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Some Implications of Uncertainty and Misperception for Monetary Policy

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1. Introduction and Summary

Inflation remains below target even though the unemployment rate has for some time been below most FOMC participants' estimates of the natural rate of unemployment (u*). This situation has heightened concerns about the reliability of estimates of the natural rate of unemployment and about the strength of the Phillips curve relationship between inflation and labor market slack. Discussions of policy approaches to deal with such uncertainty, and of how to communicate these approaches to the public, now play a larger role in Committee deliberations. For example, policymakers have asked whether policy accommodation aimed at boosting inflation by allowing a persistent undershooting of unemployment may increase the risks of adverse outcomes such as unexpectedly high inflation or substantial overheating in financial markets down the road.

This memo begins by briefly reviewing evidence on the precision of estimates of the natural rate of unemployment and on the evolution of parameters determining the relationship between resource utilization and inflation. In light of this evidence, we then use a small version of the FRB/US model to gauge the performance of several policy rules under different realizations of these uncertainties; specifically, our analysis compares economic performance under a simple rule, akin to the Taylor (1999) rule, which responds fairly strongly to deviations of both inflation and unemployment from objectives, to rules that focus more heavily on stabilizing either inflation or unemployment. In each case, we use stochastic simulations of the model to derive distributions of outcomes for unemployment, inflation, and the policy rate that are associated with the alternative rules. The distributions of potential outcomes for each rule reflect shocks that may hit the economy over the next several years, the range of alternative structural features of the inflation process we consider, and policymakers' misperceptions about resource utilization.

Our analysis highlights some shortcomings of rules that put a sizable weight on stabilizing the unemployment gap when the policymaker is uncertain about u*. In

[1] We thank James Clouse, Thomas Laubach, David Lebow, Brian Madigan, Steve Meyer, Trevor Reeve, David Reifschneider, David Wilcox, and Beth Anne Wilson for comments. We also thank Tilda Horvath and James Trevino for sharing their technical expertise, Simeon Markind for research assistance, and Flint Brayton for helpful advice regarding the small FRB/US model. Last but not least, much of the computational work for this memo used the DSGE modeling suite of the Macroeconomics and Quantitative Studies section of R&S and the excellent code for simulating linear models subject to the effective lower bound restriction on nominal interest rates for which our colleague Hess Chung was the primary architect.

particular, a strategy of responding aggressively to the policymaker's estimate of the unemployment gap, as with an "unemployment-averse rule," tends to keep the distribution of unemployment clustered around the policymaker's estimate of u^*. If the policymaker's estimate of u^* differs from its true value, the resulting persistent gap between unemployment and u^* exerts protracted upward or downward pressure on inflation. All else equal, these considerations point to the potential benefits of following a rule that puts a smaller weight on stabilizing resource slack and larger weight on inflation stabilization when there is substantial uncertainty about u^*.

However, the notion that policymakers should downweight the unemployment gap and respond aggressively to inflation is substantially weakened in the empirically-relevant case in which the Phillips curve is flat and inflation is buffeted by sizable shocks. Under these conditions, reacting strongly to inflation tends to induce a high degree of volatility in the (true) unemployment gap. Moreover, under current conditions, an aggressive response to below-target inflation could increase the likelihood that the unemployment rate falls to historically low levels. Overall, our stochastic simulations show that responding significantly to the unemployment gap—even if mismeasured—tends to perform better in achieving dual mandate goals than does responding aggressively to stabilize inflation. While our results should be regarded as somewhat tentative, they do suggest some caution is warranted in pursuing strategies that focus heavily on stabilizing inflation and that downweight the unemployment gap in setting policy.

Turning to the implications of alternative parameterizations of the Phillips curve, we find that the probability of inflation running in a range of 3 to 4 percent would be considerably higher if the Phillips curve were to revert to a form similar to that seen in the 1970s, so that inflation responded more substantially and persistently to the unemployment gap. In such circumstances, the forceful response to higher inflation implied by some of the rules we consider would push unemployment above its natural rate in order to return inflation to its 2 percent target. Even so, we find little risk of an extreme rise in the unemployment rate. A lesson of our analysis is that a reversion in the Phillips curve to its 1970s form would be unlikely, in and of itself, to lead to a reprise of the 1970s experience of high inflation and unemployment—albeit with the caveat that monetary policy would need to be set in a manner consistent with achieving its price stability mandate over time.

2. Background on risks and their implications for policy strategy

In this section, we briefly review evidence on changes in the Phillips curve and the degree of uncertainty regarding resource utilization. We then review the implications of uncertainty along these dimensions for monetary policy strategy that have been emphasized in the literature. Our review motivates the simulation analysis that follows.

Evolution of the Phillips curve

The reduced-form relationship between resource utilization and inflation has evolved substantially over the last thirty years, as illustrated in figure 1: The Phillips curve is flatter, as shown in the upper panel (i.e., the coefficient on the unemployment gap in a regression has fallen in absolute value); and the persistence of inflation (as gauged by the coefficient on lagged inflation in the same regression) has dropped from about one—an accelerationist Phillips curve—to a much lower value, consistent with the anchoring of inflation near 2 percent in recent years. A substantial body of research documents these changes.[2]

While these shifts are apparent from the data, their causes are less well understood. The anchoring of inflation expectations near 2 percent plausibly reflects the relatively low and stable inflation seen since the mid-1980s, which in turn owes to central bankers' focus on controlling inflation over this period. The reduction in the sensitivity of inflation to resource utilization may reflect that price changes become less frequent in an environment of low and stable inflation, but this remains an open question.[3] In light of these uncertainties, our analysis below will consider a reversal of these developments. In particular, we use a specification similar to that from the mid-1960s to mid-1980s in which the slope of the Phillips curve is several times higher than in our baseline model and the Phillips curve takes an accelerationist form.

Uncertainty about resource utilization

Research has emphasized the challenges associated with measuring resource utilization – challenges that arise both from imprecision associated with inferring the value of an unobserved concept such as the natural rate of unemployment and from differences in the concepts used by various researchers.[4] Indeed, economists have attributed the rise of inflation in the 1970s in part to policymakers' errors, including underestimation of the natural rate of unemployment.[5] Despite much research, the confidence bands around estimates of u^*—the natural rate of unemployment—are wide, as illustrated in the bands

[2] For example, the flattening of the Phillips curve and anchoring of long-run inflation expectations since the 1980s is discussed in Kiley (2015) and Blanchard (2016). Aaronson and others (2016) summarize related staff analyses. Lagged inflation in regression models is often taken as a proxy for long-term inflation expectations. De Pooter and others (2016) discuss the challenges of inferring long-term inflation expectations from the data.

[3] For a review of a range of possible explanations for the combination of low inflation and low unemployment this year, see De Michelis and others (2017).

[4] Staiger, Stock, and Watson (1997) highlight the wide confidence intervals associated with estimation of u^*. Fleischman and Roberts (2011) review later research and provide an updated analysis of similar issues. Kiley, Reifschneider and Rudd (2011) and Kiley (2013) review a range of conceptual issues that arise when economists attempt to define resource utilization.

[5] See, for instance, Orphanides (2003) and Romer and Romer (2002). Throughout this memo, at modest loss of generality, we will take the natural rate of unemployment and the non-accelerating inflation rate of unemployment to be the same.

implied by several staff models shown in figure 2: The 70 percent confidence interval for the current estimate of the natural rate extends from just below 4 percent to about 5½ percent.

Implications for policy strategy

The implications for monetary policy strategy of uncertainty regarding resource utilization and the nature of the Phillips curve has been a focus of research for decades. For our analysis, we see two lessons from the literature as central. The first is that misperceptions of economic slack led to policy mistakes, an argument that holds a prominent place in explaining the rise in inflation during the late 1960s and 1970s. Based in part on this experience, an influential literature recommends that monetary policy reduce the responsiveness of the policy rate to (mismeasured) slack, and instead focus more on movements in inflation.[6]

The second lesson is that the relationship between inflation and economic slack appears to have weakened significantly, a development that points toward a heightened focus on keeping the unemployment gap near zero rather than on stabilizing inflation. This conclusion reflects, in part, that stabilizing inflation is very costly in terms of the resource gap volatility that must be tolerated when the Phillips curve is flat and the economy subject to supply shocks.[7] Instead, a more direct response to the unemployment gap better achieves dual mandate objectives. In this vein, a policy strategy that focused mainly on inflation during the Great Recession would have slowed the economic recovery significantly, as disinflation was moderate.

Motivated by this tension between strategies, our analysis below examines economic performance under three monetary policy strategies that are representative of the literature. These rules are described briefly here and explicitly shown in Appendix A:

A *balanced-approach rule*: Policymakers adjust the path of the federal funds rate in line with their estimates of the equilibrium real interest rate and respond moderately to deviations of inflation and unemployment from their objectives. This rule is otherwise known as the Taylor (1999) rule, except that the unemployment gap substitutes for the output gap; these two gaps generally move together and we will treat them as interchangeable.

An *inflation-averse rule*: Policymakers downweight the signal from their estimates of resource utilization and respond more forcefully to deviations of inflation from target,

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[6] Arguments along these lines can be found in Orphanides and others (2000) and Orphanides and Williams (2005).

[7] In principle, a policy reaction function that strongly responds to inflation could offset demand shocks to effectively stabilize inflation and unemployment gaps. However, because of the flatness of the Phillips curve, such a policy would induce high volatility in the unemployment gap in response to supply shocks. Accordingly, in our analysis, we are assuming that only a modestly higher weight on inflation than in the Taylor (1999) rule seems plausible.

implying an appreciably stronger policy reaction to above- or below-target inflation than to the gap between unemployment and *u**. Given the staff's current baseline outlook in which the unemployment gap is large and inflation is subdued, this strategy implies a more accommodative near-term policy stance than implied by the balanced-approach rule.

An *unemployment-averse rule*: Policymakers downweight the signal from low inflation and respond more forcefully to unemployment deviations from *u**. This approach would be less accepting of the undershooting of the unemployment rate in the staff's current baseline outlook, implying a more rapid removal of accommodation than under the balanced-approach rule.

3. Economic Performance Under Alternative Strategies and Economic Structures

Model and simulation approach

Much of our analysis concerns the uncertainty around a particular baseline describing how the economy will evolve in the future; we use the September 2017 staff forecast as the baseline. To illustrate the risks to the baseline outlook, we employ *stochastic simulations* to produce simulated *distributions* of outcomes based on random sequences of economic shocks.[8] We use the "small FRB/US" (sFRB) model. The sFRB model is a simplified, linear version of FRB/US with similar properties, including a similar characterization of inflation dynamics and the mechanisms through which monetary policy affects the economy; its smaller size and linear structure makes the technical complexity of the computations required for our analysis feasible.[9]

The assumptions underlying our benchmark simulations are summarized in table 1, where we also show the alternative assumptions we will explore. Two warrant discussion. First, for our benchmark simulations, we assume that certain economic decision makers have *model consistent expectations* (MCE), which means that they form expectations with knowledge of the structure of the economy, including the monetary policy rule followed by the central bank. In particular, we assume MCE in those sectors that are central to the monetary policy transmission mechanism, namely in asset pricing and wage and price

[8] Stochastic simulations are simulations where the model is repeatedly hit with shocks randomly sampled from shocks extracted from history, and simulated, date by date. Technically, we bootstrap shocks, which means that we randomly choose dates from history from which we draw the *full set* of (in our model 13) shocks that applies to that date. This procedure preserves the potentially important cross-correlation of shocks occurring at each specific date. See Appendix E for details.

[9] The sFRB model has about 50 equations, many of which are identities, as compared to about 400 for FRB/US. There are 13 key (stochastic) equations. The reduced size of sFRB, relative to FRB/US, is achieved partly through aggregation: 16 equations for expenditure components are shrunken to three in sFRB; five bond and mortgage rates are reduced to two. See Brayton (2015) for a detailed description of sFRB.

determination, but not elsewhere. The assumption of MCE is a strong one that conveys considerable power to monetary policy via the central bank's ability to directly affect agents' expectations through changes in current and future policy; to gauge the implications of this assumption, we also report results for simulations in which we alternatively assume that all agents employ VAR-based expectations. Under VAR-based expectations, decision makers form expectations on the basis of past observations of a small selection of economic variables, which limits the power of monetary policy to directly influence expectations.[10] Second, for our benchmark simulations, we use stochastic shocks drawn from a long history, specifically from 1969 to 2016, which means that we implicitly regard shocks from the volatile period before the Volcker disinflation to be as likely to be incurred in the future as shocks from more recent periods. We regard this as the most prudent assumption given our focus on risks and their implications for monetary policy; as we shall soon see, however, this has important implications for outcomes, namely lots of economic variability. Accordingly, we also consider a shorter, milder, post-Great-Moderation shock set.

Stochastic simulations under the benchmark policy rule

To provide a gauge of the likely range of outcomes in the medium term, figure 3 shows the probability density function of the unemployment rate and inflation as of 2019:Q4 under the benchmark balanced-approach rule. The distributions are reported based on shocks drawn from both the longer sample period—shown by the solid black lines—and the shorter sample period—the dashed blue lines. (The vertical lines show the staff's estimate of the natural rate of unemployment and the target rate of inflation.) The relatively wide tails of the distribution of unemployment, based on either sample, imply a sizable chance that unemployment could run at extremely low levels within a couple of years. In particular, the analysis suggests that there is at least a 15 percent chance of unemployment running below 3 percent at the end of 2019, a level not seen since shortly after the Korean War.

Despite the substantial probability that unemployment becomes very low, the model simulations suggest a fairly modest chance that inflation will run notably above 2 percent provided that shocks resemble those occurring since the mid-1980s.[11] The low probability that inflation will run much above target reflects both the flat Phillips curve slope and the relatively small estimated shocks to the Phillips curve over this period. By

[10] A special exhibit in the Monetary Policy Strategies section of the June 2017 Tealbook (pp. 102-6) illustrated the implications of VAR-based versus model-consistent expectations as applied to optimal control scenarios.

[11] For example, our simulations suggest that the probability of four-quarter core PCE inflation rising persistently above 3 percent over the next five years—where persistently is taken to mean two years or more—is about 3 percent. The corresponding figure for the benchmark 1969-2016 shock set is 8 percent.

contrast, the range of inflation outcomes (the black line) is much larger when shocks are drawn over the post-1969 sample given the high volatility of inflation during the Great Inflation.[12]

The stochastic simulations are also useful in helping gauge the joint distributions of key variables. In this vein, table 2 suggests that policymakers may continue to face significant tension between achieving their mandated policy objectives even two years hence. For illustrative purposes, we consider a situation in which average inflation is less than 1¾ percent even though average unemployment is below 3½ percent over the year 2019. Under the benchmark balanced approach policy, the joint probability of this event is slightly above 17 percent. On the other hand, the simulations suggest that there is slightly less than a 5 percent chance that the economy would show signs of significant overheating in 2019, which we take to be a situation in which unemployment has fallen below 3½ percent and core inflation has risen above 2½ percent.

Alternative policies with natural rate misperceptions

In this section, we study the implications of alternative monetary policy strategies given a plausible characterization of policymaker uncertainty about the natural rate. Recalling figure 2 and the broader literature, we consider three alternative possibilities for the current value of u^*: 4.8 percent, the staff baseline assumption in the September Tealbook, and 4 percent and 5½ percent, the latter two figures being at about the edges of the 70 percent confidence interval for typical estimates. In each case, we assume that policymakers follow the policy rules described above under the baseline assumption that u^* is 4.8 percent but is subject to stochastic shocks.[13,14]

Balanced approach rule Figure 4 presents the distributions of key outcomes in 2019:Q4 for the three cases. The solid black lines show the benchmark case in which policymakers use the correct 4.8 percent level of the natural rate in the rule (identical to figure 3). In the case in which the true natural rate is 4 percent but policymakers think it is 4.8 percent—the blue dashed lines, policymakers maintain too tight a policy stance, on average. Unemployment is expected to run persistently above the true natural rate, and this persistent gap in turn puts downward pressure on inflation. Inflation falls and the

[12] Confidence intervals for our experiments exhibit slightly more variation in four-quarter PCE inflation in 2019:Q4, and slightly less in the unemployment rate, than in the stochastic simulations shown in the Risks and Uncertainties section of the Tealbook. Relative to the confidence intervals reported in the September SEP minutes, our intervals are similar for inflation and narrower for the unemployment rate.
[13] The natural rate of unemployment is subject to shocks of a standard deviation of 4 basis points. Those shocks die out very slowly over time.
[14] The opposite case, where it is true that $u^* = 4.8$ and is subject to persistent shocks over time, but policymakers wrongly think that $u^* =$ 5½ percent or 4 percent, as applicable, is covered in a table in Appendix D.

inflation probability distribution, the blue dashed line, lies well to the left of that under the baseline path for the natural rate.[15] In the converse case, in which the true natural rate exceeds policymakers' estimate, the red dotted lines, the distribution of inflation is shifted to the right.

Inflation-averse rule Given the risk that misperceptions about the natural rate can have substantial effects on both the unemployment gap and inflation under the benchmark reaction function, we next consider the alternative in which policymakers put a much higher weight on the inflation gap (1½ rather than ½) while putting a much smaller weight on their estimate of the unemployment gap. The distributions of outcomes for 2019:Q4 under this reaction function are presented in the upper panels of figure 5. Misperceptions clearly have more modest consequences for the distribution of inflation (upper-right panel) than under the benchmark rule (right panel of figure 4). Intuitively, because the central bank under the inflation-averse rule lowers the policy rate aggressively when inflation declines, a natural rate of 4 percent would induce a much faster decline in the policy rate, allowing unemployment to decline more quickly, mitigating the fall in inflation. Hence, as suggested by the literature mentioned above, this alternative policy has some benefits in shifting the distribution of inflation closer to the target and of unemployment closer to the (true) natural rate in the event of shocks to the natural rate.[16]

While the inflation-averse rule is well-suited to responding to the natural rate shocks that lead to unemployment gap mismeasurement, it is less adept than the benchmark rule in stabilizing the unemployment gap—and even inflation—in response to supply and demand shocks. To establish this point, it is helpful to assess economic performance using a simple (quadratic) loss function that penalizes equally deviations of inflation from 2 percent and the unemployment rate from the natural rate of unemployment. This loss function is similar to those used in previous staff assessments of policy performance in computational exercises. The computed losses are normalized such that the median loss across draws of shocks in our benchmark case is unity; Appendix B discusses loss calculations in more detail.

In particular, table 3 indicates that the inflation-averse rule markedly increases the deviation of unemployment from its natural rate relative to the benchmark policy; for example, under the misperceptions case with the true $u^* = 4$, the volatility of the (true) unemployment gap rises from 1.04 under the balanced approach to 1.42, as seen in column B. Correspondingly, policymakers' performance based on the loss function

[15] Inflation falls immediately given the assumption of model-consistent expectations; similar results would hold under VAR-based expectations, except that the decline in inflation would be more gradual.

[16] The results for the unemployment rate are similar under VAR-based expectations (the bottom-left panel), though the disparity in inflation outcomes is barely evident by 2019 (as inflation adjusts only very slowly to unemployment gaps, and the gap is pretty small under this aggressive rule toward inflation).

would be substantially worse under this policy (with the loss rising from 1.03 to 1.20, as seen in column D). This poor performance mainly reflects two factors. First, with inflation currently below target, the inflation-averse rule prescribes additional accommodation in the near term, leading to lower unemployment, which the loss function interprets as undesirably low unemployment (relative to the true u^*). Second, responding forcefully to deviations of inflation from 2 percent increases the volatility of the unemployment gap in response to supply shocks. Intuitively, a favorable supply shock would induce a much larger decline in policy rates than under the balanced approach rule; but, with a flat Phillips curve, the larger induced fall in unemployment would do little to mitigate the downward pressure on inflation.

The highly aggressive reaction to inflation clearly performs poorly based on the stabilization metric used here. But while our loss function is a conventional one, there are other plausible ones, including those that do not interpret low unemployment to be as costly as high unemployment; for loss functions of this class, the deterioration in economic performance implied by our loss function may well overstate the losses associated with the inflation-averse strategy. That is, if the natural rate of unemployment is 4.8 percent, the assumed loss function views unemployment of 4 percent as having about the same social loss as unemployment of 5½ percent, which may not be the case.

Unemployment-averse rule Policymakers may have serious concerns that putting less weight on resource slack, even if imperfectly measured, could ultimately prove more problematic than suggested by our model results; in this regard, they may view a more aggressive easing in response to low inflation as running the risk of pushing unemployment to extremely low levels, and possibly raising other risks.

Accordingly, we also compute the distribution of outcomes in 2019:Q4 under a policy approach that responds more aggressively to unemployment gaps and less aggressively to deviations of inflation from the objective. Because this approach reacts strongly to a mismeasured unemployment gap, it performs poorly in pushing unemployment towards the true natural rate. Accordingly, the distribution of the unemployment rate is nearly invariant to the actual value of u^*—the top panel of figure 6—and the unemployment gaps are large. As a consequence, this policy rule produces a slightly wider range of inflation outcomes than the inflation-averse rule.[17]

Although this policy allows sizable and persistent unemployment gaps and inflation gaps to emerge in response to natural rate mismeasurement—this systematic target error notwithstanding—this rule still performs comparatively well in counteracting the effects of both demand and supply shocks. In this sense, it is essentially the flip-side of the

[17] A close comparison of figure 6 with figure 4 shows that the unemployment-averse rule produces more variation in inflation than does the balance-approach rule, in 2019:Q4, with a larger increase for $u^* = 5½$ than for $u^* = 4$. That said, the differences are not large, mostly because of the flatness of the Phillips curve.

inflation-averse strategy. In particular, turning to policymaker losses shown in table 3, the economic loss is less than under the inflation-averse rule. Moreover, as shown in column E, when considering especially poor outcomes under each rule—in the spirit of tail risks—the unemployment-averse rule continues to perform relatively well. Finally, column F shows the proportion of draws for which the performance of the two alternative rules is superior to that of the benchmark rule. The unemployment-averse rule improves economic performance in about 87 percent of draws whereas the inflation-averse rule produces superior performance only about 6 percent of the time.[18]

As the preceding discussion suggests, the characteristics of the baseline scenario can make a material difference to results; an outlook that does not foresee a noteworthy undershooting of the unemployment rate would lead to a somewhat different focus than what we describe here. Indeed, a table in Appendix F shows, not surprisingly, that outcomes under stochastic simulations are notably better for experiments carried out from initial conditions of steady-state equilibrium than from the September Tealbook. Similarly, these same experiments conducted from a baseline that is consistent with the September SP median outlook performs at a level somewhere in between that of the Tealbook and a steady-state baseline.[19]

<u>Risks Associated with a Steeper and Accelerationist Phillips curve</u>

Our analysis now returns to the case in which the natural rate of unemployment equals the staff baseline assumption of 4.8 percent and shifts focus to the consequences of an inflation process that resembles more closely that of the 1970s. This alternative characterization of inflation dynamics has two elements. First, the Phillips curve is steeper; specifically, we assume that the sensitivity of inflation to the unemployment gap is roughly four times the value witnessed over the twenty year period ending in the late 2000s. In addition, we assume that the coefficient on lagged inflation is near one, so that high inflation in the previous year carries over substantially to higher inflation this year.[20]

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[18] Because we consider only a small subset of uncertainties and misperceptions, we consider policies that are designed specifically for the particular misperceptions considered here to be outside the scope of the memo. Nevertheless, we did carry out some experiments using a first-difference rule parameterized as follows: $\Delta R_t = 0.6(\tilde{\pi}^c_t - \pi^*) - 4.14(u_t - u_{t-1})$ where $\tilde{\pi}^c$ is four-quarter core PCE inflation (e.g., Orphanides and Williams (2007)). We found that this rule performs about the same or slightly worse than the balanced-approach rule at the median of the distribution of outputs, regardless of whether *u** is properly perceived or not. At the 90th percentile of losses, the FD rule performed notably better than the alternative rules for the case when *u** is stochastic but known, but turned in an inferior performance when the true *u** = 5½ percent.

[19] A steady-state baseline can be thought of as the conditions the staff forecast (or an SEP forecast) would reach after all the shocks and frictions of the baseline outlook have dissipated, which means that output gaps are closed, inflation is at target and the federal funds rate is at its longer-run normal level. See Appendix F for a summary of comparisons of stochastic simulations applied to different baseline outlooks.

[20] We adopt a value slightly below one because the models we employ become unstable in the pure accelerationist case, making it problematic to generate reliable probability estimates. See Appendix C for details on the specification.

Together, these assumptions result in a Phillips curve that is closer to that over the fifteen years spanning from 1966 to 1980, when inflation rose substantially and efforts to bring inflation down starting in late 1979 brought about the recessions of the early 1980s.

Figure 7 presents three outcomes: first, for the benchmark Phillips curve under the balanced-approach rule (black lines); second, for the steeper and accelerationist Phillips curve under the same rule (blue lines); and third, for the steeper and accelerationist Phillips curve coupled with a more aggressive response to inflation (dotted red lines). In each case, we again focus on outcomes in 2019:Q4. Given that the unemployment rate currently lies below the staff estimate of its natural rate, the inflation outlook shifts up under the 1970s-style Phillips curve, as can be seen by comparing the blue and red lines to the black lines; in both cases, the distributions of outcomes for 2019:Q4 are centered close to 2½ percent. While some policymakers may view this higher level of inflation as a concern, others may focus on the fact that a steeper and accelerationist Phillips curve largely eliminates the substantial risk of low inflation seen under the benchmark Phillips curve and balanced-approach rule.

If these upside inflationary risks materialize, the higher inflation would call for a more rapid removal of monetary accommodation, thereby shifting the distribution of unemployment towards higher levels. At a horizon of several years, this shift results in a substantially higher probability of unemployment running between 4.8 percent and 6 percent in 2023:Q4 (as shown in figure 8) but relatively little change in the risk of extremely adverse unemployment outcomes. Broadly similar results are obtained under the two alternative rules considered (not shown).

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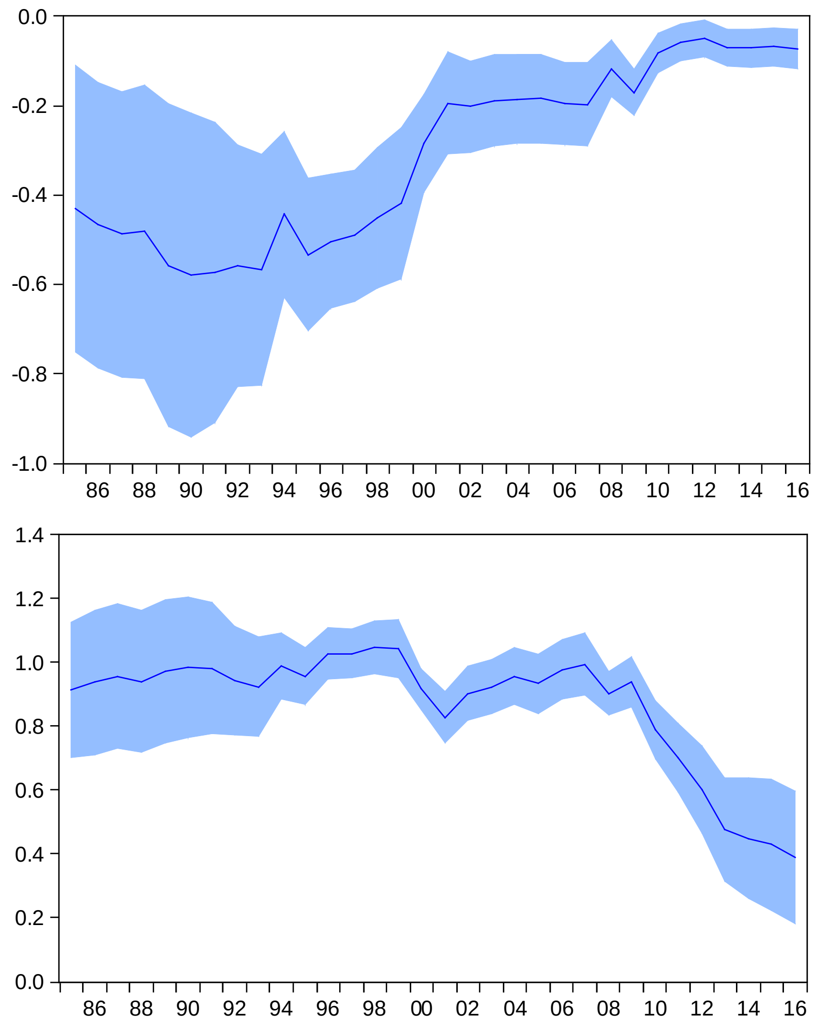
Figure 1: Evolution of the Phillips Curve Coefficients



Note: Top panel and bottom panel show estimates of coefficients **a** and **b**, respectively, from $\Delta p^{core}(t) = \boldsymbol{a}(U - U^{*}) + \boldsymbol{b}\Delta p^{core}(t-1) + e(t)$ over 20-year rolling windows using annual data.

Figure 2: Confidence Interval for Natural Rate of Unemployment

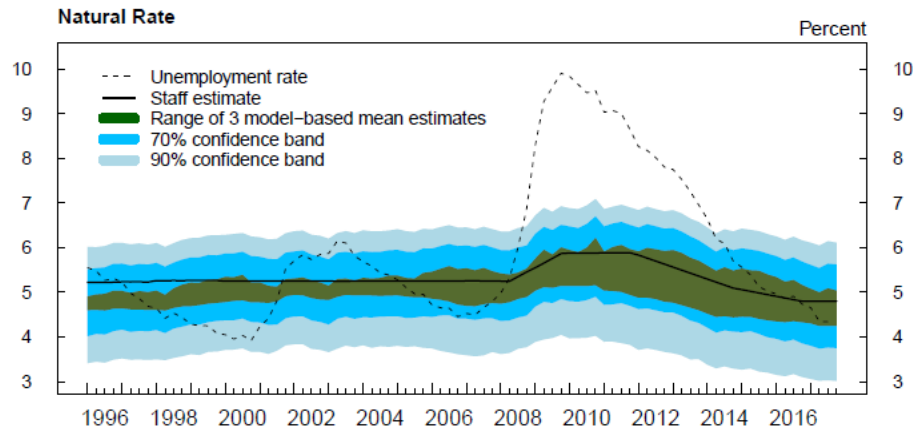
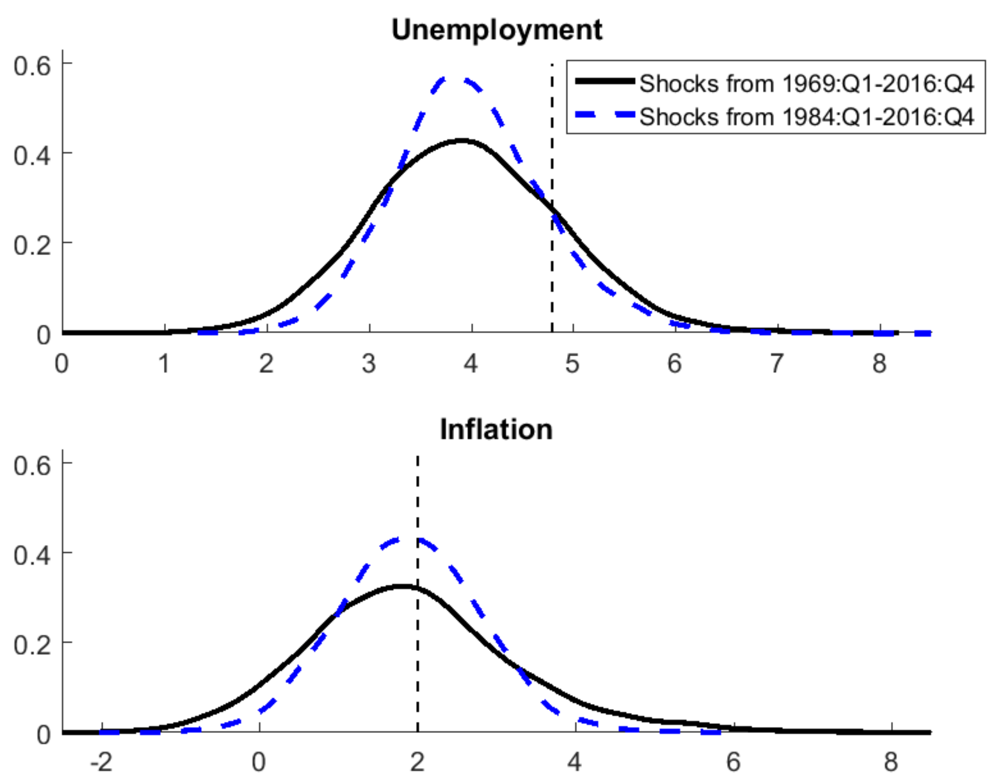
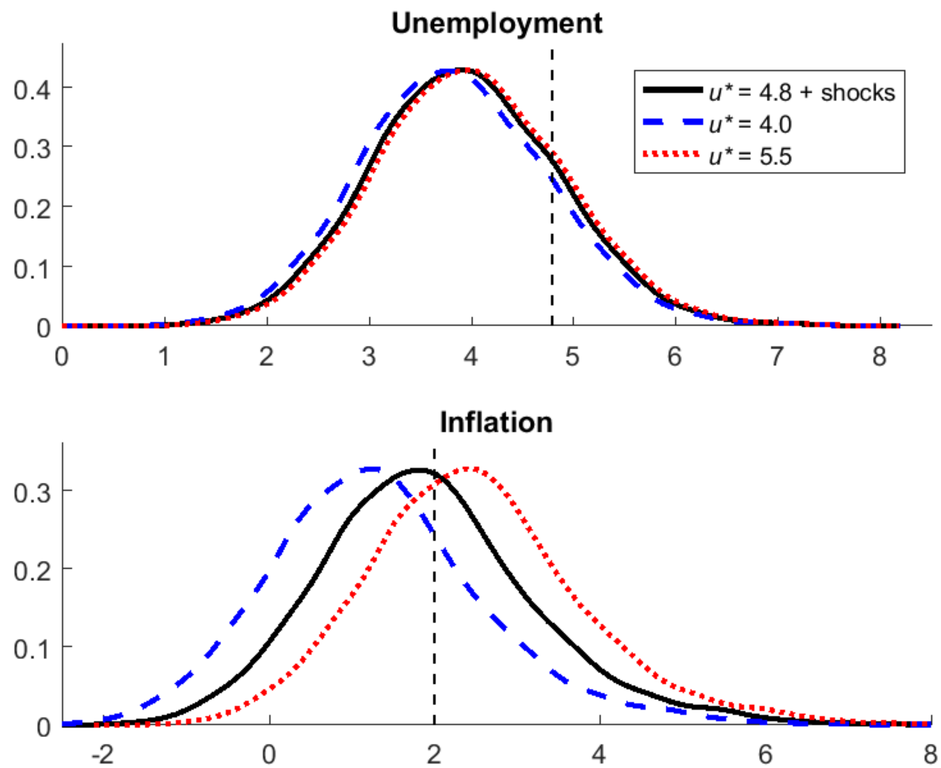


Figure 3: Distributions of Unemployment and Inflation in 2019:Q4



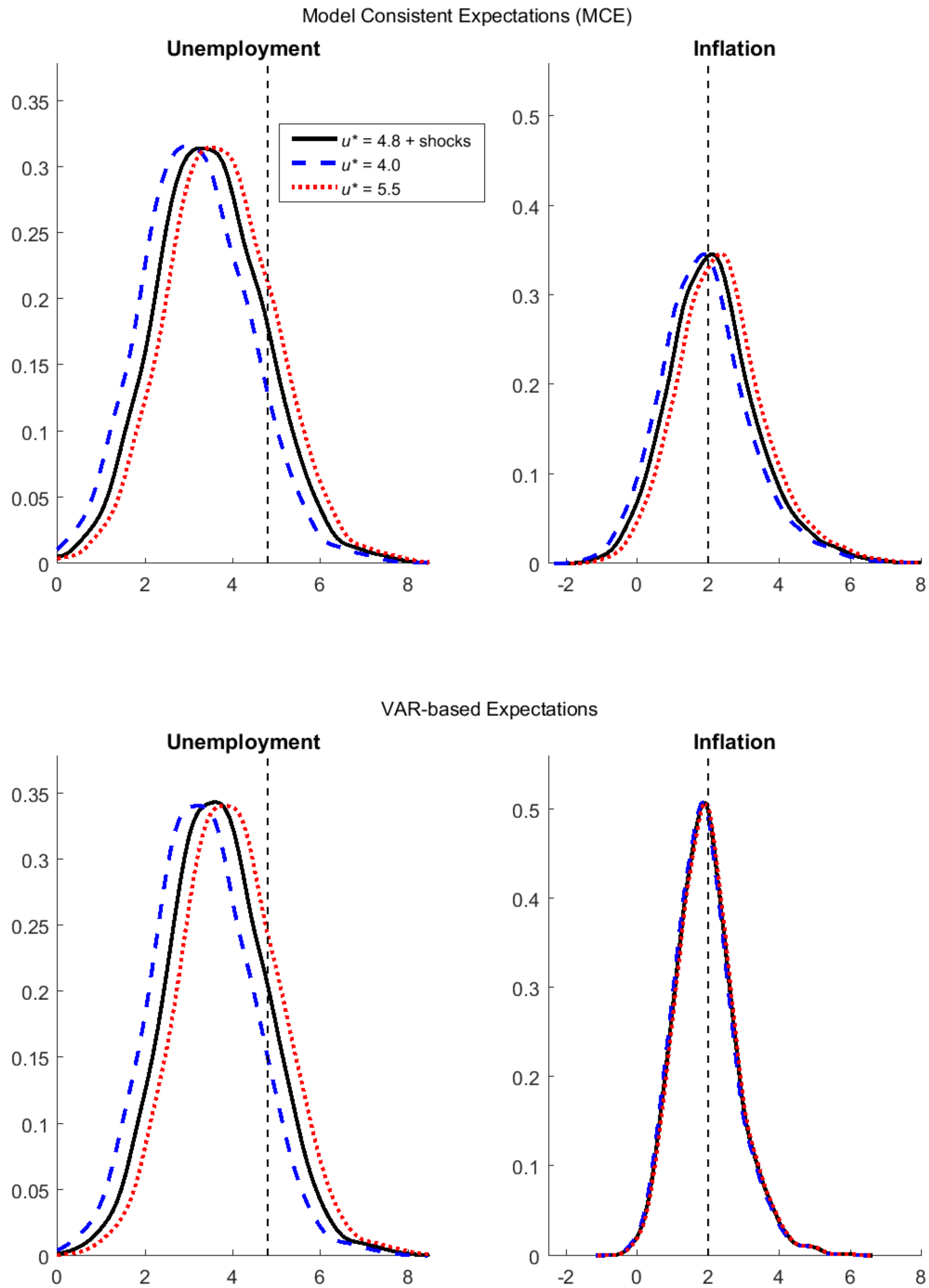
Note: The figure summarizes two sets of 5000 stochastic simulations in sFRB around the TB baseline, beginning in 2017:Q4, under model consistent expectations (MCE). The black lines show the distributions of outcomes when shocks are resampled model residuals from 1969:Q1 to 2016:Q4, while the blue lines show the distributions of outcomes when shocks are resampled residuals from 1984:Q1 to 2016:Q4.

Figure 4: Outcomes in 2019:Q4 for Alternative *u When Policymakers Believe *u** = 4.8 Percent and Follow a Balanced-Approach Rule**



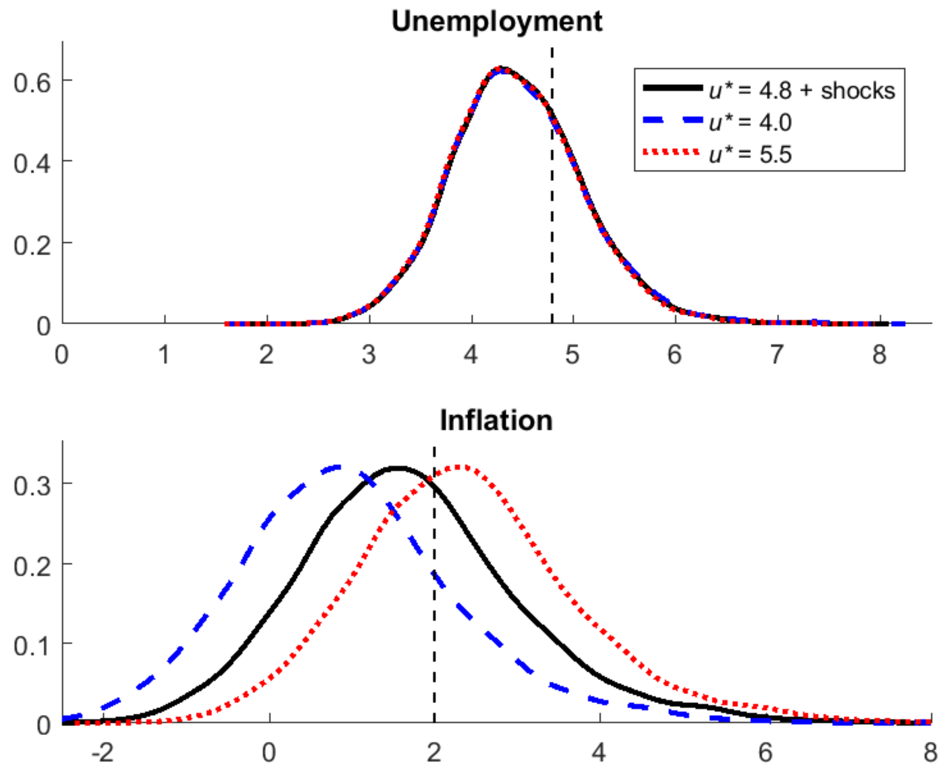
Note: The figure summarizes three sets of 5000 stochastic simulations in sFRB around three deterministic scenarios, respectively: *u** = 4.8 + shocks, an alternative where *u** = 4.0, and an alternative where *u** = 5.5. Each simulation begins in 2017:Q4 and is under model consistent expectations (MCE). Shocks are resampled model residuals from 1969:Q1 to 2016:Q4.

Figure 5: Outcomes in 2019:Q4 for Alternative *u When Policymakers Believe *u** = 4.8 Percent and Follow a Rule That Responds More Aggressively to Inflation**



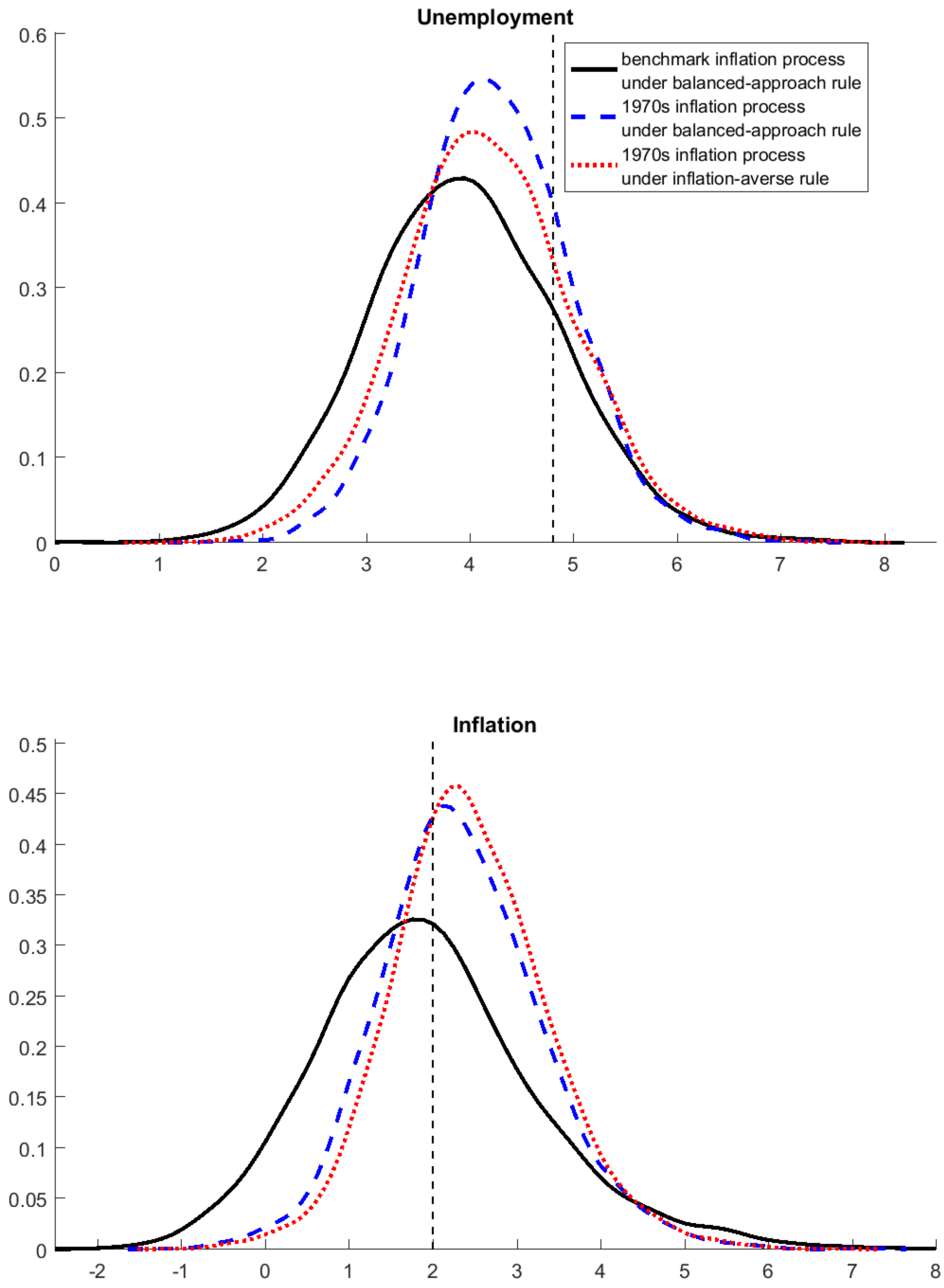
Note: Each row of the figure reflects three sets of 5000 stochastic simulations in sFRB around three deterministic scenarios, respectively: *u** = 4.8 + shocks, an alternative where *u** = 4.0, and an alternative where *u** = 5.5. Each simulation begins in 2017:Q4. The top row shows the distributions of outcomes under model consistent expectations (MCE), while the bottom row shows the distributions of outcomes under VAR-based expectations. Shocks are resampled model residuals from 1969:Q1 to 2016:Q4.

Figure 6: Outcomes for Alternative *u When Policymakers Believe *u** = 4.8 Percent and Follow a Rule That Responds More Aggressively to Unemployment in 2019:Q4**



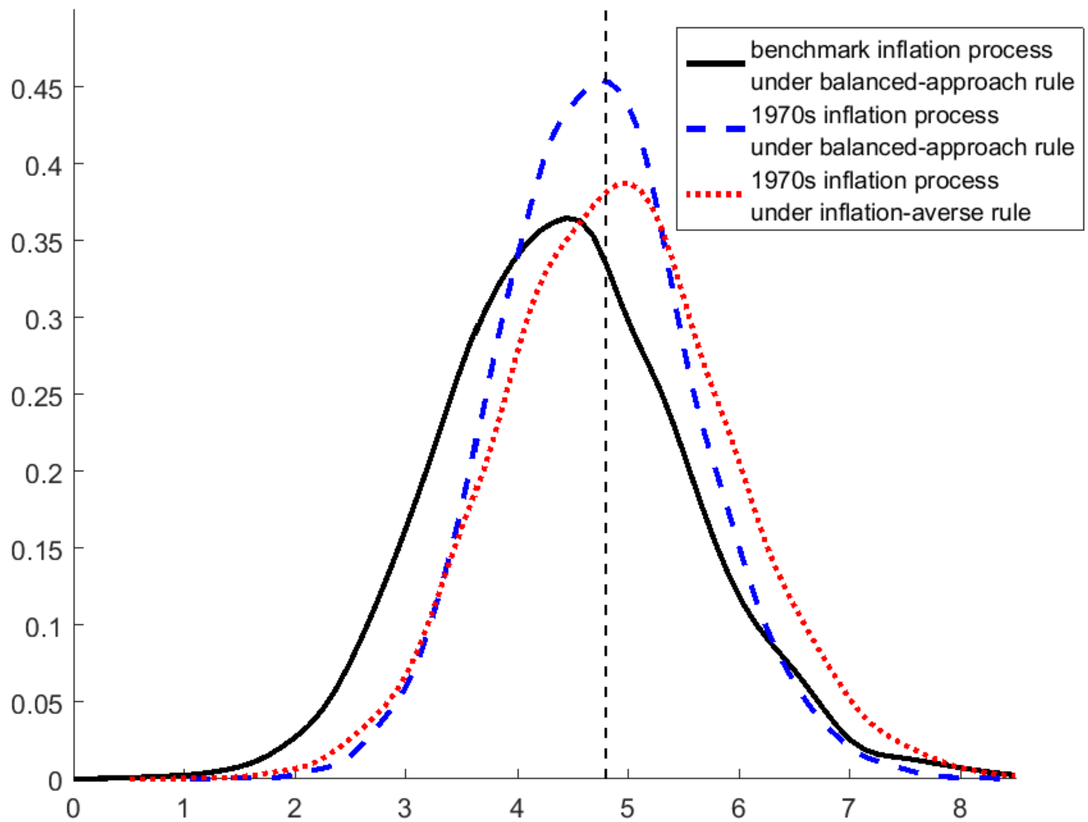
Note: The figure shows three sets of 5000 stochastic simulations in sFRB around three deterministic scenarios, respectively: u^* = 4.8 + shocks, an alternative where u^* = 4.0, and an alternative where u^* = 5.5. Each simulation begins in 2017:Q4 and is under model consistent expectations (MCE). Shocks are resampled model residuals from 1969:Q1 to 2016:Q4.

Figure 7: Outcomes for Steeper and Near Accelerationist Phillips Curve Under Alternative Policy Approaches in 2019:Q4



Note: The figure displays results from three sets of 5000 stochastic simulations in sFRB for the following cases, respectively: the benchmark model under the balanced-approach rule, an alternative model with a steeper and near accelerationist Phillips curve under the balanced-approach rule, and the alternative model with its modified Phillips curve under an inflation-averse rule. Each simulation begins in 2017:Q4 and is under model consistent expectations (MCE). Shocks are resampled model residuals from 1969:Q1 to 2016:Q4.

Figure 8: Unemployment Distributions over Longer Run (2023:Q4) for Steeper and Near Accelerationist Phillips Curve



Note: The figure shows three sets of 5000 stochastic simulations in sFRB for the following cases, respectively: the benchmark model under the balanced-approach rule, an alternative model with a steeper and near accelerationist Phillips curve under the balanced-approach rule, and the alternative model with its modified Phillips curve under an inflation-averse rule. Each simulation begins in 2017:Q4 and is under model consistent expectations (MCE). Shocks are resampled model residuals from 1969:Q1 to 2016:Q4.

Table 1. Base Case Assumptions and Alternatives
(stochastic simulations; sFRB model)

	Model Feature	***Benchmark***	***Alternative Assumptions***
1	**Expectations**	MCE in asset pricing wages & price determination VAR-based for expenditures	VAR-based expectations for all agents
2	**Monetary policy**	Balanced approach (Taylor (1999))	Inflation-averse rule Unemployment-averse rule Inertial Taylor (1999)
3	**Shocks**	1969:Q1 to 2016:Q4 Includes the Great Inflation period	1984:Q4 to 2016:Q4 Great moderation and GFC
4	**Baseline forecast**	September 2017 Tealbook	September 2017 SEP (median) Steady state
5	**Model structure**	Known	Selected misperceived features
6	**Simulation period**	2017:Q4 to 2025:Q1 (30 quarters of shocked dates)	

Table 2. Macroeconomic Performance in 2019
Under Monetary Policy Strategies
(policymaker believes *u** = 4.8 + shocks)

	[A]	[B]	[C]	[D]
	u < 3.5% and π < 1.75%		u < 3.5% and π > 2.5%	
True *u** Process:	Probability	Q4 FFR	Probability	Q4 FFR
***u** = 4.8 + shocks**				
1 Balanced approach	17.46	5.19	4.62	8.97
2 Inflation averse	23.82	2.02	10.88	7.95
3 Unemployment averse	2.68	11.83	0.28	14.73
***u** = 4.0 (fixed)**				
4 Balanced approach	25.78	4.97	2.70	9.16
5 Inflation averse	33.48	2.16	10.86	8.17
6 Unemployment averse	3.20	11.68	0.14	14.02
***u** = 5.5 (fixed)**				
7 Balanced approach	10.42	5.43	8.14	8.67
8 Inflation averse	16.84	2.00	11.18	7.76
9 Unemployment averse	1.84	12.29	0.76	15.24

Note**:** Each entry reports the probability of an event in which the criteria are based on the average level of the unemployment rate and of the four-quarter core PCE inflation rate (π) over the year 2019. The federal funds rate reported is the mean 2019:Q4 funds rate in simulations satisfying the respective criteria.

Table 3. Policymaker Loss Under Alternative Monetary Policy Strategies
For Selected (Mis)perceptions of *u**

(policymaker believes *u** = 4.8 + shocks)

	[A]	[B]	[C]	[D]	[E]	[F]
	Standard Deviation		Normalized Losses Percentiles			Welfare Improvement Share
True *u** process:	π	*ugap*	10	50	90	
***u** = 4.8 + shocks**						
1 Balanced approach	1.33	0.98	0.52	1.00	1.83	0.00
2 Inflation averse	1.26	1.38	0.68	1.35	2.60	6.18
3 Unemployment averse	1.36	0.72	0.40	0.80	1.56	86.86
***u** = 4.0 (fixed)**						
4 Balanced approach	1.33	1.04	0.53	1.03	1.93	47.54
5 Inflation averse	1.26	1.42	0.58	1.20	2.34	16.70
6 Unemployment averse	1.36	0.84	0.58	1.16	2.30	38.32
***u** = 5.5 (fixed)**						
7 Balanced approach	1.36	1.00	0.83	1.45	2.45	6.16
8 Inflation averse	1.28	1.41	0.87	1.66	3.05	2.60
9 Unemployment averse	1.38	0.72	0.65	1.09	1.96	36.02

Note: Each entry corresponds to a set of 5000 stochastic simulations for the stated assumptions about *u** and the policy rule. The individual simulations begin in 2017:Q4 and go through 2025:Q1, and are under model consistent expectations (MCE). Columns A and B show the standard deviation of the four-quarter core PCE inflation rate (π) and unemployment gap, respectively. Columns C, D, and E show the 10th, 50th (median), and 90th percentiles of a loss function which equally penalizes deviations in headline inflation from 2 percent and unemployment from the stated *u** assumption. Reported losses are cumulative and discounted, and have been normalized by the median loss of the row 1 case. Column F reports the percent of 5000 individual simulations in which the losses are strictly lower than in the corresponding 5000 individual simulations for the row 1 case. The corresponding simulations are those in which identical sets of shocks are imposed, enabling a simulation-to-simulation lineup across different assumptions about *u** and the policy rule.

Appendix A. Policy Rules

The policy rules used in this memo differ slightly from those that appear regularly in the Monetary Policy Strategies section of Tealbook. First, rules that are usually written in terms of output gaps are recast in unemployment gap terms, rescaling the rule response coefficients accordingly, using Okun's Law. Second, rather than using an exogenous intercept term which represents an intermediate-run *r**, we allow the intercept term to drift with real interest rates in a manner that is standard for the FRB/US model, as it is for the sFRB model. Third and finally, we consider alternative parameterizations, described as inflation-averse and unemployment-averse specifications.

The table below shows the specifications and their parameterizations. In this table, R_t denotes the nominal federal funds rate prescribed by a strategy for quarter *t;* rr_t is the real rate of interest; rr_t^{LR} is a medium-term concept of the equilibrium real interest rate; $ugap_t = u_t - u_t^*$ is the unemployment gap, and π_t is four-quarter core PCE

The Rules

Balanced approach rule	$R_t = r_t^{LR} + \pi_t + 0.50(\pi_t - \pi^{LR}) - 1.85ugap_t$
Inflation-averse rule	$R_t = r_t^{LR} + \pi_t + 1.50(\pi_t - \pi^{LR}) - 0.62ugap_t$
Unemployment-averse rule	$R_t = r_t^{LR} + \pi_t + 0.17(\pi_t - \pi^{LR}) - 5.56ugap_t$
Inertial rules	$R_t = 0.85R_{t-1} + 0.15(rule_t)$
r^{LR} updating equation	$r_t^{LR} = r_{t-1}^{LR} - 0.05(r_{t-1}^{LR} - rr_{t-1})$

Appendix B. The Loss Function

Economic performance in the stochastic simulations is assessed using a standard quadratic loss function in two arguments: the deviation of the unemployment rate from the natural rate of unemployment, $ugap_t$, and the deviation of the four-quarter headline PCE inflation rate, π_t^{PCE}, from the target rate of 2 percent. In the following equation, the resulting loss function embeds the assumption that policymakers discount the future using a quarterly discount factor, $\beta = 0.99$:

$$\boldsymbol{L_t} = \sum_{\boldsymbol{\tau=0}}^{T} \boldsymbol{\beta^\tau} \{\lambda_\pi (\pi_{t+\tau}^{PCE} - \pi^{LR})^{\mathbf{2}} + \lambda_u (ugap_{t+\tau})^{\mathbf{2}}\}.$$

with $\lambda_\pi = \lambda_u = 1$ with $t = 2017:Q4$ and $\tau = 29$ (quarters). This loss function, which might be called the "mandate loss function" in reflection of the fact that its two arguments span the Committee's typical conceptualization of its mandate, differs from the loss function that has been used most frequently in the exhibit "Optimal Control Simulations under Commitment" in the Monetary Policy Strategies section of the Tealbook in that it omits a term penalizing the change in the federal funds rate; that is: $(R_{\boldsymbol{t+\tau}} - R_{\boldsymbol{t+\tau-1}})^{\mathbf{2}}$. This instrument smoothing term is used in optimal control simulations because in its absence the prescribed optimal control policies would feature counterfactually large once-off jumps in the federal funds rate.

Appendix C. The 1970s-Style Phillips Curve

The experiments in section 3 that center on a "1970s-style" Phillips curve are carried out by replacing the sFRB model's equation for core PCE inflation with a simpler near-accelerationist variant. That equation is shown below, along with the standard sFRB equation for long-term inflation expectations:

$$\pi_t^c = \alpha \sum_{i=1}^{4} \pi_{t-i}^c / 4 + (1-\alpha)\pi_{t-1}^{LT} + \kappa(u_t - u_t^*) + \phi(rw_t - rw_t^*) \qquad \text{(C1)}$$

$$\pi_t^{LT} = 0.9\pi_{t-1}^{LT} + 0.05\pi_{t-1}^c + 0.05\pi_{t-1}^* \qquad \text{(C2)}$$

where π^c is core PCE inflation, π^{LT} is long-term inflation expectations, $u - u^*$ is the unemployment gap, and rw is the real wage rate. In the special case where $\alpha = 1$, long-term inflation expectations falls out of the equation and the Phillips curve takes on the "accelerationist" form, which means that temporary shocks have permanent effects on inflation, all else equal. With the parameterization of π^{LR}, and a low value for α , expectations can be said to be "well anchored."

A circa 2003 specification of this simple reduced-form Phillips curve would have $\alpha = 0.6; \kappa = -0.10; \phi = 0.863$. The 1970s-style Phillips curve uses a steep and near-accelerationist specification: $\alpha = 0.96; \kappa = -0.40; \phi = 0.863$. Table C1 shows some performance statistics for the model economy with the steeper, near-accelerationist Phillips curve, with some comparisons with alternatives. As can be seen, the largest difference the 1970s-style Phillips curve makes is a sizable reduction in the probability that both inflation and unemployment will be simultaneously low (column A).

Table C1. Macroeconomic Performance in 2019
Under Steeper, Near-Accelerationist Inflation Process

	(policymaker believes *u** = 4.8 + shocks)			
	[A]	[B]	[C]	[D]
	u < 3.5% and π < 1.75%		u < 3.5% and π > 2.5%	
True *u** Process:	Probability	Q4 FFR	Probability	Q4 FFR
u** = 4.8 + shocks				
1. Base π process, balanced approach	17.46	5.19	4.62	8.97
2. 1970s π process, balanced approach	3.08	5.45	4.58	8.47
3. 1970s π process, inflation averse	4.62	2.36	7.34	7.52

Note**:** Each entry reports the probability of an event in which the criteria are based on the average level of the unemployment rate and of the four-quarter core PCE inflation rate (π) over the year 2019. The federal funds rate reported is the mean 2019:Q4 funds rate in simulations satisfying the respective criteria.

Appendix D. More Results on Natural Rate Misperceptions

The main text features results for experiments involving misperceptions of the natural rate of unemployment in which the true natural rate is either fixed at 4 percent or 5½ percent, as applicable, but policymakers perceive that *u** drifts over time according to a process: $u_t^* = 0.98u_{t-1}^* + \sigma v_t \;\; v_t \sim N(0,1)$ where $\sigma = 0.04$ sigma = 0.04. Table D1 below shows results for the opposite case where the true data generating process is that *u** begins at 4.8 percent and is subject to shocks as described immediately above, but policymakers mistakenly take *u** to be constant at a value of either 4 or 5½ percent, as applicable.

Table D1. Policymaker Loss Under Alternative (Mis)perceptions of *u with Beliefs Eu***

(various policymaker beliefs for *u**; true *u** = 4.8 + shocks)

	[A]	[B]	[C]	[D]	[E]	[F]
	Standard Deviation		Normalized Losses Percentiles			Welfare Improvement Share
Policymaker beliefs Eu*:	π	*ugap*	10	50	90	
Eu* = 4.8 + shocks						
1 Balanced approach	1.33	0.98	0.52	1.00	1.83	0.00
2 Inflation averse	1.26	1.38	0.68	1.35	2.60	6.18
3 Unemployment averse	1.36	0.72	0.40	0.80	1.56	86.86
Eu* = 4.0 (fixed)						
4 Balanced approach	1.37	0.96	0.78	1.41	2.51	9.14
5 Inflation averse	1.28	1.38	0.75	1.50	2.84	4.94
6 Unemployment averse	1.41	0.68	0.63	1.12	2.14	33.82
Eu* = 5.5 (fixed)						
7 Balanced approach	1.34	1.03	0.54	1.04	1.89	47.76
8 Inflation averse	1.26	1.38	0.63	1.26	2.43	9.54
9 Unemployment averse	1.37	0.84	0.58	1.15	2.17	38.86

Note: Each entry corresponds to a set of 5000 stochastic simulations for the stated assumptions about the policy rule and the policymaker's beliefs Eu* about the true *u**. These beliefs directly affect the perceived deviations from full employment in the respective policy rules. The individual simulations begin in 2017:Q4 and go through 2025:Q1, and are under model consistent expectations (MCE). Columns A and B show the standard deviation of the four-quarter core PCE inflation rate (π) and unemployment gap, respectively. Columns C, D, and E show the 10th, 50th (median), and 90th percentiles of a loss function which equally penalizes deviations in headline inflation from 2 percent and unemployment from *u** = 4.8 + shocks. Reported losses are cumulative and discounted, and have been normalized by the median loss of the row 1 case. Column F reports the percent of 5000 individual simulations in which the losses are strictly lower than in the corresponding 5000 individual simulations for the row 1 case. The corresponding simulations are those in which identical sets of shocks are imposed, enabling a simulation-to-simulation lineup across different assumptions about Eu* and the policy rule.

Appendix E : Stochastic Shock Sets

We noted in the main text that our benchmark stochastic shock set was defined over the lengthy history from 1969:Q1 to 2016:Q4. As we explained, an alternative shock set omits the high-volatility shocks of the pre-Great-Moderation period, by using shocks from 1984:Q1 to 2016:Q4.

In applying these stochastic shocks, we applied a standard bootstrap which means we randomly selected (with replacement) the date of a vector of shocks and then applied those shocks as a group to the simulation. Bootstrapping stochastic shocks preserves the cross-correlation in model residuals at each point in time. Another issue in bootstrapping concerns the autocorrelation of shocks. In the sFRB model, like its larger parent FRB/US, shocks are uncorrelated on average; however recessions tend to feature some bunching of shocks. One way to capture that feature of the data is to use a Markov-switching bootstrap. The MS bootstrap features first randomizing over historical periods, namely, recessions or not recessions, with historically determined probabilities, and then selecting shocks from the appropriate bin of dates. A method that accentuates the occurrence of sequences of bad shocks takes this process one step further by inserting another branch of the algorithm by considering once the recession branch has been chosen, then choosing which recession in history and feeding in the entire recession sequence of shocks.

The table below shows some descriptive statistics for three of the possible shock set/bootstrapping combinations.

Table E1. Summary of outcomes in stochastic simulation, for date 2019:Q4
(sFRB model, alternative shock sets and bootstrapping methods)

	$u > 7\%$	Value of u at percentile: 90th	99th	% draws with ELB+	$\pi > 2.5^{*}$ (4Q Avg)
benchmark	0.3	5.5	6.3	3.8	27.6
1984-2016 shocks	0.1	5.3	5.9	2.8	21.3
MS bootstrap**	4.9	6.9	8.5	5.6	24.4

* Percentage of draws in which four-quarter rate of core PCE inflation average more than 2½ percent in the four quarters ending 2019:Q4. MS bootstrap with full recession shocks used; drawn from 1969:Q1-2016:Q4. ** Markov Switching bootstrap with full recessions of shocks randomly chosen; shock set 1969:Q4-2016:Q4. + Draws in which the funds rate reaches 0.125 percent at least once.

Appendix F : Stochastic Simulations Results with Alternative Baselines

To construct an SEP-consistent baseline for the sFRB/US model, we interpolated the annual SEP information to a quarterly frequency and assumed that, beyond 2020 (the last year reported in the September 2017 SEP), the economy transitions to its long-run values in a smooth and monotonic way. This SEP-consistent baseline projection is close to the projection included in the August 8, 2017 public release of the FRB/US model available on the Federal Reserve's website (https://www.federalreserve.gov/econresdata/frbus/us-models-package.htm). Additional details can also be found in the MPS Section included in the March 2017 Tealbook A.

Table F1. Policymaker Loss Under Alternative Baselines
(balanced approach rule)

	[A]	[B]	[C]	[D]	[E]	[F]
	Standard Deviation		Normalized Losses Percentiles			Welfare Improvement Share
Alternative Baseline	π	*ugap*	10	50	90	
1 September TB	1.33	0.98	0.52	1.00	1.83	0
2 Steady state	1.33	1.01	0.42	0.87	1.74	71.0
3 SEP-consistent	1.34	1.02	0.45	0.91	1.75	74.9

Note: Each entry corresponds to a set of 5000 stochastic simulations around the stated baseline under the balanced-approach rule. The individual simulations begin in 2017:Q4 and go through 2025:Q1, and are under model consistent expectations (MCE). Columns A and B show the standard deviation of the four-quarter core PCE inflation rate (π) and unemployment gap, respectively. Columns C, D, and E show the 10th, 50th (median), and 90th percentiles of a loss function which equally penalizes deviations in headline inflation from 2 percent and unemployment from u^* (4.8 + shocks in the cases of the TB and steady-state baselines, and a path converging to 4.6 along with shocks in the case of the SEP-consistent baseline). Reported losses are cumulative and discounted, and have been normalized by the median loss of the row 1 case. Column F reports the percent of 5000 individual simulations in which the losses are strictly lower than in the corresponding 5000 individual simulations for the row 1 case. The corresponding simulations are those in which identical sets of shocks are imposed, enabling a simulation-to-simulation lineup across different baselines.