, the asymmetric rule would have called for lowering the federal funds rate to -8 percent, which, when implemented in the model, takes off 1½ percentage points

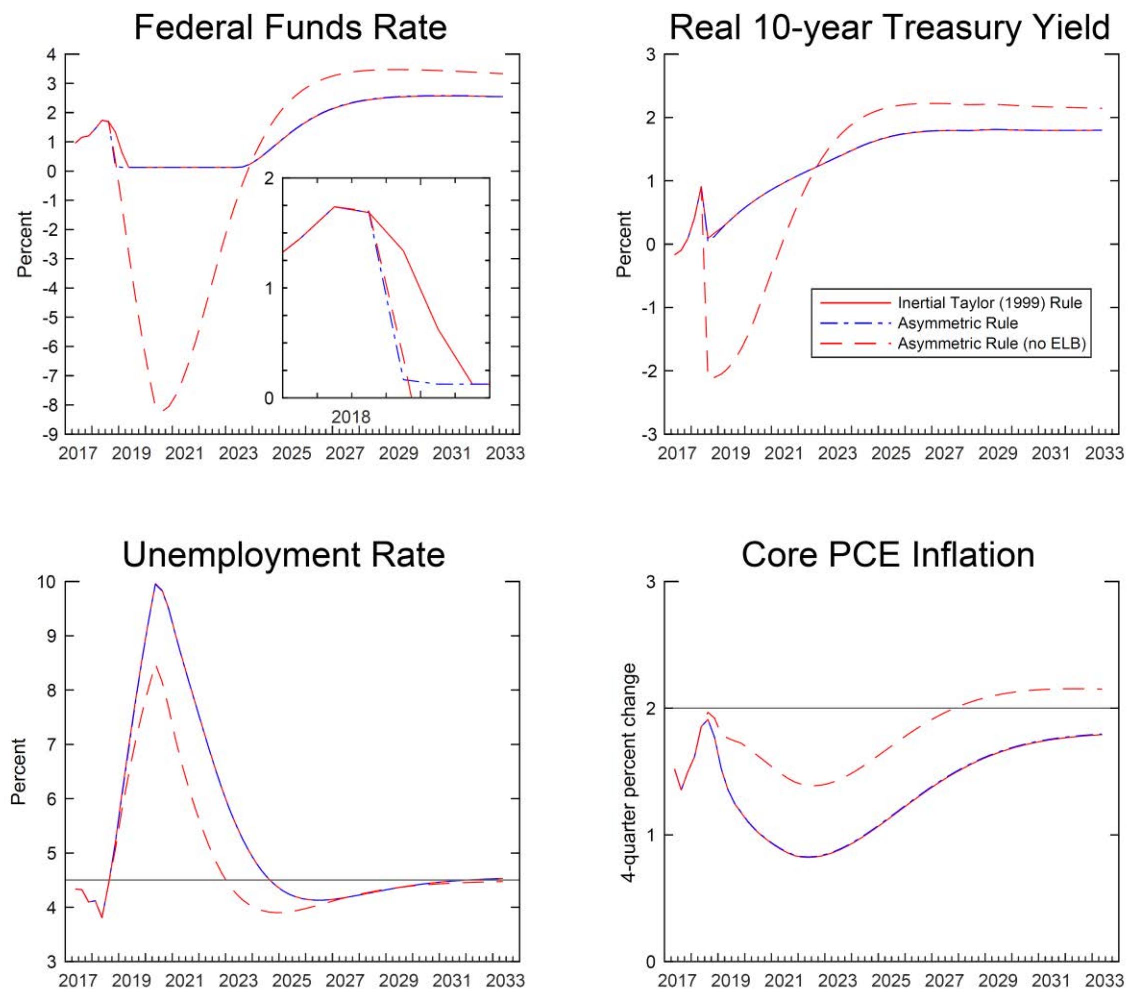
[15] This approach is similar to that in Reifschneider (2016), Yellen (2016), and Chung and Herbst (2016).
[16] The deterioration in macroeconomic outcomes in our recession scenario is also similar to that in the "severely adverse scenario" featured in the Federal Reserve's 2018 supervisory stress tests.
[17] Whereas the amount of maturing Treasury securities and agency debt are known, at least in the near term, principal payments on agency MBS in our simulations depend on the evolution of the economic outlook. Our cap structure is a simplified version of the one currently in place for principal payments on SOMA securities, as detailed in the addendum to the FOMC's Policy Normalization Principles and Plans released on June 14, 2017.

from the peak in the unemployment rate. Hence, the ELB materially constrains policymakers' ability to stabilize the economy in this scenario.

In the FRB/US model, the more rapid cuts in the federal funds rate prescribed by the asymmetric rule in response to the recession do little, by themselves, to improve economic conditions. As seen in the inset box of Figure 1, under the asymmetric rule, policymakers lower the federal funds rate to the ELB two quarters earlier than under the inertial Taylor (1999) rule, and subsequently implement the same paths for the policy rate. Under the assumption maintained in the simulations that price setters, wage setters, and financial market participants perfectly understand the policy rule in place, the difference in policy stance during the first few quarters of the simulation makes virtually no difference for the real longer-term interest rates that influence economic activity in the model.[18] As a result, the unemployment rate and inflation outcomes are almost identical between the asymmetric rule and the inertial Taylor (1999) rule. This result is a reminder that it is the entire expected path of policy—rather than only the prevailing policy settings—that influences economic conditions in the model. With that in mind, we next turn to policy strategies that seek to influence policy expectations over extended horizons.

[18] In practice, a failure of the FOMC to cut policy rates as swiftly as expected by the public in response to an incipient recession might lead the public to question policymakers' resolve and, in turn, erode confidence and aggravate the economic situation. More generally, the adoption of a particular policy strategy by the FOMC—including recourse to threshold-based forward guidance and balance sheet policies—might well entail periods during which the public learns the policy strategy and its macroeconomic implications. We abstract from such consideration in our analysis.

Figure 1: Recession scenario under baseline policy rule with and without ELB



Notes: We constructed the recession scenario in the FRB/US model around the SEP-consistent baseline projection using a sequence of negative spending shocks starting in the third quarter of 2018, the first quarter in the simulation. We assumed that the federal funds rate is determined by the asymmetric policy rule without thresholds and that the balance sheet is passive.

Threshold-based forward guidance

In models like FRB/US, in which some or all agents are forward looking, central bank communications about the future path of monetary policy can stimulate economic activity and inflation by lowering expectations of the path of short-term interest rates, which helps, in turn, ease overall financial conditions.[19] We explore the effects of

[19] For empirical assessments of the financial market effects of past FOMC communications, as well as for discussions and illustrations of the related transmission channels of central bank communications to

explicit forward guidance about the future path of the policy rate in the form of credible announcements that policymakers will keep the federal funds rate at the ELB at least until some specific improvement in economic conditions has been achieved; thereafter, the policy rate is guided by the asymmetric rule.[20] Similar to the forward guidance implemented by the FOMC in December 2012, the forward guidance assumed here takes the form of thresholds for the unemployment rate and inflation. To the extent that the thresholds delay liftoff from the ELB, the forward guidance in our simulations is a commitment to a more accommodative path for the federal funds rate in the future than under the asymmetric rule. In practice, policymakers can also use forward guidance to clarify the intended path of monetary policy or might issue forward guidance about the speed at which they intend to raise the federal funds rate after departure from the ELB; our analysis abstracts from these aspects.[21]

Effects on macroeconomic outcomes

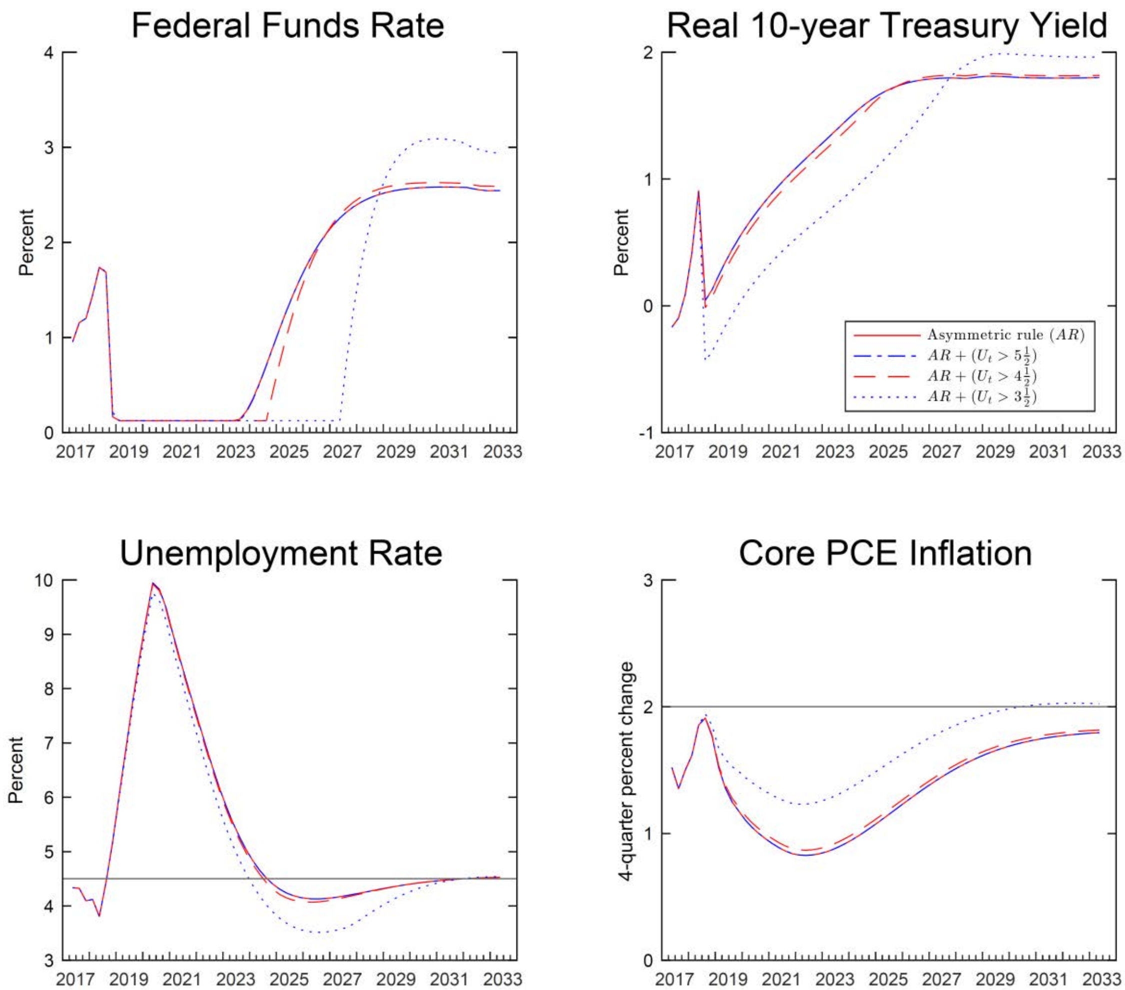
Figure 2 shows simulation results for three unemployment rate thresholds: 5.5 percent, 4.5 percent, and 3.5 percent. These thresholds are, respectively, 1 percentage point above, equal to, and 1 percentage point below the natural rate of unemployment in the SEP-consistent baseline. The setting of an unemployment rate threshold above the natural rate—as the FOMC did in 2012—can be motivated on the basis that Taylor-type policy rules typically call for removing accommodation before the unemployment rate and inflation have returned to their longer-run values. Alternatively, such a threshold may reflect policymakers' concern about inadvertently choosing too low a threshold in light of uncertainty about the value of the natural rate. Moreover, when policymakers value a gradual approach to policy normalization, raising the federal funds rate from the

economic activity and inflation, see, notably Campbell and co-authors (2012), Woodford (2012), Engen, Laubach, and Reifschneider (2015), and Campbell and co-authors (2016).

[20] For simplicity, we also assume that the TPEs are held at their levels under the baseline recession scenario.

[21] Clarifying the intended path of monetary policy was a central motivation for the issuance of threshold-based forward guidance by the FOMC in response to the global financial crisis. Such motivation is difficult to capture in our model because there is no disagreement among agents about the future course of monetary policy. Moreover, the assumptions that price setters, wage setters, and financial market participants form model-consistent expectations and understand policymakers' intended course of policy curtail the possibility that monetary policy communications would be misunderstood.

Figure 2: Forward guidance with unemployment rate thresholds in a recession scenario



Note: We constructed the recession scenario in the FRB/US model by subjecting the SEP-consistent baseline to a sequence of negative spending shocks starting in the third quarter of 2018, the first quarter in the simulation. We assumed that the federal funds rate is determined by the asymmetric policy rule without thresholds and that the balance sheet is passive.

ELB early does not necessarily conflict with the maintaining of an accommodative stance of monetary policy in subsequent years. That said, given the severity of the recession scenario considered here, policymakers might judge it desirable to provide even more policy accommodation by setting an unemployment rate threshold at or below the natural rate. We combine our unemployment rate thresholds with an “escape clause” that allows liftoff from the ELB when inflation rises above 2.5 percent.[22] This clause turns out not to be invoked in this recession scenario but is invoked occasionally in the stochastic simulations performed later.[23]

Forward guidance in the form of an unemployment rate threshold of 5.5 percent has no effect on the simulation results because, in our recession scenario, the unemployment rate is already below 5.5 percent by the time the asymmetric rule prescribes raising the federal funds rate above the ELB.[24] A threshold of 4.5 percent delays liftoff by three quarters and results in a path for the real 10-year Treasury yield that is only slightly lower than under the asymmetric rule through 2025, so that the unemployment rate and inflation paths are little changed. A threshold of 3.5 percent is more consequential: Compared with the asymmetric rule, it delays liftoff by more than three years and lowers the real 10-year Treasury yield about ½ percentage point, on average, through 2025. Given the lags in the monetary transmission mechanism, the 3.5 percent threshold shaves off only 0.2 percentage point from the peak in the unemployment rate. Later in the scenario, the extra monetary stimulus gains traction and the unemployment rate bottoms out at 3½ percent, about ½ percentage point less than under the asymmetric rule. Inflation under this threshold policy is ¼ to ½ percentage point higher than otherwise. This more accommodative monetary policy lifts inflation toward 2 percent immediately in the simulations because of our assumption that price and

[22] We specify the escape clause in terms of realized rather than projected inflation, in contrast with the FOMC's December 2012 forward guidance that policymakers would maintain policy rates at the ELB at least until "inflation between one and two years ahead [was] projected to be no more than a half percentage point above the Committee's 2 percent longer-run goal." Because the simulations shown in Figure 2 are conducted under perfect foresight, we could have achieved the same liftoff dates and macroeconomic outcomes using threshold specified in terms of projected values. In a dynamic environment, the use of projected values for inflation might help policymakers communicate that they would see through transitory influences.

[23] These results depend on the model specification and could be different in alternative models. For example, Chung, Herbst, and Kiley (2015) use DSGE models and report sizable and persistent overshooting of inflation following threshold policies for the unemployment rate that are less accommodative than the more aggressive strategies we consider; this result points to the possibility that inflation risks associated with these strategies could be greater than suggested by simulations of the FRB/US model.

[24] In an uncertain environment, a 5.5 percent unemployment rate threshold would clarify that the Federal Reserve stands ready to provide more accommodation than under the asymmetric rule in the event that the labor market deteriorates. Because our simulations assume perfect foresight, this potential benefit is not captured in the results shown in Figure 2.

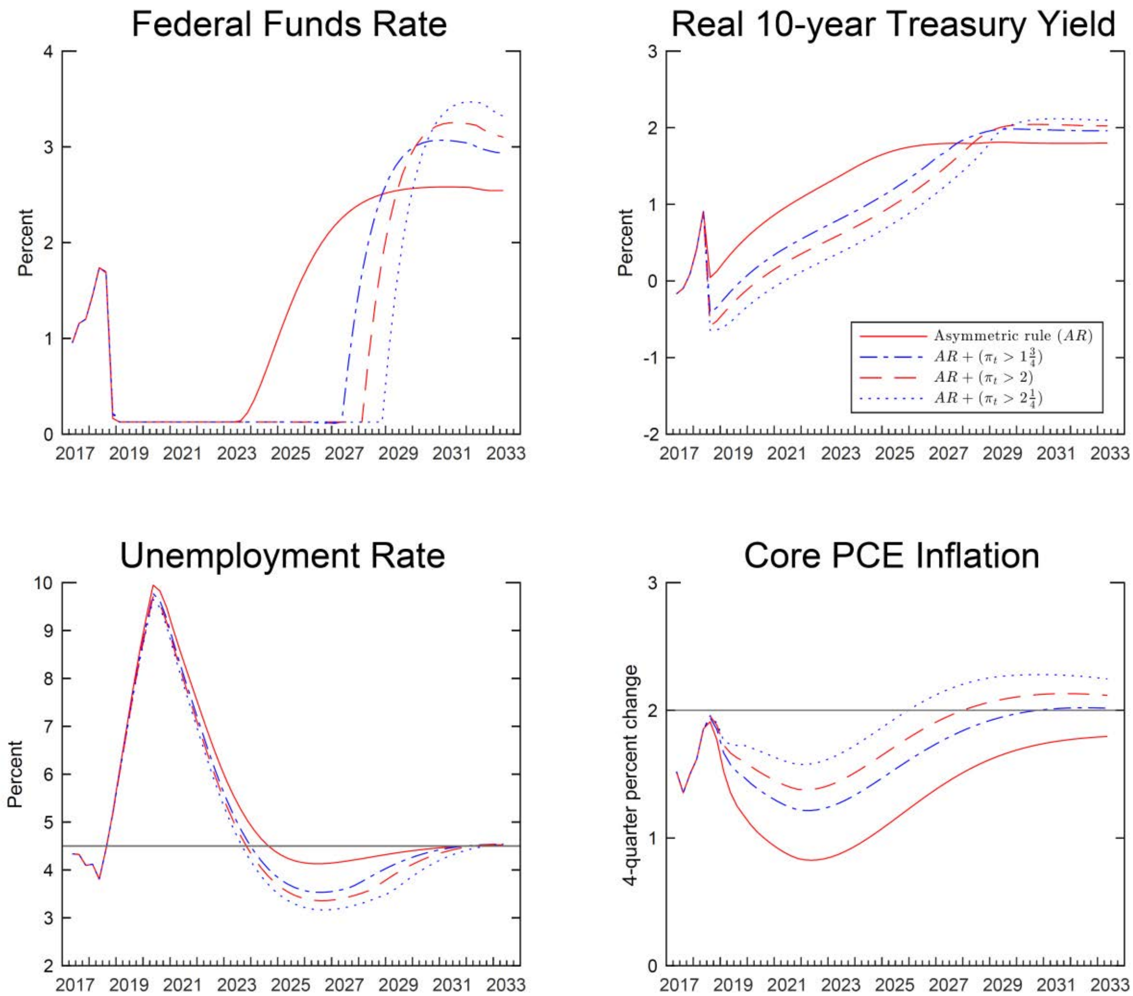
wage setters are forward looking: In short, the specification of a binding unemployment rate threshold leads to the anticipation of less resource slack over the medium term than in the absence of the threshold, which, in turn, results in the setting of higher prices and wages in the near term.[25]

In this recession scenario, the return of inflation to the 2 percent goal lags the return of the unemployment rate to its natural level, as appears to be the case in the U.S. recovery from the global financial crisis. Even under our most aggressive unemployment rate threshold, inflation runs well below the FOMC's goal for nearly a decade, a situation that could pose a serious risk to longer-run inflation expectations. For this reason, it is natural to consider forward guidance formulations that delay departure from the ELB at least until policymakers have achieved meaningful progress in returning inflation to 2 percent. In Figure 3, we consider three inflation thresholds: 1¾ percent, 2 percent, and 2¼ percent. These thresholds delay liftoff from the ELB by between three and five years relative to the asymmetric rule with no threshold. After liftoff from the ELB, the path for the federal funds rate is steeper for a time under the inflation thresholds than without them because future policymakers respond to higher inflation and tighter resource utilization. In particular, under the most aggressive threshold of 2¼ percent, the path for the real 10-year Treasury yield is, on average, about ¾ percentage point lower than under the asymmetric rule over the first seven years of the scenario. Under this policy, the decline in inflation is greatly attenuated; inflation bottoms out at 1½ percent and runs slightly above the inflation target starting in 2025.[26] By comparison, under the less aggressive thresholds of 2 percent and 1¾ percent, the return of inflation to 2 percent is delayed until 2027 and 2030, respectively.

[25] Whether policymakers would see the improvements in macroeconomic outcomes during the recession and recovery phase as worthy of a more pronounced undershooting of the natural rate of unemployment and, possibly, inflation running above 2 percent for a time depends on policymakers' preferences over outcomes. In Appendix V, we provide some simple metrics to compare the extent of deviations from longer-run values in our recession scenario and of how unconventional policies can attenuate or amplify these deviations.

[26] The inflation overshooting and the unemployment rate undershooting are key features of optimal commitment policy in New Keynesian DSGE models. See, for example, Eggertsson and Woodford (2003).

Figure 3: Forward guidance with inflation thresholds in a recession scenario



Note: We constructed the recession scenario in the FRB/US model by subjecting the SEP-consistent baseline to a sequence of negative spending shocks starting in the third quarter of 2018, the first quarter in the simulation. We assumed that the federal funds rate is determined by the asymmetric policy rule without thresholds and that the balance sheet is passive.

Key lessons and caveats

Our analysis suggests that threshold-based forward guidance only modestly limits the deterioration of labor market conditions during a severe recession because of the long lags in the transmission of monetary policy. The thresholds can have somewhat larger beneficial effects during the subsequent economic recovery but the gains are obtained through commitments to keep policy more accommodative than otherwise for many years into the future. Because the return of inflation to the 2 percent objective lags the closing of the unemployment gap in our recession scenario, we find that a commitment to remain at the ELB until labor market slack is absorbed leaves inflation running well below 2 percent for many years. In fact, given the flatness of the short-run Phillips curve in the FRB/US model, achieving the inflation thresholds requires running the economy hot for an extended period of time. In that respect, forward guidance formulations that delay departure from the ELB until inflation has returned to, or exceeded, 2 percent are most successful in preventing inflation from running persistently below the FOMC's goal for an extended period, though this results hinges in part on the behavior of inflation in the model.

The results are subject to at least four important caveats. First, the potency of forward guidance might depend crucially on the formation of expectations. In our simulations, we assume that some agents fully understand the forward guidance and dynamics of the model whereas other agents form expectations through simple projections of current and past variables without regard to the forward guidance. To some readers, these assumptions might suggest that we are underestimating the effects of forward guidance: In the FRB/US model, limitations in the forward-looking behavior of households and businesses contribute to creating long lags in the transmission of shocks, so that threshold-based forward guidance has little effect on the unemployment rate in the first couple years after its issuance. In other macroeconomic models, agents are more forward looking and the transmission lags are accordingly shorter.[27] By contrast, other readers might argue that the assumption that price setters, wage setters, and financial market participants form model-consistent expectations is too strong, leading us to overstate the effectiveness of the forward guidance and, in particular, the initial boost to inflation expectations.

Second, the potency of threshold-based forward guidance to improve economic outcomes rests on policymakers' ability to make credible commitments to keep the federal funds rate lower than otherwise at distant horizons. Under such commitments,

[27] Appendix IV presents a simulation of the recession scenario and threshold-based forward guidance in a variant of the DSGE model of Del Negro, Giannoni, and Schorfheide (2015) in which households discount future interest rates when making spending decisions similar to what is assumed in the FRB/US model. The effects of forward guidance on inflation and output are somewhat larger than in our FRB/US simulations.

economic conditions might eventually improve to such an extent that future policymakers would prefer ex post to implement a tighter monetary policy than the one originally communicated (that is, the policy commitments entailed by the forward guidance may not be "time consistent"). For example, in Figure 3, the improvement in economic conditions achieved under inflation thresholds of 2 percent or more is associated with promises to keep the federal funds rate at the ELB even as the unemployment rate falls well below its longer-run level and inflation is on its way to modestly overshoot 2 percent for several years. When faced with the prospect of an overheating economy, future policymakers may well judge that they are "falling behind the curve" and opt to drop the policy commitment. In practice, policymakers would have to weigh various benefits, costs, and risks in deciding whether to depart from an announced forward guidance. Notably, policymakers might worry that the public would react negatively to such a departure, causing a loss of reputation that would make recourse to forward guidance less effective in future recessions. Appendix VI explores some of the prospective costs and benefits of deviating from the forward guidance. To the extent that the public anticipates such time-inconsistent behavior, the provision of forward guidance could lack credibility and economic conditions could fail to improve as a result. The recent Japanese experience provides a note of caution on the effectiveness of forward guidance in the form of inflation thresholds in some circumstances.[28]

A third caveat is that the potency of forward guidance hinges on the public's understanding of the implications of a strategy to keep policy rates low for an extended period. The adoption of a particular policy strategy by the FOMC—including recourse to threshold-based guidance in response to economic downturns—might well entail periods during which the public learns about the policy strategy and its macroeconomic implications. The market reaction to the FOMC's adoption of calendar-based forward

[28] In 2013, the Bank of Japan (BOJ) announced a 2 percent inflation target along with a substantial open-ended asset purchase program aimed to achieve that objective. Longer-run inflation expectations moved up sharply around the time of the announcement but partly retraced these gains subsequently. In September 2016, the BOJ—in conjunction with the introduction of a target for the 10-year yield on the Japanese government bond—committed to expand the monetary base until inflation exceeds 2 percent and stays above that target in a stable manner. To date, these measures have not succeeded in lifting longer-run inflation expectations to the new target and inflation has continued to run well below 2 percent.

guidance in August 2011 is encouraging in that respect because the announcement led to immediate, sizeable adjustments in federal funds rate expectations.[29] That said, policy commitments beyond a few years or involving complex conditionality on economic outcomes might be more difficult for the public to process. For example, it could be challenging for policymakers to communicate to the public that they would see through a breach of an inflation threshold due to transitory factors.

Finally, our analysis focuses on a relatively small number of transmission channels that are well modeled using standard macroeconomic theory. However, forward guidance and other unconventional policies might operate through other channels. For example, during the global financial crisis, the FOMC's policy actions might have boosted confidence to a greater extent than in the past. Therefore, the limited effects that we find might understate the benefits of forward guidance in some situations.

Balance sheet policies

Next, we analyze the effects of four balance sheet policies in the recession scenario and compare their macroeconomic outcomes to those achieved under the passive balance sheet policy used to construct the recession scenario. In these simulations, we solve jointly the FRB/US model and a detailed model of the Federal Reserve's balance sheet and of its effects on financial conditions and macroeconomic outcomes.[30] The four balance sheet policies are assumed to affect macroeconomic conditions through their influence on the term premiums embodied in longer-term interest rates.

Description of balance sheet policies

All four balance sheets policies that we consider are initiated as soon as the ELB binds, a fact known by the model's price setters, wages setters, and financial market participants at the onset of the simulations. Under the "reinvestment-only" policy, the

[29] In August 2011, the FOMC stated its anticipation "that economic conditions—including low rates of resource utilization and a subdued outlook for inflation over the medium run—[were] likely to warrant exceptionally low levels for the federal funds rate at least through mid-2013." Market expectations of the federal funds rate over that period and beyond fell immediately upon the announcement.

[30] For background on the integrated model, its solution, and its applications, see the forthcoming FEDS note by Hess Chung, Cynthia Doniger, Cristina Fuentes-Albero, Bernd Schlusche, and Wei Zheng "Simulating the Macroeconomic Effects of Unconventional Monetary Policy."

Federal Reserve resumes full reinvestment of principal payments on its SOMA security holdings as soon as the federal funds rate reaches the ELB. Under the "MEP" policy, the Federal Reserve extends the average duration of its SOMA security holdings while keeping the size of its SOMA portfolio unchanged. Under our "LSAP" and "LSAP + inflation threshold" policies, the Federal Reserve increases the size of its SOMA holdings through purchases of longer-term Treasury securities. Compared with the passive policy used to construct the recession scenario, all four balance sheet policies result in the Federal Reserve reducing the total duration risk faced by private investors in the model, which, in turn, puts downward pressure on term premiums and longer-term borrowing rates, thereby supporting economic activity. We implement the four policies as follows:

- Reinvestment-only. We assume that principal payments from the Federal Reserve's holdings of Treasury securities are fully reinvested into Treasury securities and, similarly, principal payments from agency debt and agency mortgage-backed securities (MBS) are fully reinvested into agency MBS until either the unemployment rate drops below 5½ percent, inflation rises above 1¾ percent, or the asymmetric rule prescribes raising the federal funds rate from the ELB.[31] Thereafter, only principal payments on Treasury securities in excess of $30 billion per month and on agency securities in excess of $20 billion per month are reinvested until the size of the balance sheet is normalized.
- MEP. We posit that the Federal Reserve purchases $55 billion of Treasury securities with remaining maturities between six and 30 years each month for 12 months.[32] These purchases are funded through the sale or redemption of equal amounts of Treasury securities with remaining maturities between zero and three years. Principal payments on SOMA

[31] For a discussion of the effects of reinvestment policies, see Hess Chung, Cynthia Doniger, Cristina Fuentes-Albero, David López-Salido, and Bernd Schlusche (2017), "The Macroeconomic Effects of State Contingent Ending of Reinvestment," memorandum to the FOMC, March 3.

[32] The total size of the program ($660 billion) and its length (one year) roughly match those of the Federal Reserve's 2011–2012 MEP. Moreover, the total size is similar to the Federal Reserve's current holdings of Treasury securities with a remaining maturity of three years or less.

holdings are reinvested under the same conditions as under the reinvestment-only policy.

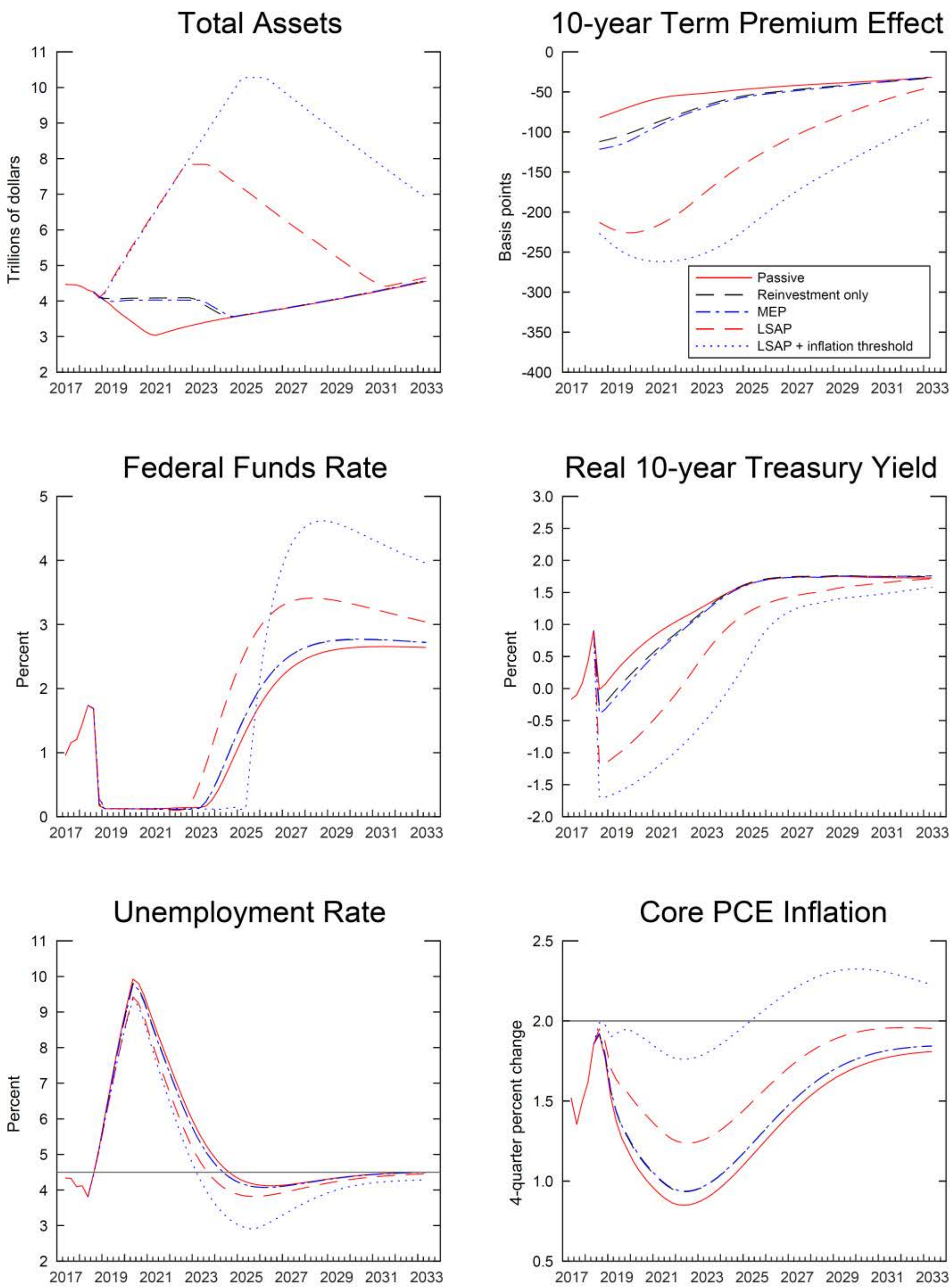
- LSAP. The program consists of purchases of $85 billion per month in longer-term Treasury securities—the same monthly combined amount of Treasury securities and MBS purchased under the third LSAP program launched by the Federal Reserve in October 2012—until either the federal funds rate lifts off from the ELB, the unemployment rate drops below 5½ percent, or inflation rises above 1¾ percent.[33] Principal payments on SOMA securities are fully reinvested during the LSAP program as well as for a period of 12 months after its conclusion. Subsequently, only principal payments on Treasury securities in excess of $30 billion per month and on agency securities in excess of $20 billion are reinvested until the size of the balance sheet is normalized.
- LSAP + inflation threshold. Under this policy, asset purchases continue until a 2 percent inflation threshold is achieved. Similarly, we assume that liftoff from the ELB is delayed at least until the 2 percent inflation threshold is satisfied. Therefore, under this policy, the federal funds rate and balance sheet policies do not work at cross purposes. We retain the same reinvestment policy as under the LSAP policy.

Effects on the Federal Reserve's balance sheet and macroeconomic outcomes

The top-left and top-right panels of Figure 4 show the total assets held by the Federal Reserve and the TPEs on the 10-year Treasury yield, respectively, for each balance sheet policy. While under the passive policy the balance sheet continues to normalize during the recession, policymakers under the reinvestment-only and MEP policies keep the size of the balance sheet constant at around $4 trillion starting in early 2019, when they lower the federal funds rate to the ELB. As a result of the larger balance

[33] This monthly amount is for illustrative purposes and might be different from the amount that the Open Market Desk at the Federal Reserve Bank of New York may suggest as feasible at the time of implementation.

Figure 4: Balance sheet policies in a recession scenario



Note: The results are obtained by solving the FRB/US and balance sheet models jointly so that, for each balance sheet policy, the macroeconomic outcomes, balance sheet holdings, and term premium effects are mutually consistent. The results are conditioned on the assumption that price and wage setters, as well as financial market participants, have perfect foresight of the recession scenario and balance sheet policies. The “LSAP + inflation threshold” policy maintains policy rates at the ELB and continues asset purchases until inflation reaches 2 percent.

sheet compared with the passive balance sheet policy, the reinvestment-only policy achieves somewhat more negative TPEs. In turn, the more negative TPEs under the reinvestment-only policy imply a slight improvement in macroeconomic outcomes. TPEs under the MEP policy are marginally more negative than under the reinvestment-only policy, owing to a modest lengthening in the average duration of the SOMA portfolio.[34] Macroeconomic outcomes are nearly the same as under the reinvestment-only policy.

Under the LSAP policy, policymakers boost the size of the balance sheet to nearly $8 trillion (about 33 percent of GDP) in 2023. For reference, the Federal Reserve's actual balance sheet size peaked at about $4.5 trillion in 2015 (roughly 25 percent of GDP). The expansion of the balance sheet under the LSAP policy exerts notable downward pressure on term premiums in the model: The 10-year TPE is over 100 basis points more negative, on average, over the next several years under the LSAP policy than under the reinvestment-only and MEP policies.[35] As a result of more accommodative financial conditions, the unemployment rate path declines faster over the medium term, reaching its natural rate four quarters earlier than under the passive policy. For the same reason, the inflation path is about ½ percentage point higher than under the passive policy at the trough. Because of the overall stronger economic outlook, the federal funds rate departs from the ELB three quarters sooner than under the passive policy.

While the LSAP policy improves macroeconomic outcomes, it is still associated with inflation running well below the FOMC's 2 percent objective through much of the next decade, an outcome policymakers might judge inconsistent with their mandate. For this reason, in Figure 4, we report outcomes under a more aggressive LSAP policy by

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[34] The largest feasible size of an MEP depends on the Federal Reserve's holdings of shorter-term Treasury securities. In the future, the FOMC could, in principle, conduct more potent MEP programs than the one shown here if it were to maintain permanently larger holdings of shorter-term securities.

[35] Under the LSAP policy, the 10-year (nominal) Treasury yield initially declines below ½ percent and stays below 1 percent for two years. Although our modeling assumptions imply that the marginal effects of LSAPs are roughly invariant to the level of Treasury yields, it could be that LSAPs have diminishing potency when nominal Treasury yields are near zero and terms premiums are already low. The experience of the Bank of Japan with rapid balance sheet expansion and low longer-term rates and term premiums seems to corroborate this view.

which policymakers continue asset purchases until core inflation reaches 2 percent. This threshold delays departure from the ELB until 2025, after which date the federal funds rate rises to contain a mild overheating of the economy. Asset purchases throughout the seven years during which the ELB binds boost the size of the Federal Reserve's balance sheet to over $10 trillion (about 38 percent of GDP). The balance sheet expansion pushes the path of the TPE on 10-year Treasury yields about 60 basis points lower, on average, relative to the corresponding path under the LSAP policy over the period shown.[36] Compared with the other policies analyzed here, this more aggressive LSAP policy succeeds in bringing inflation close to 2 percent in coming years, an outcome achieved by eventually lowering the unemployment rate to around 3 percent, a level last seen in the 1950s.

Key lessons and caveats

Overall, none of the balance sheet policies considered herein meaningfully contains the sharp rise in the unemployment rate brought on by the recession, a result that arises even though we have assumed that price setters, wage setters, and financial market participants in the model fully understand and anticipate the implementation of those policies at the onset of the recession. This finding reflects the feature that, similar to movements in the federal funds rate, changes in the size and composition of the Federal Reserve's balance sheet affect economic activity with a lag in the model. More encouragingly, we find that LSAP policies do hasten the labor market recovery and lift the path of inflation somewhat. By contrast, our simulations suggest that policymakers could improve macroeconomic outcomes only marginally through an MEP or by resuming full reinvestment of principal payments on SOMA securities.

Our balance sheet simulations are subject to several caveats, of which we highlight three. First, the macroeconomic effects and channels of transmission of balance

[36] Under the "LSAP + inflation threshold" policy, the 10-year (nominal) Treasury yield initially declines to ¼ percent and stays below 1 percent for three years. Thus, the caveat noted in the previous footnote applies.

sheet policies are subject to considerable uncertainty.[37] A number of papers have found that measures of Treasury debt supply are helpful for capturing the dynamics of the yield curve and event studies of asset purchase program announcements have demonstrated that news about these programs can leave a noticeable imprint on financial markets, at least in the very short run.[38] However, the literature features some papers supporting long-lasting effects while others suggest quite rapid attenuation.[39] Moreover, regarding macroeconomic effects, our assumption that balance sheet policy affects the economy through conventional yield curve channels is only one possibility. A number of alternative transmission channels have been proposed, and these could have different implications for the effectiveness of purchase programs. For example, the market segmentation that permits Treasury supply to affect yields may also limit the sensitivity of aggregate spending to changes in term premiums, as compared to changes in the federal funds rate that would have an equivalent effect on long-term interest rates.[40] Similarly, balance sheet policies may interact with the state of the financial sector: effects could be larger if financial stress is intense, while very low long-term interest rates could negatively affect bank profitability, attenuating these effects.[41]

[37] For a review of the macroeconomic effects and transmission channels of balance sheet policies, see Deborah Leonard, David López-Salido, and Fabio Natalucci (2016), "Balance Sheet Considerations for the Federal Reserve's Long-Run Framework," memorandum to the FOMC, Federal Reserve System, October 14.

[38] Work supporting the relevance of Treasury debt supply includes Bernanke and co-authors (2004), Engen and Hubbard (2005), Krishnamurthy and Vissing-Jorgensen (2012), Laubach (2009), Hamilton and Wu (2012) and Li and Wei (2013). Early event studies of the Federal Reserve's asset purchase programs include Gagnon and co-authors (2011) and Krishnamurthy and Vissing-Jorgensen (2011). While much of the literature attributes balance sheet effects to term premium movements, it is possible that these programs also operate by affecting expectations about the future conduct of policy regarding the federal funds rate (the "signaling channel"). For example, Christensen and Rudebusch (2012) and Woodford (2012) find an important signaling channel for the United States.

[39] Using data on LSAP purchases at the CUSIP level, D'Amico and King (2013) find substantial and persistent effects from purchases. Wright (2011) and Greenlaw and co-authors (2018) report very transient effects from LSAPs. By contrast, Swanson (2017) argues that the appearance of transient LSAP effects is highly dependent on the behavior of yields following the QE1 announcement and, if that event is excluded, LSAP effects appear durable.

[40] The models of Chen and co-authors (2012) and Kiley (2014) both have this feature.

[41] The effectiveness of U.S. balance sheet policy in the Gertler and Karadi (2013) paper depends on a constraint limiting the lending ability of financial intermediaries; LSAPs would have larger effects when this constraint is more tightly binding. Brunnermeier and Koby (2017) provide a model in which the negative effects of low long-term interest rates on bank profitability may make such policies contractionary beyond a certain minimum rate.

Second, the accommodation provided through LSAPs under the most aggressive policies is achieved by pushing the size of the balance to levels that have never been experienced in the United States; such large increases in the balance sheet may entail costs and risks that are not captured by our analysis.[42] Third, balance sheet policies, like threshold-based forward guidance, entail multi-year commitments by policymakers so that the efficacy of those policies might hinge on their credibility and on expectation formation. That said, the FOMC's policy decisions to date to reduce the size of the balance sheet in a gradual and predictable manner would likely enhance the public's confidence in such commitments in the future.

II.B Unconventional policies in stochastic simulations

We next investigate how a policy strategy involving systematic recourse to either threshold-based forward guidance or balance sheet policies during ELB episodes might limit the duration and severity of these episodes going forward, and, more generally, improve macroeconomic outcomes and mitigate macroeconomic risk over time. Doing so requires the performance of stochastic simulations in which we specify a monetary policy strategy that encompasses both conventional and unconventional tools.

Threshold-based forward guidance

We first conduct stochastic simulations for each of the six policy strategies considered earlier that entail setting the federal funds rate according to the asymmetric policy rule in normal times and, whenever the ELB binds, delaying normalization of the stance of policy at least until some pre-announced unemployment rate or inflation threshold has been satisfied. The simulations abstract from balance sheet policies and are conducted under the assumptions that policymakers credibly commit to following a particular policy strategy forever and that price setters, wage setters, and financial market participants immediately and correctly understand the implications of this commitment

[42] That said, a number of foreign central banks have increased the size of their balance sheets relative to their GDP to higher levels than the Federal Reserve in response to the global financial crisis, in particular the European Central Bank (about 40 percent of GDP), the Bank of England (almost 30 percent of GDP), the Bank of Japan (nearly 100 percent of GDP), and the Swiss National Bank (about 110 percent of GDP). Overall, staff sees these interventions as having had positive effects, though the extent of policy accommodation achieved is uncertain.

for interest rates and the macroeconomy. The simulations extend many decades into the future in order to derive the distributions of macroeconomic outcomes in the longer run that are associated with each policy rule.

Table 4 summarizes our key findings. The first two columns report the probability that in any given period the ELB is binding and the mean duration of ELB episodes over the longer run for the asymmetric rule with no forward guidance and for each of the six strategies with threshold-based forward guidance. The subsequent four columns report statistics on the distribution of unemployment rate and inflation outcomes. For comparability, the latter statistics are computed over the set of periods during which the asymmetric rule without thresholds is constrained by the ELB and use the same shock sequences.[43]

Consistent with the findings for our illustrative recession scenario, we find that setting a relatively high threshold for the unemployment rate under the asymmetric rule alters the path of policy little, if at all, compared with the same policy rule without such a threshold. By contrast, policy strategies that entail commitments to keep the federal funds rate at the ELB at least until either the unemployment rate has fallen below its longer-run level ("$U_t < 3½$ percent") or inflation has risen back to or modestly exceeded its longer-run value ("$\pi_t > 2$ percent" or "$\pi_t > 2¼$ percent") deliver moderately better outcomes over time. In particular, these rules are shown to achieve, on average, unemployment rates and inflation rates that are between ¼ to ½ percentage point lower and higher, respectively, than the outcomes under the asymmetric rule for periods during which the ELB binds under that latter rule. The simulations also point to some commensurate reduction in the severity of tail events. For example, the 95th percentile highest unemployment rate and 95th percentile lowest inflation readings during periods

[43] Table 4 also reports statistics under the inertial Taylor (1999) rule. In contrast with our earlier finding that the asymmetric and inertial Taylor (1999) rules achieve nearly identical outcomes in a baseline recession scenario, we find that the asymmetric rule leads to modestly lower unemployment rates and higher inflation rates in ELB episodes in stochastic simulations. The reason for this difference is that, in a stochastic environment, sequences of shocks lifting the unemployment rate above the natural rate, even by small amounts, occasionally call for extra easing relative to the inertial Taylor (1999) rule, making the asymmetric rule relatively more accommodative on average.

when the ELB binds under the asymmetric rule fall ¼ percentage point and rise ½ percentage point respectively. The range of gains is admittedly modest.[44]

Table 4: Longer-run ELB risks and macroeconomic outcomes under threshold-based forward guidance

	ELB episodes		U_t		π_t	
	Per-period probability (in percent)	Mean duration (in quarters)	median	95th highest	median	95th lowest
Asymmetric rule (AR)	15.0	7.8	6.5	8.8	1.0	-0.4
AR + unemployment rate threshold						
U_t < 5½ percent	16.5	9.1	6.5	8.8	1.0	-0.4
U_t < 4½ percent	19.0	11.4	6.4	8.8	1.0	-0.4
U_t < 3½ percent	17.8	7.4	6.2	8.5	1.4	0.1
AR + inflation threshold						
π_t > 1¾ percent	19.2	10.5	6.3	8.7	1.2	-0.1
π_t > 2 percent	19.5	9.8	6.3	8.6	1.3	0.0
π_t > 2¼ percent	19.8	9.3	6.2	8.6	1.4	0.1
Addendum						
Inertial Taylor (1999) rule	13.5	10.5	6.8	9.5	0.9	-0.7

Note: For comparability, the statistics in the last four columns are calculated using periods in which the ELB is binding under the asymmetric rule without threshold.

In our simulations, a policy of keeping the federal funds rate at the ELB until some unemployment rate or inflation threshold is met is associated with a greater fraction of periods spent at the ELB than in the absence of thresholds. However, policies that entail relatively large amounts of accommodation might improve outcomes to such an extent that they are associated with shorter ELB episodes, on average, than policies with relatively small amount of extra accommodation. For example, the setting of an unemployment rate threshold equal to the natural rate lengthens the average duration of ELB episodes from 15 to 19 quarters compared with the asymmetric rule without the

[44] For reference, we show in Appendix VII the longer-run distributions of unemployment rates and inflation rates at the ELB under the asymmetric rule and a forward guidance policy in the form of an inflation threshold.

threshold. However, lowering the unemployment rate threshold to 3½ percent then reduces the average duration by one quarter. This phenomenon illustrates the stabilizing effects of a strong forward guidance strategy in the model. This stabilization hinges on the assumed credibility of the forward guidance and the forward-looking nature of agents in the model.

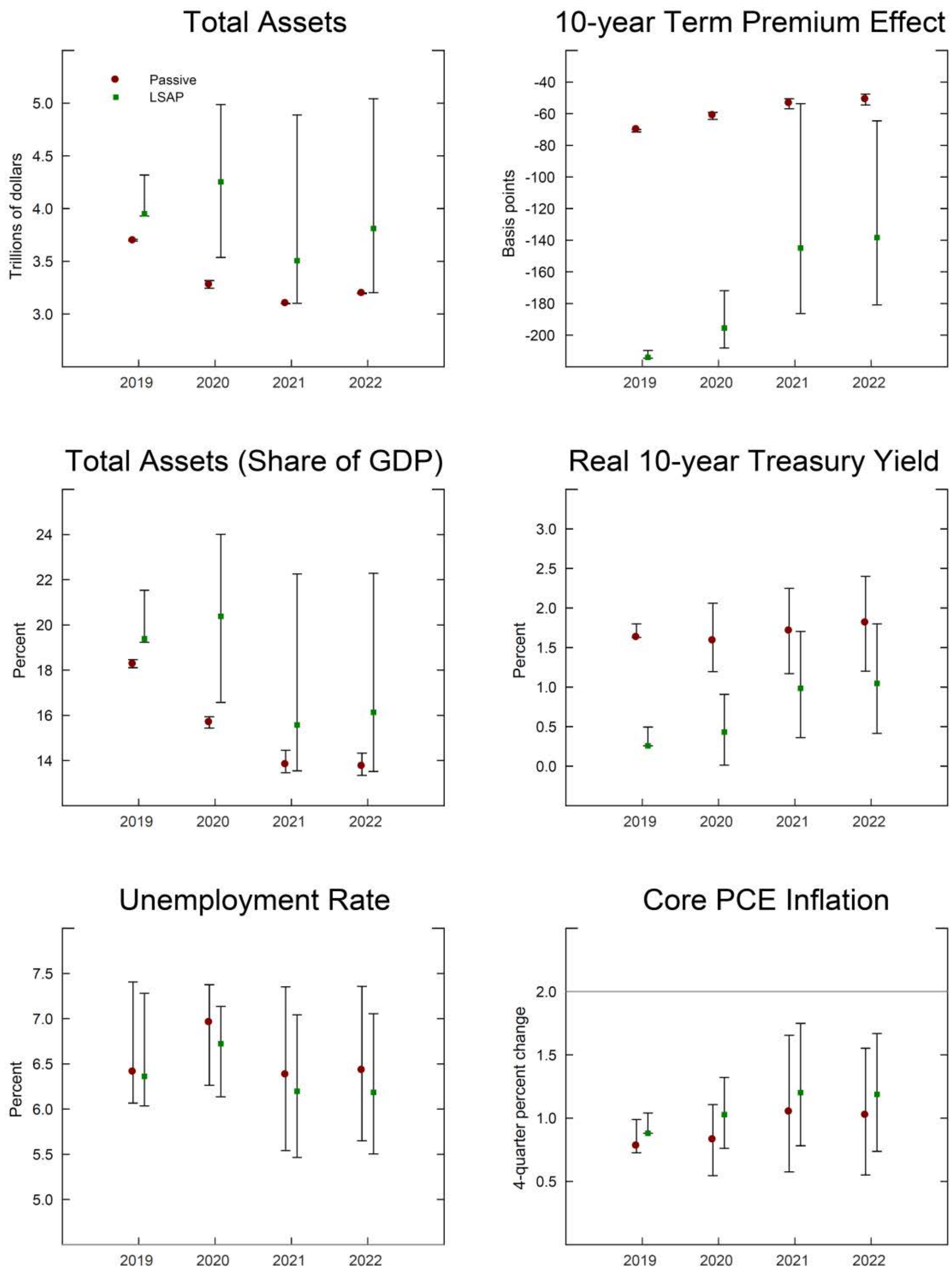
Balance sheet policies

In this section, we analyze the performance of the LSAP policy relative to the passive policy benchmark in stochastic simulations around the SEP-consistent baseline. The outcomes are generated using the integrated FRB/US and balance sheet models under the assumption that the federal funds rate follows the prescriptions of the asymmetric rule. Because the two balance sheet policies differ principally when the policy rate reaches the ELB, we restrict our focus to outcomes around ELB episodes.[45] To this end, we begin by identifying the simulations for which the ELB binds under the passive policy in the final quarter of each year through 2022. For each such simulation, we then compute the outcomes under the LSAP policy for the same underlying shocks. By following this approach, we are able to attribute differences in outcomes exclusively to differences in balance sheet policies.

Figure 5 presents the median and interquartile range of macroeconomic outcomes and balance sheet sizes. As shown in the top-left panel, under the passive policy, the balance sheet size decreases over time as policymakers in the simulations are assumed to continue with their balance sheet normalization program even as the ELB binds. Moreover, the distribution of balance sheet sizes exhibits negligible variability, as evidenced by the interquartile range being almost indistinguishable from the median.[46] By contrast, under the LSAP policy, the distribution of balance sheet sizes is much more

[45] Because price setters, wage setters, and financial market participants in the model understand policymakers' strategy, they may anticipate the ELB constraint to bind and LSAPs to be conducted in the future if the incoming shocks have led them to expect a significant deterioration in economic conditions. In such a case, the anticipation of balance sheet actions would exert downward pressure on longer-term interest rates even before the ELB is reached and LSAPs are launched, leading to a difference in outcomes under the two policies.
[46] Variability in balance sheet size is possible in our stochastic simulations under a passive policy because of the possibility that declines in interest rates affect MBS prepayments.

Figure 5: Outcomes in stochastic simulations with balance sheet policies conditional on a binding ELB



Note: The markers and the intervals show the median and the interquartile range, respectively, of the distribution of macroeconomic outcomes under each policy. For comparability, the distributions are calculated for the same sequences of shocks for which the ELB binds under the passive balance sheet policy in the final quarter of each period shown. The statistics are computed through stochastic simulations around the SEP-consistent baseline projection.

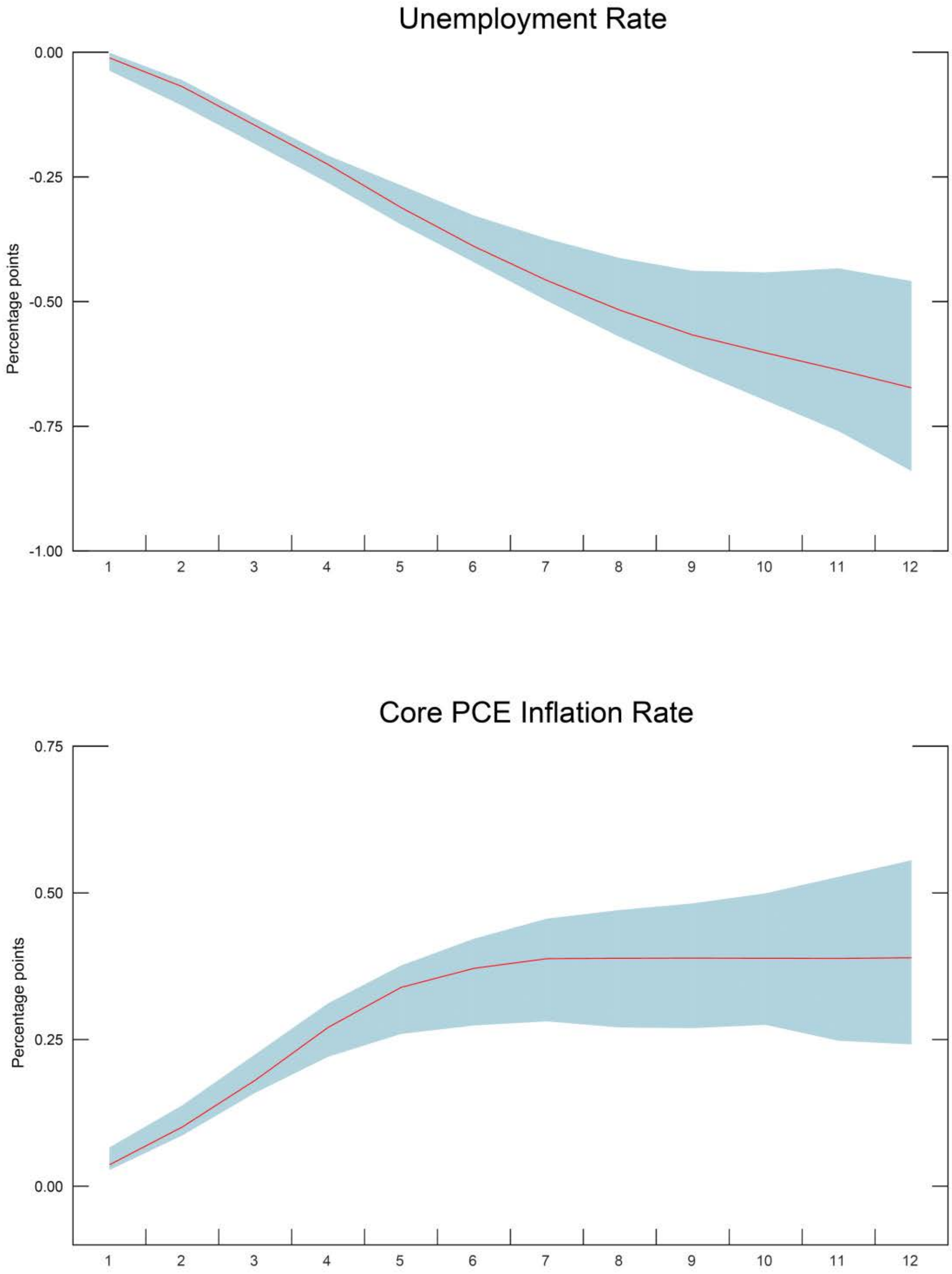
dispersed and stretches much higher than under the passive policy. The interquartile range widens progressively through 2022 as economic shocks accumulate. As the top-right panel shows, the larger balance sheet sizes under the LSAP policy imply median TPEs that are much more negative than those under the passive policy and, hence, real longer-term interest rates (the middle-right panel) that are notably lower.

The additional stimulus under the LSAP policy leads to a somewhat improved distribution of macroeconomic outcomes. By the end of 2020, the median unemployment rate associated with being at the ELB in that quarter is 6.7 percent as compared to 7.0 percent under the asymmetric rule with the passive balance sheet policy; the interquartile range shifts down by a similar amount. Also, at the end of 2020, the median inflation rate conditional on a binding ELB in that quarter is 1 percent under the LSAP policy as compared to 0.8 percent under the passive balance sheet policy.

On the surface, these modest differences seem to suggest that the LSAP policy has only small effects. Such a conclusion needs to be qualified, however, because, as we noted earlier, the transmission of unconventional monetary policies in the FRB/US model occurs with substantial lags. The distributions of economic outcomes in Figure 5 comprise primarily observations for which the effects of LSAPs have yet to transmit to the economy. For this reason, we examine in Figure 6 the distributions of macroeconomic outcomes conditional on the number of quarters that have elapsed since the beginning of ELB episodes.[47] Because of the lags in monetary policy transmission, the median differences in unemployment rates and inflation between the LSAP policy and the passive policy are initially small but eventually grow in significance: After 12 quarters, the median difference in unemployment rates is almost -70 basis points and the median difference in inflation reaches nearly 40 basis points. In short, the LSAP policy leads to a significant improvement in macroeconomic outcomes over time relative to the passive policy. And because it takes time for the effects to build, our simulations

[47] Specifically, we identify sequences of shocks that cause the ELB to bind in 2019 and 2020 under the passive balance sheet policy. For each ELB episode, we then compute the difference between outcomes under the LSAP policy and the passive policy at a given number of quarters from the start of the episode, whether the episode is continuing or not. Finally, we pool all such differences to construct the distribution of effects induced by the LSAP policy.

Figure 6: Distribution of macroeconomic effects of LSAP policy conditional on the number of quarters elapsed since reaching the ELB



Note: The red line and the shaded region show the median difference and the interquartile range of differences, respectively, in macroeconomic outcomes between the LSAP policy and passive balance sheet policy. For comparability, the differences are measured for the same periods and sequences of shocks for which the ELB binds under the passive balance sheet policy. The statistics are reported from the first quarter in the ELB episode up to 12 quarters out whether the ELB continues to bind or not.

suggest that policymakers may find it beneficial to deploy LSAPs rapidly when faced with an incipient recession.

As noted earlier, our estimates of the macroeconomic effects of balance sheet policies are subject to much uncertainty, as is the importance of various transmission channels. One such potential channel is the response of term premiums to economic activity. In our simulations, we have assumed that the modestly negative correlation between economic activity and excess returns on bonds in the data does not reflect an endogenous countercyclical component in term premiums. In Appendix VIII, we show that balance sheet policies are more potent when we posit that term premiums are countercyclical.

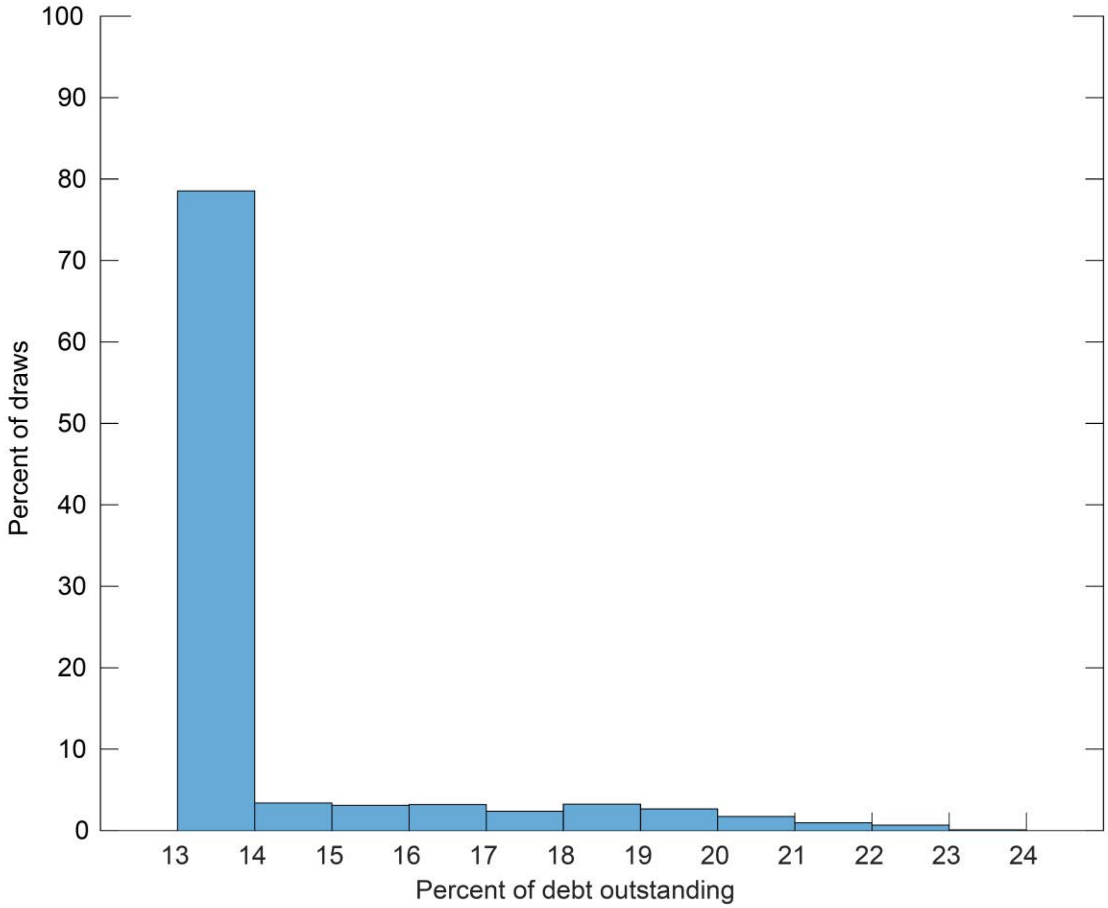
Balance sheet risks

A possible risk stemming from LSAP policies is the “ratcheting-up” effect: In an environment with frequent and prolonged ELB episodes, either because asset purchases continue for an extended time in a lengthy ELB episode or because new LSAP programs are initiated before past programs have had time to unwind, the size of the balance sheet may drift up over time to very high levels. A related concern is that the Federal Reserve could end up holding a large share of outstanding government securities, a situation that might hinder market functioning. Our model simulations suggest that these concerns are unlikely to materialize for at least the next several years. In particular, as shown in the top-left panel of Figure 5, the size of the Federal Reserve’s balance sheet exceeds $5 trillion by 2022 in roughly 25 percent of the simulations that entail a return to the ELB under the passive policy. A balance sheet of that size would be equivalent to about 25 percent of GDP, a ratio comparable to the peak observed during the global financial crisis. So far, none of the asset purchase programs have been associated with undue disruptions to market functioning. Figure 7 shows that, under all of our simulations, including those draws that call for large expansions of the balance sheet, the share of outstanding federal debt held by the Federal Reserve over the 2018–2022 period stays at moderate levels.[48] In part, these modest levels are attributable to the fact that, during

[48] For reference, the Federal Reserve currently holds a little less than 14 percent of federal debt outstanding.

severe downturns, Treasury debt issuance rises sharply, creating room for the Federal Reserve to expand its balance sheet through purchases of government securities without necessarily crowding out private investors.

Figure 7: Distributions of Treasury holdings in stochastic simulations



Note: Frequency counts for the Federal Reserve's Treasury holdings as a share of the outstanding federal debt are obtained via stochastic simulations in the FRB/US model around the SEP-consistent baseline over a four-year horizon. The frequency counts shown here condition on being at the ELB under the passive policy. The statistic for each simulation corresponds to the maximum value of the share between the third quarter of 2018 and the final quarter of 2022.

Due to the computational complexities of our augmented FRB/US–balance sheet model, it is difficult to assess balance sheet risks over long horizons.[49] Obviously,

[49] Using an alternative approach, which allows for the performance of stochastic simulations over long horizons, Kiley (2018) provides an encouraging assessment of the ratcheting-up risk. Under a proactive

estimates of the distribution of the balance sheet size over long horizons are highly uncertain and are likely sensitive to assumptions about the conduct of monetary policy going forward—including the assumption about the longer-run level of reserve balances, the frequency and depth of recessions, the equilibrium level of policy rates, and various other modeling factors that affect ELB risk.[50]

Concluding remarks

Our analysis indicates that there is a significant risk that conventional interest rate policy will be constrained by the ELB in future recessions. Unconventional policies of the sort used by the FOMC during the last recession can help diminish the severity of ELB episodes. In particular, although threshold-based forward guidance and balance sheet polices have only a small effect in our simulations in limiting the rise in the unemployment rate during a recession, if credible, they can be modestly effective in speeding up the subsequent labor market recovery and return of inflation to 2 percent.

LSAP policy, he finds that policymakers would conduct asset purchases roughly 7 percent of the time and that the Federal Reserve's total asset holdings due to ongoing and past LSAP programs—that is, the size of the balance sheet relative to its steady state—would be less than $3.2 trillion (measured in constant 2015 dollars) about 95 percent of the time; for comparison, a $3.2 trillion expansion of the balance sheet is roughly on the order of the expansion observed in response to the global financial crisis.

[50] For example, Cavallo and co-authors (2018) assess the implications of alternative assumptions about the Federal Reserve's longer-run balance sheet size for both remittances to the U.S. Treasury and broader fiscal outcomes. The authors find that for sufficiently large longer-run balance sheet sizes, the probability of negative net earnings and of recording a deferred asset increases substantially as the policy rate along the economic recovery is expected to rise after the termination of an asset purchase program.

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Appendix I: Key modeling assumptions

Unless otherwise noted, we perform our simulations using the linearized version of the FRB/US model under the following set of assumptions:

- The baseline economic projection comes from the public FRB/US data base that is consistent with the median responses of FOMC participants in the June 2018 Summary of Economic Projections.
  - To construct this baseline projection, we interpolated annual SEP information to a quarterly frequency and assumed that, beyond 2020 (the final year reported in the June 2018 SEP), the economy transitions to the longer-run values in a smooth and monotonic way. We also posited economic relationships to project variables not covered in the SEP. For example, we assume an Okun's law relationship to recover an output gap from the deviation of the median SEP unemployment rate from the median SEP estimate of its longer-run value.
  - The projection is consistent with longer-run values of the unemployment rate and inflation of 4½ percent and 2 percent, respectively.
- Unless specified otherwise in the text, the federal funds rate in our simulations is set according to an asymmetric version of the inertial Taylor (1999) rule that staff uses to construct the Tealbook baseline.
  - The inertial Taylor (1999) rule is given by $R_t = 0.85R_{t-1} + 0.15(r^{LR} + \pi_t + 0.5(\pi_t - 2) + ygap_t)$, where R_t is the federal funds rate, r^{LR} is the real federal funds rate in the longer run, π_t is four-quarter core PCE inflation, and $ygap_t$ is the output gap.
  - The asymmetric version of that rule includes an extra term, $-0.85(U_t - U_{t-2})\mathbb{I}\{U_t - U_{t-2} > 0\}\mathbb{I}\{U_t > U_t^*\}$, that calls for lowering the federal funds rate more rapidly than otherwise when the unemployment rate, U_t, is both rising and above the natural rate of unemployment , U_t^*.

  - We impose an ELB of 12.5 basis points, a value equal to the mid-point of the lowest range for the federal fund rate implemented by the FOMC during the global financial crisis.
- We specify the model equations as follows:
  - We assume that price setters, wage setters, and financial market participants form model-consistent expectations; all other agents project future variables using small systems of equations and historical data.
  - We assume that the term premiums in the model do not respond to resource slack. See Appendix VIII for a discussion.
  - When running stochastic simulations over many decades, as we do for the threshold-based forward guidance simulations in Part II.B, we assume that fiscal policy is twice as responsive to the output gap as in the standard version of FRB/US. This alternative assumptions helps ensure that simulations produce stable solutions over long horizons. See Appendix III for a discussion of that assumption.
- We perform stochastic simulations of the model using an approach similar to that implemented in the Risks and Uncertainty section of Tealbook A to derive uncertainty bands around the staff projection.
  - We sample from the model's equation residuals from the 1969–2016 period.
  - To ensure consistency with the frequency and severity of historical economic downturns, we sample recessions with the same probability as in the data and, when a recession occurs, we draw the entire sequence of equation residuals associated with one of the historical recessions.
  - We scale down mark-up shocks to lower their variance by half, which helps limit occurrences of ELB episodes driven by falls in inflation unrelated to developments in real economic activity. This change is motivated by our judgment that historical innovations to

inflation were more volatile than innovations to inflation going forward because the FOMC lacked an explicit inflation objective over most of the sample period.

- For Part I of this memo, we perform stochastic simulations using 20,000 draws in order to have reasonably small sampling uncertainty for tail event statistics.

Appendix II: ELB risk and outcomes under the Tealbook baseline

Table A1 reports the probability that the ELB will bind at some point between now and various future periods based on stochastic simulations of the model around the June 2018 Tealbook baseline (as opposed to the SEP-consistent baseline shown in the main text). The simulations suggest only a modest probability of returning to the ELB between now and the end of 2022 whether one uses the inertial Taylor (1999) rule or its asymmetric version. These probabilities are smaller than those shown in Table 1 for the SEP-consistent baseline, a difference that primarily reflects the larger rise in the federal funds rate projected by the staff in coming years than in the path of median SEP responses. These probabilities are also well below those assigned by market participants over the next few years, as reported in the Desk's Survey of Primary Dealers. As was the case with the SEP-consistent baseline, moderate departures from the assumed baseline value of r^{LR} have only a limited incidence on ELB risk in the simulations.

Table A1: Probability of ELB episode between now and period shown based on stochastic simulations around June 2018 Tealbook baseline

	2020:Q4	2022:Q4	2027:Q4
r^{LR} = 0.50 (staff assumption)			
Baseline rule	1.9	5.6	23.1
Asymmetric rule	3.1	8.5	32.6
r^{LR} = 1.00 (staff assumption + 0.50)			
Baseline rule	1.6	4.8	19.5
Asymmetric rule	3.0	7.7	28.1
r^{LR} = 0.00 (staff assumption − 0.50)			
Baseline rule	2.1	6.3	27.6
Asymmetric rule	3.3	9.7	38.0
Addendum			
Survey of Primary Dealers (Median, June 2018)	20.0	n.a.	n.a.

Note: Staff calculations using 20,000 stochastic simulations of FRB/US model.

Appendix III: Comparison of longer-run ELB risk in studies using the FRB/US model

This appendix illustrates the sensitivity of ELB risk estimates to a number of key modeling assumptions. We focus on the per-period probability that the federal funds rate is constrained by the ELB over the long run, which allows us to compare our findings more directly to earlier studies in the literature. Because shocks take time to diffuse in the FRB/US model, this longer-run focus also allows us to look more broadly at the range of macroeconomic outcomes likely to be experienced over time.

As shown in Table A2, the probability of being at the ELB at any point in time over the long run is 13.5 percent and 15.0 percent for the inertial Taylor (1999) rule and the asymmetric version of that rule, respectively.[51] The ELB episodes under these policies last, on average, between 8 and 11 quarters. The per-period probabilities are similar to those reported by Williams (2009), when he assumes that r^{LR} equals 1 percent and that the shocks to the model are drawn from the 1968–2002 period (these assumptions are the most similar to ours among the various parameter values and sample periods considered in Williams (2009)). By contrast, Kiley and Roberts (2017) report per-period probabilities between 30 and 40 percent, depending on the monetary policy rule, for a comparable value of r^{LR} and shocks drawn from the 1960–2007 period.

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[51] Gust and co-authors (2017) estimate a DSGE model imposing that the ELB is only occasionally binding. Their estimates of the per-period ELB probability are disperse across stochastic simulations but in a similar range as ours: About 15 percent of their stochastic simulations have a probability of being at the ELB more than 10 percent of the time and about 3 percent of the draws have a probability of being there more than 17 percent of the time. In addition, these authors show that the distribution for the duration of an ELB spell is skewed to the right and also has a long right tail.

Table A2: ELB risk in the longer run in the FRB/US model

	r^{LR} (in percent)	Per-period probability (in percent)	Mean duration (in quarters)
This memo			
Inertial Taylor (1999) rule	0.88	13.5	10.5
Asymmetric rule	0.88	15.0	7.8
…+ passive fiscal policy	*0.88*	*24.0*	*12.2*
…+ full model-consistent expectations	*0.88*	*39.6*	*25.8*
Williams (2009)			
Taylor (1993) rule	1.00	13	n.a.
Kiley and Roberts (2017)			
Estimated rule	1.00	31.7	9.2
Non-inertial Taylor (1999) rule	1.00	38.3	9.8

Note: The baseline economic projection, model parameters, and simulation parameters differ across studies; see each study for a description.

Although these studies all use the FRB/US model, they differ in several key assumptions. With regard to behavior at the ELB, the most important such assumptions govern how common are episodes with explosive dynamics when the ELB binds for a sufficiently long duration.[52] These dynamics are widely regarded as implausible and users of the FRB/US model typically offset them when running long-horizon stochastic simulations.[53] Much of the differences between our simulations and the others presented in Table A2 stem from different strategies for dealing with these pathologies. We highlight two key differences.

- Fiscal policy: Our long-run simulations are conducted under fiscal assumptions such that only extremely long ELB episodes may lead to explosive dynamics. These assumptions help keep the volatility of

[52] In particular, as demonstrated by Carlstrom, Fuerst, and Paustian (2015), in many New Keynesian models with sticky prices, such as FRB/US, there is a certain length of time at the ELB such that, as one nears this horizon, the stimulus provided by positive shocks to aggregate demand grows very rapidly, only to become sharply contractionary once this horizon has been passed. Simulations in the vicinity of this horizon will tend to feature explosive dynamics in which the output gap diverges without bound.

[53] For example, Williams (2009) and Kiley and Roberts (2017) assume that economic slumps are eventually reversed by the implementation of an emergency fiscal package.

macroeconomic outcomes in a range that we see as plausible but they may not provide an accurate depiction of fiscal policy in all adverse situations. When we assume less stabilization from fiscal policy, the per-period probability under the asymmetric policy rule steps up to 24 percent (see entry labeled "... + *passive fiscal policy*").[54]

- Expectations formation: In our simulations, price setters, wage setters, and financial market participants form model-consistent expectations whereas other agents, in particular households, form expectations using small systems of equations that rely solely on past economic outcomes. When, in addition to assuming a more passive fiscal policy, we assume that all agents form model-consistent expectations, we find that the per-period ELB probability jumps to a level similar to that reported in Kiley and Roberts (2017). The modeling of expectations matters to such a degree because the time horizon for explosive amplification under fully model-consistent expectations is much shorter than under our setting. The risk of unbounded divergence is especially heightened when the model lacks a stabilizing fiscal policy.

Finally, although the choice between the inertial Taylor (1999) rule and its asymmetric version has only a small effect on long-run ELB risk in our simulations, the monetary policy strategy assumptions can nonetheless matter much for longer-run ELB risk. For example, Kiley and Roberts (2017) attribute much of the gap in their assessment of ELB risks and that of Williams (2009) to an assumption in the latter paper that leads to additional accommodation when the economy deteriorates.[55]

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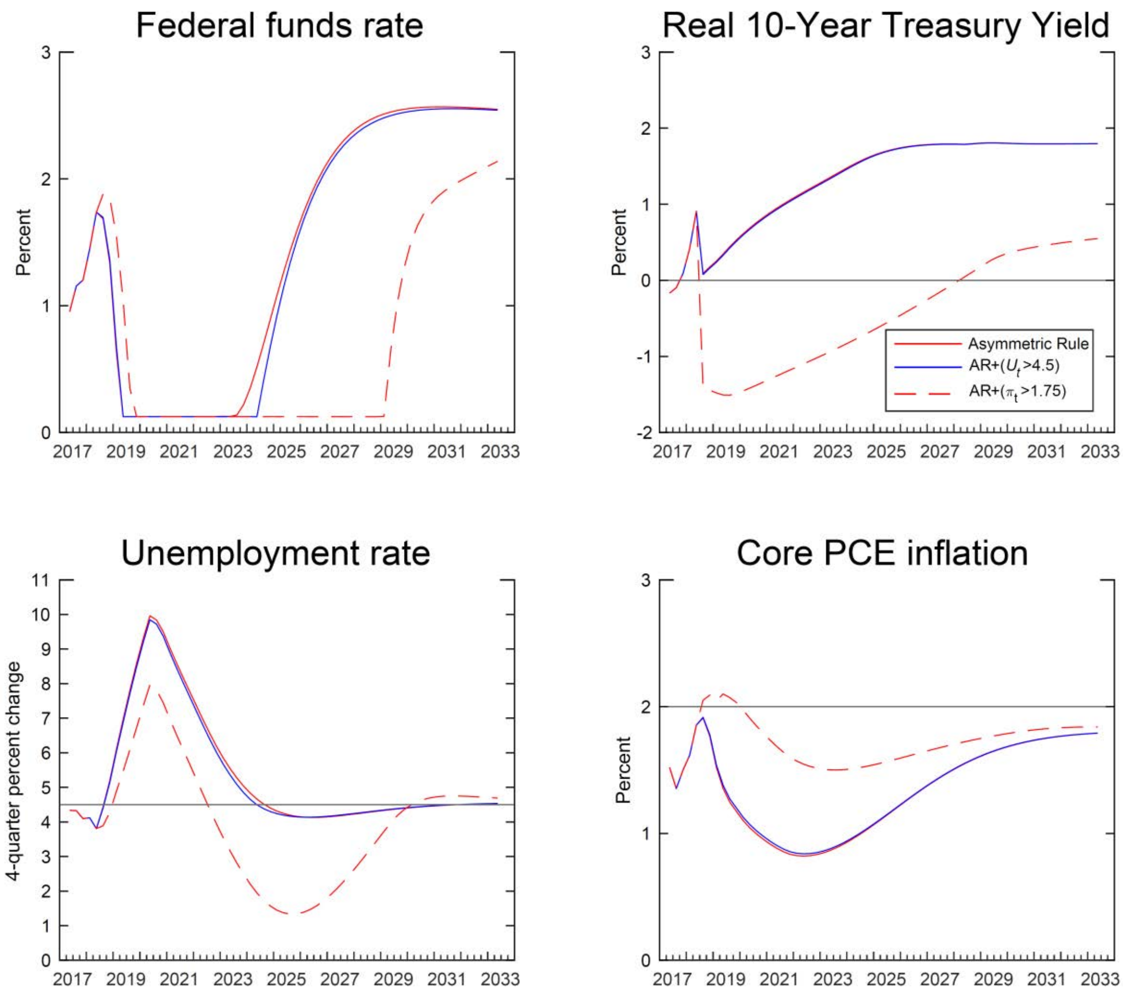
[54] Our results labeled "... + *passive fiscal policy*" and "... +*full model-consistent expectations*" also undo the toning down of the volatility of the markup shocks in the model, which has only a small effect on longer-run ELB risk.

[55] In Williams (2009), the intercept of the policy rule falls in a persistent manner when economic conditions deteriorate. The anticipation of more accommodative monetary policy, in turn, helps strengthen the economic outlook and limit the occurrence and duration of ELB episodes. In this memo as well as in Kiley and Roberts (2017), the intercept of policy rules is fixed. Moreover, Williams (2009) allows for a shorter maximum length of ELB episodes than Kiley and Roberts (2017), which the latter authors argue account for much of the remaining difference in ELB risk.

In sum, our discussion illustrates the sensitivity of ELB risk assessment to the assumptions under which the model simulations are conducted, even holding large aspects of the model constant. In particular, the extent of ELB risk seems particularly sensitive to assumptions that limit the amount of policy stabilization by monetary and fiscal authorities, or that makes agents in the model more prone to becoming pessimistic about economic outcomes.

Appendix IV: Forward Guidance in a DSGE model

Figure A1: Forward guidance in a DSGE model with discounting



Note: Simulations of forward guidance strategies in a variant of the model of Del Negro, Giannoni, and Schorfheide (2015), in which consumers discount future interest rates at a rate of 5 percent per quarter. The simulations is constructed around the same baseline as in the recession scenario in the FRB/US model in Part II of this memo.

Appendix V: Monetary policy and the tradeoffs in macroeconomic outcomes over time

When faced with severe shocks, policymakers can limit the deterioration in economic outcomes and hasten the economic recovery by pursuing accommodative policies that, eventually, may lead to a tight labor market and inflation running above 2 percent. Table A3 illustrates the tradeoffs in macroeconomic outcomes over time for each of the unconventional policies that we considered in our recession scenario. For the unemployment rate, we report the cumulative difference from the natural rate, distinguishing between the initial period when the unemployment rate overshoots the natural rate and the subsequent period when the unemployment rate undershoots the natural rate. Similarly, for inflation, we report the cumulative difference from 2 percent, distinguishing between the initial period when inflation undershoots that goal and the subsequent period (if present) when inflation overshoots that goal. The calculations are performed over the simulation periods shown in Figures 2, 3, and 4, which run from the third quarter of 2018 through the second quarter of 2033. The statistics are expressed in percentage points per year equivalents. For example, under the asymmetric rule, inflation undershoots 2 percent over the entire period shown by an equivalent of 9.8 percentage-point-years, meaning that the cumulative undershooting of inflation over the period shown is equivalent to inflation undershooting the inflation goal by 9.8 percentage points for one year.

Overall, Table A3 shows that greater policy accommodation, as expected, leads to a reduction in the overshooting of the natural rate of unemployment and in the undershooting of the inflation objective during the recession and ensuing economic recovery. However, greater policy accommodation subsequently comes at the cost of a more pronounced undershoot of the natural rate of unemployment under all policies and, in some cases, with a modest inflation overshoot of 2 percent. To decide which policy is most appropriate in response to the recession, policymakers would need to weigh the improvement in macroeconomic outcomes early on against the possible deterioration in macroeconomic outcomes later on.[56] The loss policymakers attach to various outcomes may well differ from the simple cumulative sums reported in Table A3. For example, policymakers might attach greater importance to improving the worse outcomes or might put greater weight on economic developments in the near term than several years out.

Table A3: Cumulative overshoots and undershoots of longer-run values in a recession scenario under unconventional policies

	U_t		π_t	
	overshoot (in p.p.-year)	**undershoot (in p.p.-year)**	**overshoot (in p.p.-year)**	**undershoot (in p.p.-year)**
Asymmetric rule (AR)	15.3	1.5	0	9.8
AR + threshold-based forward guidance				
U_t < 5½ percent	15.3	1.5	0	9.8
U_t < 4½ percent	15.1	1.7	0	9.4
U_t < 3½ percent	13.8	4.3	0.1	5.0
π_t > 1¾ percent	13.9	4.2	0	5.1
π_t > 2 percent	13.4	5.5	0.6	3.5
π_t > 2¼ percent	13.0	7.2	1.7	2.0
AR + balance sheet policies				
Passive	15.3	1.5	0	9.8
Reinvestment only	14.3	1.8	0	8.6
MEP	14.2	1.8	0	8.6
LSAP	12.1	3.3	0	5.3
LSAP + inflation threshold	11.2	7.8	2.0	0.9

Note: The table shows, for each policy considered, the cumulative difference from either the natural rate of unemployment or the 2 percent inflation goal under the recession scenario. Separate statistics are computed for the periods of undershooting and overshooting. The statistics are computed over the 2018:Q3–2033:Q2 period.

[56] In addition to specifying their preferences over outcomes, policymakers would likely take account of other elements, such as risk management and communication considerations.

Appendix VI: Reputational concerns and forward guidance

In our discussion of forward guidance under a recession scenario, we noted that threshold policies that entail promises to overheat the economy in the future may not be time consistent: Eventually, economic conditions might improve to such an extent that policymakers would prefer to abandon their forward guidance in favor of a tighter stance of policy to contain the projected undershoot of the natural rate of unemployment and its accompanying inflationary pressures. Although departing from announced forward guidance might bring some immediate benefits, policymakers might worry that doing so entails a loss of credibility that could diminish the potency of central bank communications in future downturns.

In this appendix, we quantitatively explore reputational concerns under the assumption that policymakers face an uncertain future around the recession baseline, set the federal funds rate in normal times according to the asymmetric rule, and seek to implement forward guidance in the form of a 2¼ percent inflation threshold whenever the ELB is binding. We further posit that policymakers' preferences are captured by a simple loss function that penalizes unemployment rate realizations above the natural rate and inflation deviations—positive and negative—from the FOMC's 2 percent goal.[57] Finally, we assume that policymakers' forward guidance is initially fully credible and that any departure from an announced forward guidance prevents policymakers from issuing forward guidance for a fixed number of periods; thereafter, their forward guidance is again fully credible until another departure occurs. The latter assumptions capture, in a simple manner, the loss of credibility due to broken policy promises.[58]

We measure the net benefit of deviating from the forward guidance as the difference in expected discounted losses between a policy that departs from the forward guidance and a policy that abides by it. The net benefit can be decomposed into the short

[57] Formally, we assume that policymakers' preferences are given by a discounted sum of the squared excesses in the unemployment rate and squared deviations of inflation from 2 percent, $\sum_{\tau=0}^{T} \beta^{\tau}((U_t - U^*)^2 \mathbb{I}\{U_t > U^*\} + (\pi_{t+\tau}^{PCE} - 2)^2)$, where $\beta = 0.99$ and T is large. This loss function could capture the preferences of policymakers who do not regard unemployment rate realizations below the natural rate as undesirable unless these realizations are accompanied by inflation readings above 2 percent.

[58] For formal analysis of the role of reputation for monetary policymaking in a liquidity trap, see Nakata (2015, 2018) and Walsh (2018).

run gain from reneging from a promise and the long run cost of not being able use forward guidance in a future recession. When this difference is positive, policymakers judge it advantageous to abandon the guidance and, conversely, prefer to follow through with the guidance when this difference is negative.

The first line of Table A4 shows the net benefit of deviating from an inflation threshold of 2¼ percent in the absence of economic uncertainty in our baseline recession scenario. The net benefit is measured in 2026—as policymakers contemplate a lengthy overheating period—under the assumption that deviating from the announced policy forever prevents recourse to forward guidance. The net benefit is positive in that period, meaning that policymakers unambiguously prefer to abandon the forward guidance. As Table A3 shows, this net benefit is equivalent to preventing inflation from exceeding 2 percent by 0.4 percentage point for three years. Because there is no uncertainty in the baseline recession scenario, losing the ability to issue forward guidance in the future entails no cost in terms of economic stabilization because the economy never faces the ELB again.

The remaining rows of Table A4 show the net benefit when the evolution of the economy is uncertain, so that a loss of credibility limits policymakers' ability to stabilize economic activity through forward guidance in future ELB episodes. We consider three durations for policymakers' inability to use forward guidance after a departure: 5 years, 10 years, and 20 years. The net benefit is calculated as the expected difference in losses over the duration under consideration between the asymmetric rule with and without forward guidance, starting from the model's steady state. The net benefit is negative for all three durations considered, suggesting that preserving the credibility of future forward guidance improves outcomes in future downturns to such an extent that policymakers today are better off implementing the announced guidance, even if it implies overheating the economy for a time, rather than deviate and face more severe ELB episodes in the future. The table also suggests that the greater the loss in credibility (as measured by the duration without recourse to forward guidance), the less inclined policymakers would be to deviate from their past communications.

This type of cost-benefit analysis is subject to various caveats, including our assumption about policymakers' preferences over macroeconomic outcomes. However, our simulations suggests that, once reputational concerns are taken into account, carrying through with an announced forward guidance offers benefits in terms of better economic stabilization over the longer run: Those benefits may more than outweigh the near-term gains from abandoning the forward guidance.

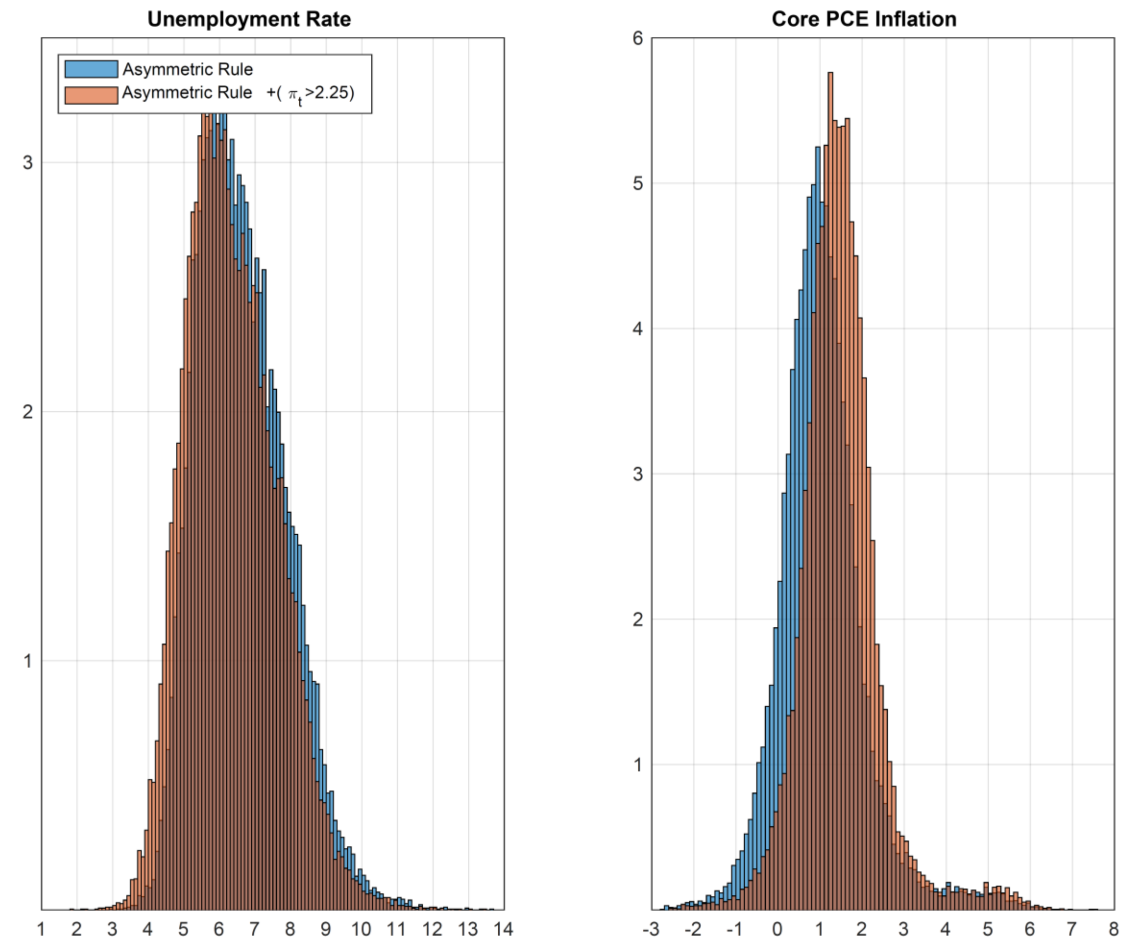
Table A4: Net benefit of abandoning the forward guidance in a recession scenario

	Net benefit	Equivalent three-year inflation deviation (in percentage point)
Recession scenario (no uncertainty)	1.4	0.4
Extended simulations (with uncertainty)		
5-year loss of credibility	-1.4	-0.4
10-year loss of credibility	-5.3	-0.7
20-year loss of credibility	-12.8	-1.1

Note: "Net benefit" statistics are calculated as the difference in the present discounted loss between versions of the asymmetric rule without and with a 2¼ percent inflation threshold. The assumed loss function penalizes unemployment rate realizations above the natural rate and inflation deviations—positive and negative—from 2 percent. "Equivalent three-year inflation deviation" statistics are calculated as the percentage-point deviations of inflation from 2 percent that, if maintained for three years, would result in present discounted losses equivalent to the (absolute) net benefit, holding future inflation and the unemployment rate at their long-run levels.

Appendix VII: Macroeconomic outcomes in the longer run under threshold-based forward guidance

Figure A2: Distribution of longer-run macroeconomic outcomes under threshold-based forward guidance



Note: The left and right panels show a distribution of unemployment rate outcomes and inflation outcomes, respectively, in stochastic simulations around a steady-state baseline and conditional on being in an ELB episode. The blue histograms show distributions for the asymmetric rule without threshold-based forward guidance, whereas the orange histograms show the distributions when the asymmetric rule is complemented with credible forward guidance that the ELB will bind at least until inflation exceeds 2¼ percent. For comparability, both sets of histograms are calculated using the subset of periods for which the ELB binds under the asymmetric rule without threshold-based forward guidance.

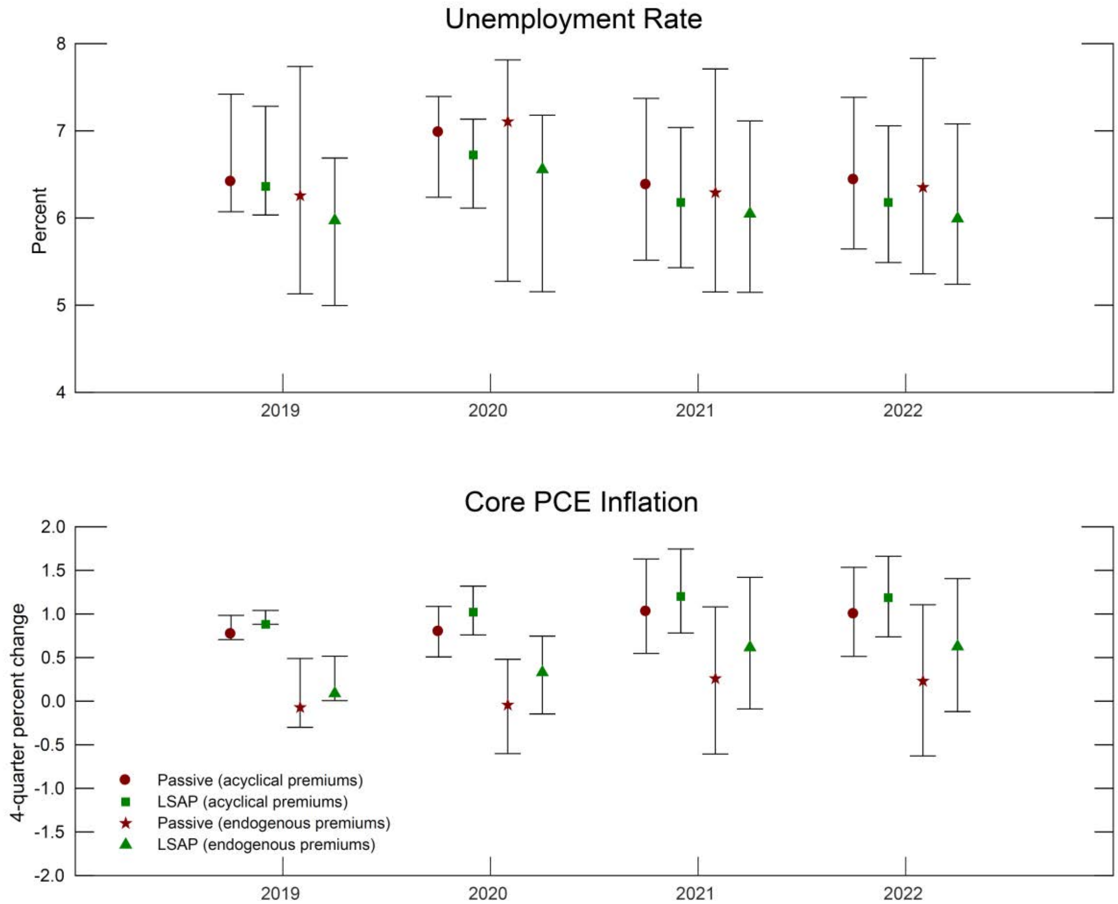
Appendix VIII: Macroeconomic effects of LSAPs under countercyclical term premiums

In the data, simple correlations suggest that the term premiums are mildly countercyclical, though the economic reasons for such countercyclicality and the possible connections to monetary policy are debated. In our simulations, we have assumed for simplicity that term premiums do not respond to the business cycle. If, instead, we were to assume an endogenous countercyclical component in term premiums consistent with the idea that risk premiums in general tend to rise amid poor economic conditions, our simulated monetary policy effects would be larger, both for conventional interest rate policy and for balance sheet policy. We isolate this effect for the LSAP policy in Figure A3, which, like Figure 5, focuses on distributions of the unemployment rate and inflation outcomes when the ELB binds in each period shown. The first two intervals in each year are the same as previously reported in Figure 5: They are the interquartile range of the distributions assuming acyclical term premiums for the LSAP and passive balance sheet policies. The next two intervals are the corresponding interquartile ranges when we instead assume term premiums that are as countercyclical as in the data.

When the term premiums incorporate a countercyclical element, all else equal, cyclical movements in the unemployment rate and inflation are amplified. For example, a strengthening in the economy brings about a reduction in term premiums, which supports additional economic strength. This mechanism also means that monetary policy can be more effective at macroeconomic stabilization. On net, our simulations indicate that the economy tends to be more volatile, as evidenced by the increased dispersion in unemployment rate and inflation outcomes under both the passive policy and the LSAP policy.

Under the passive policy, for inflation, the bulk of the interquartile range with countercyclical term premiums is below the median outcomes for the same policy with acyclical term premiums. For the unemployment rate, the medians are similar between the simulations with and without endogenous term premiums. However, with the greater dispersion, the 75^{th} percentile of the unemployment rate distribution with countercyclical term premiums is well above the corresponding percentile with acyclical term premiums.

Figure A3: Effect of assumptions about the cyclicality of term premiums on balance sheet policy outcomes



Note: The markers and the intervals show the median and the interquartile range, respectively, of the distribution of macroeconomic outcomes under each policy. For comparability, the distributions are calculated for the same sequences of shocks for which the ELB binds under the passive balance sheet policy in the final quarter of each period shown. The statistics are computed through stochastic simulations around the SEP-consistent baseline projection. The red dot and green square show the medians of the distribution assuming acyclical term premiums, under the passive and LSAP policies, respectively. The red star and green triangle show the medians assuming endogenous term premiums, again under the passive policy and the LSAP policy, respectively.

If we compare the difference between the macroeconomic outcomes under the LSAP policy and the passive policy, the differences are typically larger when the term premiums are countercyclical than when they are acyclical:

- With countercyclical term premiums, by the end of 2022, the median unemployment rate under the LSAP policy is 36 basis points lower than it is under the passive policy; by contrast, with acyclical term premiums, the median unemployment rate under the LSAP policy is only 25 basis points lower than under the passive policy.

- Moreover, with countercyclical term premiums, the LSAP policy is more successful in limiting extreme outcomes. For example, when term premiums are countercyclical, the 75th percentile of the unemployment rate under the passive policy is somewhat above 7¾ percent, but is close to 7¼ percent under the LSAP policy. When term premiums are instead assumed to be acyclical, the 75th percentile of the unemployment rate under the passive policy is 7.4 percent, whereas that percentile of the distribution under the LSAP policy is around 7.2 percent—a much smaller difference than we show when term premiums are countercyclical.