

**Finance and Economics Discussion Series  
Divisions of Research & Statistics and Monetary Affairs  
Federal Reserve Board, Washington, D.C.**

**Some Implications of Uncertainty and Misperception for  
Monetary Policy**

**Christopher Erceg, James Hebden, Michael Kiley, David  
López-Salido, and Robert Tetlow**

**2018-059**

Please cite this paper as:

Erceg, Christopher, James Hebden, Michael Kiley, David López-Salido, and Robert Tetlow (2018). "Some Implications of Uncertainty and Misperception for Monetary Policy," Finance and Economics Discussion Series 2018-059. Washington: Board of Governors of the Federal Reserve System, <https://doi.org/10.17016/FEDS.2018.059>.

NOTE: Staff working papers in the Finance and Economics Discussion Series (FEDS) are preliminary materials circulated to stimulate discussion and critical comment. The analysis and conclusions set forth are those of the authors and do not indicate concurrence by other members of the research staff or the Board of Governors. References in publications to the Finance and Economics Discussion Series (other than acknowledgement) should be cleared with the author(s) to protect the tentative character of these papers.

# Some Implications of Uncertainty and Misperception for Monetary Policy

CHRISTOPHER ERCEG, JAMES HEBDEN, MICHAEL KILEY, DAVID LÓPEZ-SALIDO AND ROBERT TETLOW<sup>1</sup>

*When choosing a strategy for monetary policy, policymakers must grapple with mismeasurement of labor market slack, and of the responsiveness of price inflation to that slack. Using stochastic simulations of a small-scale version of the Federal Reserve Board's principal New Keynesian macroeconomic model, we evaluate representative rule-based policy strategies, paying particular attention to how those strategies interact with initial conditions in the U.S. as they are seen today and with the current outlook. To do this, we construct a current relevant baseline forecast, one that is constructed loosely based on a recent FOMC forecast, and conduct our experiments around that baseline. We find the initial conditions and forecast that policymakers face affect decisions in a material way. The standard advice from the literature, that in the presence of mismeasurement of resource slack policymakers should substantially reduce the weight attached to those measures in setting the policy rate, and substitute toward a more forceful response to inflation, is overstated. We find that a notable response to the unemployment gap is typically beneficial, even if that gap is mismeasured. Even when the dynamics of inflation are governed by a 1970s-style Phillips curve, meaningful response to resource utilization is likely to turn out to be worthwhile, particularly in environments where resource utilization is thought to be tight to begin with and inflation is close to its target level.*

August 9, 2018

JEL CLASSIFICATION: E31, E32, E52, C63

KEYWORDS: monetary policy, uncertainty, stochastic simulation, policy analysis

---

<sup>1</sup> Board of Governors of the Federal Reserve System, 20<sup>th</sup> and Constitution Avenue, NW, Washington, DC 20551. Emails: [christopher.erceg@frb.gov](mailto:christopher.erceg@frb.gov); [james.s.hebden@frb.gov](mailto:james.s.hebden@frb.gov); [michael.t.kiley@frb.gov](mailto:michael.t.kiley@frb.gov); [david.lopez-salido@frb.gov](mailto:david.lopez-salido@frb.gov) or [robert.j.tetlow@frb.gov](mailto:robert.j.tetlow@frb.gov). We thank James Clouse, Thomas Laubach, David Lebow, Brian Madigan, Steve Meyer, Trevor Reeve, David Reifschneider, David Wilcox, and Beth Anne Wilson for helpful comments and suggestions. 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. Finally, we thank our colleague Hess Chung for making available to us his excellent code for simulating linear models with occasionally binding effective lower bound constraints. All remaining errors are ours. The views in this document do not necessarily reflect those of the Federal Reserve System, its Board of Governors, or staff.

## 1. Introduction

Although the unemployment rate in the United States has run persistently below conventional estimates of the natural rate of unemployment ( $u^*$ ) for some time, inflation has been subdued, and only recently nudged up to the Federal Reserve's mandated objective of 2 percent. These developments have heightened concerns about the reliability of estimates of the natural rate of unemployment and about the strength of the relationship between labor market slack and inflation—or more colloquially, the slope of the Phillips curve.<sup>2</sup>

Uncertainty about the natural rate of unemployment and the Phillips curve slope has important implications for monetary policy strategy. On the former, an influential research (e.g., Orphanides, 2003) has argued that the high inflation of the 1970s was fueled by the Fed's persistent underestimation of the natural rate of unemployment, with the implication that the Fed should largely eschew conditioning policy on measures of aggregate demand and mainly aim to stabilize inflation. However, other authors have counseled strongly against a singular focus on inflation (e.g., Svensson 1997, 2017; Blanchard *et al.*, 2010). According to this view, monetary policy faces important tradeoffs—including the stickiness of wages in adjusting to supply shocks—that make it desirable to respond to not just inflation but resource slack as well, despite acknowledged shortcomings in the measurement of the latter.

With regard to the Phillips curve, the apparently low sensitivity of inflation to measures of resource utilization in recent decades would, all else equal, provide a rationale for allowing unemployment to undershoot its estimated natural rate in order to boost inflation to 2 percent (see, e.g., Blanchard, 2016). Accordingly, the Federal Reserve, as well as other central banks, including the Bank of Japan and Bank of England, have allowed unemployment to decline below typical estimates of the natural rate. But an open question facing policymakers is whether the persistent undershooting of the natural rate may increase the risk of subsequent adverse outcomes such as unexpectedly higher inflation or substantial overheating in financial markets.

In this paper, we begin by briefly reviewing evidence on the precision of estimates of the natural rate of unemployment and on the evolution of parameters of the Phillips curve determining the relationship between resource utilization and inflation. In light of this evidence, we then use a small-scale 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

---

<sup>2</sup> Memos on structural unemployment prepared by staff economists of the Federal Reserve System were delivered to the Federal Open Market Committee on January 19, 2011, in advance of a discussion on that topic at their January 2011 meeting. <https://www.federalreserve.gov/monetarypolicy/fomc-memos.htm#m2011>. Powell (2018) remarks on the difficulties associated with inferring the natural rate of unemployment from the data.

the Taylor (1999) rule, which responds fairly strongly to deviations of both inflation and unemployment from objectives, with 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 outcomes for each rule reflect the 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.

In contrast with standard academic studies of the implications of uncertainty for policy, the analysis here is rooted in economic and monetary conditions as they are today. A major theme is that the particular risks that should occupy policymakers' attention, as well as the proper response to those risks, are grounded in the conditions that policymakers face. Under its governing legislation, the Federal Reserve pursues a dual mandate of maximum employment and price stability; simple facts such as how far mandate variables are from their desired levels are critical for determining the costs and benefits of alternative policy responses in the presence of uncertainty. As a consequence, standard prescriptions from the literature, be they certainty equivalence, or the attenuation of policy in response to uncertainty, need not apply in all cases.<sup>3</sup>

Our analysis highlights some shortcomings of rules that put a sizable weight on stabilizing the unemployment gap when the policymaker is uncertain about  $u^*$ . As one would expect, a strategy of responding aggressively to the policymaker's estimate of the unemployment gap tends to keep the distribution of unemployment clustered around the policymaker's estimate of  $u^*$ . But if the policymaker's estimate of  $u^*$  differs from its true value, the resulting persistent gap between unemployment and true  $u^*$  exerts protracted 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 utilization and a larger weight on stabilizing inflation when there is substantial uncertainty about  $u^*$ .

However, the notion that policymakers should downweight the unemployment gap and compensate, in some sense, by responding more aggressively to inflation is substantially weakened in the empirically-relevant case in which the Phillips curve is relatively flat and inflation is buffeted by sizable "supply," or cost-push, shocks. Under these

---

<sup>3</sup> In fact, the homilies never applied generally. In linear models with normally distributed random errors, it is well known that policymakers with quadratic preferences should adopt a *certainty equivalent* policy; that is, choose policies as if there were no errors at all. See, e.g., Ljungqvist and Sargent (2018) for a textbook treatment. A separate strand of literature shows that often the best response to measurement error, for example, is to attenuate the strength of policy response, relative to the full-information case. This idea is often associated with Brainard (1967) and has been promoted by Blinder (1998) among others, including Rudebusch (2001). Another literature deals with uncertainty in worlds where policymakers are either unable or unwilling to attach probability distributions to outcomes, and usually, but not always, results in policy responses that are stronger than certainty equivalence; see, e.g., Hansen and Sargent (2010). See Meyer *et al.* (2001) and Swanson (2006) for approaches that are in the same spirit as this paper.

conditions, reacting strongly to inflation tends to induce a high degree of volatility in the (true) unemployment gap. Moreover, in the current environment, with unemployment already quite low, an aggressive response to inflation when it is below target could increase the likelihood that the unemployment rate falls to historically low levels with attendant risks to financial stability and more generally to the sustainability of macroeconomic outcomes. Overall, our results show that retaining a significant response to the unemployment gap—even if mismeasured—tends to perform better in achieving dual mandate goals than does shifting toward aggressive stabilization of inflation. Thus, our results suggest some caution is warranted in pursuing strategies that focus heavily on stabilizing inflation and that downweight substantially 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, two years ahead, would be considerably higher if the Phillips curve were to revert to a form similar to that seen in the 1970s, meaning that inflation responds more substantially and persistently to fluctuations in 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 target. Even so, we find little risk of an extreme rise in the unemployment rate. The lesson we take from this part 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—provided that monetary policy is conducted with the achievement of price stability in mind.

The remainder of the paper proceeds as follows. In the second section we first briefly review evidence on changes in the Phillips curve and the degree of uncertainty regarding the measurement of resource utilization. We follow with an examination of the implications of uncertainty along these dimensions for the design of monetary policy strategy that have been emphasized in the literature. Together, these factors motivate the simulation analysis that follows in the third section. A fourth section sums up and concludes.

## 2. Background on Risks and Their Implications for Policy Strategy

### The 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.<sup>4</sup>

While these shifts are apparent from the data, their causes are less well understood. The anchoring of inflation expectations plausibly reflects the relatively low and stable inflation seen since the mid-1980s, which in turn arguably owes to central bankers’ focus on controlling inflation over this period. The reduction in the sensitivity of inflation to resource utilization may reflect a lower frequency of price changes in an environment of low and stable inflation, but this remains an open question. 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 a near-accelerationist form.<sup>5</sup>

### Uncertainty about resource utilization

Research has emphasized the challenges associated with measuring resource utilization. These challenges arise both from imprecision associated with estimating an unobserved concept such as the natural rate of unemployment, and from differences in the concepts used by various researchers.<sup>6</sup> Indeed, economists have attributed the rise of inflation in

---

<sup>4</sup> 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). Note that lagged inflation is frequently taken as a proxy for long-term inflation expectations in regression models. Clark and Doh (2014) and Garnier, Mertens, and Nelson (2015) tackle the challenge of inferring long-term inflation expectations from the data.

<sup>5</sup> A typical empirical Phillips curve has inflation determined by expected inflation (with a coefficient of unity), some measure of resource utilization such as an unemployment gap, and possibly other variables. What makes the model accelerationist is that a distributed lag of past inflation is used to proxy for expected inflation, with the sum of the coefficients on these lags restricted to equal unity. This has the property that if policymakers were to attempt to maintain the unemployment rate permanently below its natural rate, an ever rising inflation rate would have to be tolerated. For our purposes, the important point is that shocks to inflation, from whatever source, are highly persistent in their effects because the accelerationist property means that inflation expectations are not “well anchored.”

<sup>6</sup> Staiger, Stock, and Watson (1997) highlight the wide confidence intervals associated with estimation of  $u^*$ . Fleischman and Roberts (2011) review more recent research and provide an updated analysis of similar

the 1970s in part to policymakers' errors, including underestimation of the natural rate of unemployment.<sup>7</sup> Despite much research, the confidence bands around estimates of  $u^*$ —the natural rate of unemployment—are generally estimated to be quite wide (see, e.g., Fleishman and Roberts (2011) and references therein).

### Implications for policy strategy

The implications for monetary policy strategy of uncertainty regarding resource utilization and the nature of the Phillips curve have been a focus of research for decades. For our analysis, we see two lessons from the literature as central. The first lesson is that misperceptions of economic slack lead 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 measures of slack, and instead focus more on movements in inflation.<sup>8</sup>

The second lesson is that the relationship between economic slack and inflation appears to have weakened significantly; that is, the Phillips curve has become flatter over time. An implication of this is that stabilizing inflation is much more costly in terms of the resource gap volatility that must be tolerated, when the economy is subject to supply shocks. This in turn tends to favor a heightened focus on keeping the unemployment gap near zero rather than on stabilizing inflation: a more direct response to the unemployment gap better achieves dual mandate objectives.<sup>9</sup> That said, it is worth noting that 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

---

issues. Kiley (2013) reviews a range of conceptual issues that arise when economists attempt to define resource utilization.

<sup>7</sup> See, for instance, Orphanides (2003) and Romer and Romer (2002). At modest loss of generality, our paper will take the natural rate of unemployment and the non-accelerating inflation rate of unemployment to be equivalent.

<sup>8</sup> Arguments along these lines can be found in Orphanides *et al.* (2000) and Orphanides and Williams (2007), among other sources.

<sup>9</sup> A policy reaction function that strongly responds to inflation could offset demand shocks and effectively stabilize inflation and unemployment gaps, in economies in which there are no supply shocks. 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 assume only a modestly higher weight on inflation than in the Taylor (1999) rule.

known as the Taylor (1999) rule, except that the unemployment gap substitutes for the output gap, with appropriate rescaling; these two gaps generally move together and we will treat them as interchangeable.

*An inflation-averse rule:* Policymakers downweight by two thirds, relative to the balanced-approach rule, the signal from their estimates of resource utilization, and seek to compensate by responding three times more forcefully to deviations of inflation from target. This implies an appreciably stronger policy reaction to above- or below-target inflation than to the gap between unemployment and  $u^*$ . Under conditions similar to the past couple of years in which inflation has run consistently below the Federal Open Market Committee's (FOMC) two-percent objective even while the unemployment rate tracked well below conventional estimates of  $u^*$ , this strategy would imply a considerably more accommodative near-term policy stance than the balanced-approach rule.

*An unemployment-averse rule:* Policymakers downweight, by two thirds, the signal from inflation and triple the response to (estimated) unemployment deviations from  $u^*$ . This approach is less accepting of an undershooting of the natural rate of unemployment by the unemployment rate, and would have implied a more rapid removal of monetary policy accommodation in recent years than under the balanced-approach rule.

### **3. Economic Performance Under Alternative Strategies and Economic Structures**

#### Baseline outlook, model, and simulation approach

Much of our analysis concerns the uncertainty as it relates to policymakers' outlook for how the economy might be expected to evolve in the future.<sup>10</sup> Thus, the baseline scenario which our analysis proceeds from will matter, in general. To illustrate, we conduct our simulations working off of a baseline that is constructed using the median values of forecast variables from the June 2018 *Summary of Economic Projections* (SEP). The SEP furnishes forecast data for only a small subset of macroeconomic variables—specifically, the growth rate of real GDP, headline and core PCE price inflation rates, the unemployment rate, and the federal funds rate—and only at an annual frequency and for only a few years (plus a longer-run value). Nothing definitive is supplied on unobserved variables such as expected inflation, the natural rate of unemployment, and potential output. The SEP is also silent on variables that are important to models like sFRB, such as Treasury bond rates and wage rates. Accordingly, staff at the Federal Reserve Board

---

<sup>10</sup> A two-stage process for policymaking in which a forecast is carried out conditional on a possibly arbitrary path for policy instruments and then a second step optimizes the policy for the economic conditions and risks associated with that particular baseline is proposed in, for example, Svensson (1997) and Svensson and Tetlow (2005).



use a collection of models, empirical relationships, and smoothing algorithms to construct a baseline that is roughly consistent with the median of FOMC participants' forecast submissions.<sup>11</sup>

Figure 2 shows the basic features of the baseline. At the start date of our simulations, shown by the vertical line, the unemployment rate is nearly a percentage point below the assumed value of the natural rate of unemployment.<sup>12</sup> Resource utilization tightens a bit further over the next year or so before declining gradually early in the next decade. In contrast, inflation begins the scenario very close to 2 percent, after having been significantly below that level for some time. Inflation eventually exceeds 2 percent, but only slightly, and only for about two years, before falling back.<sup>13</sup> The corresponding path for the federal funds rate begins the scenario at about 2 percent and rises slowly but continuously to reach just short of 3½ percent, before declining to reach the median of the FOMC's longer-run rate of 2.9 percent.

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.<sup>14</sup> 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.<sup>15</sup> Like its larger parent, sFRB falls in the class of quantitative New Keynesian models, albeit one in which microfoundations are not universally applied. An important feature of the sFRB model is its characterization of the monetary transmission mechanism. Like other models of its class, monetary policy, agents' expectations, and macroeconomic outcomes are all jointly determined in sFRB. Nevertheless, it may be instructive to trace the channels through which an exogenous

---

<sup>11</sup> In particular, we use the baseline that is consistent with the medians in the SEP that was a part of the [public release](#) of the FRB/US model code in June 2018, and then convert that database for use with the smaller sFRB model.

<sup>12</sup> The assumed path for  $u^*$  in the baseline comes merely from drawing a smooth line between the last historical value of  $u^*$  derived from the supply-side block of the FRB/US model, to the median value from SEP submissions for the unemployment rate in the longer run. The supply-side block of the FRB/US model is based on Fleishman and Roberts (2011).

<sup>13</sup> The inflation rate shown in the chart is four-quarter core PCE inflation, because that is the rate that appears as an argument in our policy rules. The path for headline PCE inflation looks very similar.

<sup>14</sup> In the stochastic simulations, the model is repeatedly subjected to disturbances that are randomly sampled from shocks extracted from history, and simulated, date by date. That is, we bootstrap shocks, randomly drawing particular dates from history, with replacement, from which we apply the complete vector 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.

<sup>15</sup> The sFRB model has about 50 equations, most 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 (2018) for a detailed description.

disturbance to the federal funds rate would affect the economy. Unanticipated changes in short-term interest rates in sFRB have no *direct* effect on expenditures; instead, it is expectations of future rates that do the work. Expected future short-term rates change Treasury bond rates, which in turn affect the lending rates faced by households and businesses, the value of stock market wealth, and the foreign exchange value of the dollar. These changes then influence expenditure decisions, and thus current and expected future resource utilization. The resulting changes in output and unemployment gaps affect expectations of a broad array of variables, which then affect wages and prices, and expected future inflation.<sup>16</sup> The upshot is that persistent mismeasurement of resource utilization drives a wedge between, on the one hand, those variables that are at the center of both the expenditure and pricing decisions of private agents and, on the other hand, those variables to which policymakers respond in formulating monetary policy.

The assumptions underlying our benchmark simulations are summarized in table 1, where we also show the alternative assumptions we explore. Two warrant discussion. First, for our benchmark simulations, we assume that certain economic decision makers have model-consistent expectations (MCE), meaning 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 determination, but not elsewhere.<sup>17</sup> Decisions by households, setting plans for consumption, and firms in capital investment, are based on expectations that are represented by a small-scale vector autoregressive model.<sup>18</sup> VAR-based expectations is the class of expectations that is commonly used in forecasting and many alternative simulations prepared for the FOMC by the staff of the Federal Reserve Board because of its realism in those contexts. Our base-case assumption of MCE implies that agents understand the monetary policy strategy that is employed by policymakers, including any misperception of fundamentals, where applicable.

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. The use of VAR-based expectations for household and business expenditure decisions here protects, to some extent, against assuming too much "rationality" on the part of agents who may be detached from the financial markets

---

<sup>16</sup> When we speak of "the Phillips curve" in the context of the sFRB model, it should be understood that this refers to a block of equations of which a core PCE price inflation equation and a wage equation are at the center. See Brayton (2018) for details.

<sup>17</sup> For purposes of brevity we shall hereinafter refer to our base-case assumption for expectations formation as model-consistent expectations notwithstanding the fact that MCE are used in a subset of the model.

<sup>18</sup> In particular, all agents who are endowed with VAR-based expectations use the same VAR model that has inflation, an output gap, and the federal funds rate as variables. This core VAR model is then augmented by other variables that are germane to each sector, as applicable. This expectations formation structure was introduced to macroeconomic modeling in the FRB/US model. See Brayton and Tinsley (1996) and Brayton *et al.* (1997) for details.

through which the first stage of the monetary policy transmission mechanism operates. Even so, 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. Second, for our benchmark simulations, we use stochastic shocks drawn from a lengthy period in 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 work with a shorter, milder, 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 of the unemployment rate and inflation as of 2020: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, Great Moderation sample period—the dashed blue lines. (The vertical lines show the target rate of inflation of 2 percent, in the lower panel, and the median longer-run projection of the unemployment rate from the SEP, which we take as our estimate of the natural rate of unemployment  $u^*$ , in the upper panel.)<sup>19</sup> 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 13 percent chance of unemployment running below 3 percent at the end of 2020, 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 likelihood that inflation will run notably above 2 percent provided that shocks resemble those occurring since the mid-1980s.<sup>20</sup> 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 low probability that inflation will run much above target reflects both the relatively flat slope of the Phillips curve—a

---

<sup>19</sup> As applied to the June 2018 public release of the SEP-consistent baseline, the procedure for constructing  $u^*$  described in footnote 12 resulted in a path that starts out at about 4.65 percent in 2018:Q1 and then declines slowly over time to 4.5 percent. For conciseness, we simply refer to this baseline as one that has a  $u^* = 4.5$  percent, and similarly for the alternative baselines we use which feature different values for  $u^*$ .

<sup>20</sup> The corresponding figure for the benchmark 1969-2016 (“long-sample”) shock set is about 8 percent.

feature that is consistent with, among other things, the remarkable lack of a substantial decline in core inflation rates during the tumult of the 2008-09 recession—and the relatively small magnitude of estimated shocks to the Phillips curve over this period. By contrast, the range of inflation outcomes is much larger when shocks are drawn over the post-1969 sample given the high volatility of inflation during the Great Inflation (the solid black line in figure 3).<sup>21</sup>

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 the objective of stabilizing inflation around 2 percent—which would tend to require a relatively accommodative monetary policy—and avoiding a large and persistent undershoot of the estimated natural rate  $u^*$ —which would require a more restrictive policy. 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 2020. Under the benchmark balanced-approach policy, the joint probability of this event is slightly above 17 percent. On the other hand, our simulations suggest that there is slightly less than a 5 percent chance that the economy would show signs of significant overheating in 2020, which we take to be a situation in which unemployment has fallen below 3½ percent and core inflation has risen above 2½ percent. The skewness of the distribution for inflation reflects the volatile world represented by the long-sample shocks, and the associated non-normalities in the distribution of the shocks. The effective lower bound on nominal interest rates is not playing a substantial role here as it binds in 2020:Q4 in only about 4 percent of draws, although probabilities rise in later years.

### 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. Instructed by the literature on this topic, we consider three alternative possibilities for the current value of  $u^*$ . The first case is 4.5 percent, which is the median longer-run value for the unemployment rate from the June 2018 SEP; the two alternative cases are 3.7 percent and 5.3 percent, which span about the width of the 70-percent confidence interval for typical estimates, when centered on 4.5. In each case, we assume that policymakers follow the policy rules described above under the baseline assumption that  $u^*$  is 4.5 percent but is subject to stochastic shocks.<sup>22,23</sup> Thus in the figures we show below, which like figure 3,

---

<sup>21</sup> Relative to the confidence intervals reported in the SEP addendum to the June 2018 FOMC minutes, our intervals are similar for inflation and narrower for the unemployment rate.

<sup>22</sup> The natural rate of unemployment is subject to shocks of a standard deviation of 10 basis points. Those shocks die out very slowly over time.

<sup>23</sup> The opposite case, where it is true that  $u^* = 4.5$  and is subject to persistent shocks over time, but policymakers wrongly think that  $u^* = 5.3$  percent or 3.7 percent, as applicable, is covered in a table in Appendix D.

focus on densities for 2020:Q4, we can think of these as outcomes for an experiment where policymakers formulate an incorrect estimate of the natural rate, and do not recognize their error for the ten quarters up to the end of 2020. Both the historical experience, as recounted by Orphanides (2003) for example, and the findings of empirical models, suggest that this is a very plausible assumption.

**Balanced approach rule.** Figure 4 presents the distributions of key outcomes in 2020:Q4 for the three cases. The solid black lines show the benchmark case in which policymakers use the correct 4.5 percent level of the natural rate in the rule (identical to figure 3). In the case in which the true natural rate is 3.7 percent but policymakers think it is 4.5 percent, the blue dashed lines, policymakers maintain too tight a policy stance, on average. If  $u^*$  were correctly interpreted as being equal to 3.7, the distribution of the unemployment rate, relative to the  $u^* = 4.5$  percent case, would shift to the left; instead, unemployment runs persistently above the true natural rate, and this persistent gap in turn puts downward pressure on inflation. Inflation is reduced and the inflation probability distribution, the blue dashed line, lies well to the left of that under the baseline path for the natural rate.<sup>24</sup> From the perspective of policymakers, policy misses its inflation objective, despite a strong perceived performance on controlling the unemployment rate; from private agents' perspective, policymakers are missing on both ends of their mandate. 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.

Noting that  $u^* = 3.7$  and  $u^* = 5.3$  are about equal to the 70-percent confidence interval of typical estimates for  $u^*$ , we can ask how likely extreme outcomes for, say, inflation are, spanning the three models. Our results show that the probability of inflation exceeding 5 percent, as of 2020:Q4, is at most 5.1 percent (in the case when  $u^* = 5.3$ ), while the probability of inflation falling below zero as of that date is notably higher at 13.7 percent.<sup>25</sup>

**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 ( $1\frac{1}{2}$  rather than  $\frac{1}{2}$ ) while putting a proportionately smaller weight on their estimate of the unemployment gap. The distributions of outcomes for 2020:Q4 under this reaction function are presented in the upper panels of figure 5. Not surprisingly, misperceptions clearly have more modest consequences for

---

<sup>24</sup> 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.

<sup>25</sup> If we open up this question to the use of our alternative rules, the probability of inflation greater than 5 percent rises to 6.3 percent ( $u^* = 5.3$ ; unemployment-averse rule) and the probability of inflation below zero rises to 18.2 percent ( $u^* = 3.7$ , unemployment-averse rule).

the distribution of inflation (upper-right panel) than under the benchmark rule (bottom panel of figure 4), in part because inflation-averse policymakers are less adamant about driving the unemployment rate to its (erroneous) natural rate. This implies smaller policy errors than otherwise, given initial conditions. At the same time, the other side of the policy mandate is also playing an important role: Intuitively, because policymakers under the inflation-averse rule lower the policy rate aggressively when inflation declines, a natural rate of 3.7 percent induces 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.<sup>26</sup>

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 in response to supply and demand shocks. To establish this point, it is helpful to assess economic performance using a standard (quadratic) loss function that penalizes equally deviations of inflation from 2 percent and the unemployment rate from the (true) natural rate of unemployment. 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 performs notably worse than either the balanced-approach rule or another rule, discussed in detail below, that we call the unemployment-averse rule. Moreover, this poor performance is obtained both on average and in the tails of the distribution of outcomes (compare row 2 against rows 1 and 3 for columns C through E). Perusing column B, it is clear that marked increases in the deviation of unemployment from its natural rate, relative to the benchmark policy, are responsible for this rule's deficiencies, regardless of what value for  $u^*$  policymakers believe to be true. The inflation-averse rule's substandard performance reflects, in part, two factors that are germane to conditions embodied in the baseline. First, with inflation initially only just approaching its target level from below, the inflation-averse rule does not prescribe a particularly rapid reduction of policy accommodation in the near term, and thereby tolerates further declines in unemployment, which the loss function interprets as undesirable, relative to the true  $u^*$ . Second, responding forcefully to deviations of inflation from 2 percent increases the volatility of the unemployment gap in the presence of 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

---

<sup>26</sup> 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 2020 (as inflation adjusts only very slowly to unemployment gaps, and the gap is pretty small under this aggressive rule toward inflation).

curve, and inflation already close to 2 percent, the larger induced fall in unemployment does little to mitigate the downward pressure on inflation.

Column F in the table shows the proportion of draws for which the performance of each combination of  $u^*$  (holding fixed policymakers' perceived  $u^* = 4.5$  percent) and policy rule improves upon the base case in row 1. As can be seen, the inflation averse rule improves outcomes in the smallest proportion of draws, and never in as many as 20 percent of draws. Thus, the highly aggressive reaction to inflation tends to perform poorly based on the stabilization metric used here. Even so, while our loss function is a conventional one, there are other plausible ones, including nonquadratic ones that do not interpret unemployment below the natural rate to be symmetrically 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 4.5 percent, the assumed loss function views unemployment of 3.7 percent as having about the same social loss as unemployment of 5.3 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 to be problematic; 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 2020:Q4 under a policy approach that responds more aggressively to unemployment gaps and proportionately less aggressively to deviations of inflation from 2 percent.<sup>27</sup> Because this approach reacts strongly to a mismeasured unemployment gap, it tends to perform poorly in pushing unemployment towards the true natural rate, when  $u^*$  is misperceived. As can be seen in the top panel of figure 6, the distribution of the unemployment rate is nearly invariant to the actual value of  $u^*$ , and the implied unemployment gaps are large. As a consequence, this policy rule produces a slightly wider range of inflation outcomes than the inflation-averse rule or the balanced-approach rule.

Returning to policymaker losses shown in table 3, and restricting consideration for the moment to the case where policymakers have assessed  $u^*$  accurately—rows 1 through 3 of the table—we see that the unemployment averse rule performs well. Losses at each of the 10<sup>th</sup>, 50<sup>th</sup> and 90<sup>th</sup> percentiles of the distribution are all lower under this rule than under the two alternatives shown. Moreover, as shown in column E, when considering

---

<sup>27</sup> As Appendix A makes clear, the unemployment-averse rule is symmetric, relative to the balanced-approach rule, to the inflation-averse rule. That is, the unemployment-averse (inflation-averse) rule triples (cuts by two-thirds) the coefficient on the unemployment gap and cuts by two-thirds (triples) the coefficient on the inflation gap.

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 90 percent of draws whereas the inflation-averse rule produces superior performance only about 11 percent of the time.

Because it reacts as strongly as it does to resource slack, the unemployment averse rule is naturally susceptible to problems of mismeasurement in the natural rate of unemployment. Yet this rule still performs comparatively well in counteracting the effects of both demand and supply shocks in this environment of mismeasurement. It is, in this sense, essentially the flip-side of the inflation-averse strategy. In particular, economic losses are lower than under the inflation-averse rule not just when the  $u^* = 4.5$  as just discussed, but also when  $u^* = 5.3$  percent (rows 7 through 9). It is only when  $u^* = 3.7$  percent that performance deteriorates and even in these cases the proportion of draws for which the unemployment adverse rule performs better than in the base case is about the same for the three policies (column F).

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. Put simply, an unemployment-averse policy is more hazardous in an environment where the current and projected sign of the unemployment gap is not already clear cut, or where inflation is well away from objective. In the baseline outlook used in this paper, simulations begin from initial conditions of tight resource utilization as measured by the unemployment rate being notably below the assumed natural rate of unemployment, and with projected decreases in the unemployment rate for some time thereafter. Moreover, inflation begins the scenario quite close to policymakers' objective. One implication of this outlook is that the probability, in stochastic simulations, of the policy rate falling to the effective lower bound over the next few years is estimated to be quite low. Baseline scenarios that feature less momentum, lower resource utilization gaps, or lower levels of inflation, bring the ELB more prominently into consideration in the design of policy with possible adverse outcomes in mind.

#### Expectations formation

As noted in the Introduction, to provide an element of robustness testing, we repeated a number of our experiments under the assumption that all economic agents employ VAR-based expectations in formulating their expenditure and pricing decisions. Two tables in Appendix F provide some detailed results on these experiments; here we offer just a couple of remarks, focusing on the bottom panels of figure 5.



Under the assumptions for our base-case experiments, private agents know that when policymakers are misguided in their beliefs about the natural rate of unemployment, the resulting policy error will be a persistent one. Some of the implications of this can be seen in figure 5 by comparing the distributions of inflation rates in the MCE case, shown in the top-right panel, with the VAR-based case, in the bottom-right panel. The variability of inflation, in 2020:Q4, is notably higher under MCE than under VAR-based expectations. This is because both stochastic shocks and policy errors are slower to manifest themselves under VAR-based expectations than under MCE: Inflation is more tied down by history under VAR-based expectations. Also, maneuvering the unemployment gap is a more powerful tool for the control of inflation when expectations are VAR-based, which is why the modes of the distributions of the unemployment rate under VAR-based expectations are a touch to the right of their MCE counterparts. Thus whereas MCE is an ally of monetary control in the cases where policymakers have the model right, it works against the policymaker when they do not, in the cases studied here.

### Risks associated with a steeper and accelerationist Phillips curve

Our analysis now returns to the case in which the natural rate of unemployment equals 4.5 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.<sup>28</sup> 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 (dashed 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 2020:Q4. Given that the unemployment rate currently lies below the assumed level of  $u^*$ , the inflation outlook shifts up under the 1970s-style Phillips curve, relative to the balanced approach rule

---

<sup>28</sup> 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. Also, a Phillips curve slope coefficient that is four times that of the most recent twenty year period is not as extreme as it might sound because the latter is a small number.

outcomes, as can be seen by comparing the blue and red lines to the black lines; in both cases, the distributions of outcomes for 2020:Q4 are centered close to 2½ percent.

The distribution for the unemployment rate also shifts, and also to the right, relative to the base case, albeit only modestly. More interesting is that the width of the distributions for unemployment rate narrow noticeably, just as they did for inflation. This reflects the fact that when the Phillips curve is steep, monetary policy operating through adjusting demand conditions, becomes more powerful: policy can not only fight off inflationary shocks more adeptly than otherwise, it takes smaller fluctuations in the unemployment rate to do it. Why then are the modes of the inflation rates well above the 2-percent objective of policy?<sup>29</sup> Because the long lags over which monetary policy operates with the 1970s-style Phillips curve make it difficult for policy to overcome in a timely way the inflationary consequences of initial conditions of significant excess demand and inflation near target. Had initial conditions been such that inflation was well below 2 percent, the strong effect of high levels of resource utilization on inflation would have been a benefit for policymakers seeking their inflation objective. Once again, this highlights the importance of the particular initial conditions (and outlook) for the balancing of risks in the conduct of monetary policy.

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. Given the 1970s-style Phillips curve, inflation continues to rise for a couple of years until the unemployment rate rises above the natural rate, and then declines gradually. Thus, as seen in figure 8, the monetary tightening results in a substantially higher probability of unemployment running between 5 and 6 percent in 2022:Q4, though with relatively little change in the risk of very adverse unemployment outcomes. The inflation-averse rule tightens more aggressively, and hence modestly reduces the probability of relatively high inflation outcomes at the cost of somewhat higher unemployment (as seen in the slight rightward shift in the distribution of unemployment in figure 8).

Consistent with the literature on natural rate misperceptions mentioned earlier, the potential costs of a sharp steepening of the Phillips curve slope could be significantly higher if policymakers misperceived the natural rate to be lower than its true value  $u^*$  for some time (rather than responding to the true  $u^*$  as in figures 7 and 8). Inflation would rise by more – and more persistently – with a considerable risk of further amplification if longer-run inflation expectations were to become unanchored. Given the heightened risk of adverse inflation outcomes, the inflation-averse rule would have considerably more

---

<sup>29</sup> While the higher modal level of inflation under the 1970s-style Phillips curve may be viewed as a cause for concern, a potential benefit is that a steeper and 1970s-style Phillips curve would largely eliminate the substantial risk of low inflation seen under the benchmark Phillips curve.

appeal in an environment with a high Phillips curve slope than in our benchmark model in which the Phillips curve is quite flat.

#### **4. Conclusion**

The combination of inflation recently being persistently below the FOMC's two-percent target, despite low rates of unemployment, highlights important uncertainties policymakers face about inflation dynamics on the one hand, and the natural rate of unemployment, on the other. In light of the fact that empirical evidence cannot meaningfully reduce these uncertainties, this paper has shown how these two aspects of model uncertainty affect the choice of strategies for monetary policy.

Uncertainties about natural rate of unemployment have led many researchers to conclude that policymakers would be well advised to ignore potentially mismeasured labor market slack and focus almost exclusively on stabilizing inflation. This paper has shown that because monetary policy acts with a lag, waiting for inflation to materialize before reacting is undesirable, particularly when economic conditions are such that outsized deviations of inflation from its target are a plausible outcome.

Our results show that what we call an inflation-averse policy, one that downweights the potentially mismeasured unemployment gap in favor of more substantive responses to inflation, can lead to poor outcomes when the Phillips curve is relatively flat and the prevalence of supply-side shocks means that inflation volatility is likely.

While inflation appears to be insensitive to labor market slack, policy needs to take proper account of the prospects for persistently tight labor markets leading to higher inflation, or other imbalances, that could eventually endanger prospects on the employment side of their policy mandate. This paper has also shown that if the dynamics of inflation were to revert to something akin to those that prevailed in the 1970s, an inflation-averse strategy would raise the likelihood of high unemployment outcomes in the longer run, relative to a balanced approach, but without noticeable improvements in stabilizing inflation.

That some of these results run counter to received wisdom on economic policy under uncertainty is a reflection of the place and time in which we have conducted our experiments. Most studies on this topic are carried out in the laboratory, as it were, where initial conditions are implicitly or explicitly equal to target, and where the risks of underperformance on the economic metrics upon which policymakers are to be judged are symmetric and diffuse. But policymakers in the real world face risks and payoffs that can differ markedly from such rarified conditions. Thus a theme of this paper has been that policymakers need to assess the risks and uncertainties they face, and the proper response to those risks, with the economy's current position and distance from policy objectives, firmly in mind.



## 5. References

Blanchard, Olivier (2016), “The U.S. Phillips Curve: Back to the 60s?” Policy Brief 16-1, Peterson Institute, Washington DC.

Blanchard, Olivier; Giovanni Dell’Ariccia, and Paolo Mauro (2010) “Rethinking Macroeconomic Policy *Journal of Money, Credit and Banking* 42(supplement), pp. 199-215.

Blinder, Alan S. (1998) *Central Banking in Theory and Practice* (Lionel Robbins Lectures series) Cambridge, MA: MIT Press.

Brainard, William (1967) “Uncertainty and the Effectiveness of Monetary Policy” 57, *American Economic Review* 57(2) May, pp. 411-425.

Brayton, Flint (2018) “sFRB: A Small Linear Version of FRB/US,” unpublished manuscript, Division of Research and Statistics, Federal Reserve Board, Washington, D.C. (available on request).

Brayton, Flint and Peter Tinsley (1996) “A Guide to FRB/US: A Macroeconomic Model of the United States” Finance and Economics Discussion Series paper no. 1996-42. Federal Reserve Board, Washington, DC

Brayton, Flint; Eileen Mauskopf, David Reifschneider, Peter Tinsley, and John Williams, (1997) "The Role of Expectations in the FRB/US Macroeconomic Model." *Federal Reserve Bulletin*, April, pp. 227-245.

Clark, Todd and Taeyoung Doh (2014) “Evaluating Alternative Models of Trend Inflation” *International Journal of Forecasting*, 30(3), pp. 426-448.

Fleischman, Charles and John Roberts (2011), “From Many Series, One Cycle: Improved Estimates of the Business Cycle from a Multivariate Unobserved Components Model,” Finance and Economics Discussion Series paper 2011-46, Federal Reserve Board, Washington, DC.

Garnier, Christine; Elmar Mertens, and Edward Nelson (2015) “Trend Inflation in Advanced Economies” *International Journal of Central Banking*, 11(4), September, pp. 65-136.

Hansen, Lars P. and Thomas J. Sargent (2010) *Robustness*. Princeton: Princeton University Press.

Ljungqvist, Lars and Thomas J. Sargent (2018) *Recursive Macroeconomic Theory*, 4<sup>th</sup> edition. Cambridge, MA: Cambridge University Press.

Kiley, Michael T. (2013), “Output Gaps,” *Journal of Macroeconomics*, 37, pp. 1-18.

Kiley, Michael T. (2015), “Low Inflation in the United States: A Summary of Recent Research,” FEDS Note, November 23, 2015.

Meyer, Laurence; Eric T. Swanson and Volker W. Wieland (2001) “NAIRU Uncertainty and Nonlinear Policy Rules,” *American Economic Review*, 91(2), May, pp. 226-231.

Orphanides, Athanasios; Richard Porter, David Reifschneider, Robert Tetlow, and Frederico Finan (2000), “Errors in the Measurement of the Output Gap and the Design of

Monetary Policy,” *Journal of Economics and Business*, 52(1/2), January/April, pp.117–141.

Orphanides, Athanasios (2003), “The Quest for Prosperity without Inflation,” *Journal of Monetary Economics*, Vol. 50(3), pp. 633-663.

Orphanides, Athanasios, and John C. Williams (2007), “Robust Monetary Policy with Imperfect Knowledge,” *Journal of Monetary Economics*, 54(5), July, pp. 1406–1435.

Powell, Jerome H. (2018) “Monetary Policy at a Time of Uncertainty and Tight Labor Markets” [speech](#) given at *Price- and Wage-Setting in Advanced Economies*, a European Central Bank Forum on Central Banking, Sintra, Portugal, June 20.

Romer Christina D. and David H. Romer, (2002) “[The evolution of economic understanding and postwar stabilization policy](#),” Proceedings - Economic Policy Symposium - Jackson Hole, Federal Reserve Bank of Kansas City, pp. 11-78.

Rudebusch, Glenn D. (2001) “Is the Fed Too Timid?: Monetary Policy in an Uncertain World” *Review of Economics and Statistics* 83, pp. 202-217.

Soderstrom, Ulf (2002) “Monetary Policy with Uncertain Parameters” *Scandinavian Journal of Economics* 104(2), pp.124-145.

Staiger, Douglas; James H. Stock, and Mark W. Watson (1997) “How Precise are Estimates of the Natural Rate of Unemployment?” in *Reducing Inflation: Motivation and Strategy* NBER Studies in Business Cycles, vol. 30, Chicago and London: University of Chicago Press, pp. 195-242.

Svensson, Lars E.O. (1997) “Inflation Forecast Targeting: Implementing and Monitoring Inflation Targets” *European Economic Review* 41(6), pp. 1111-1146.

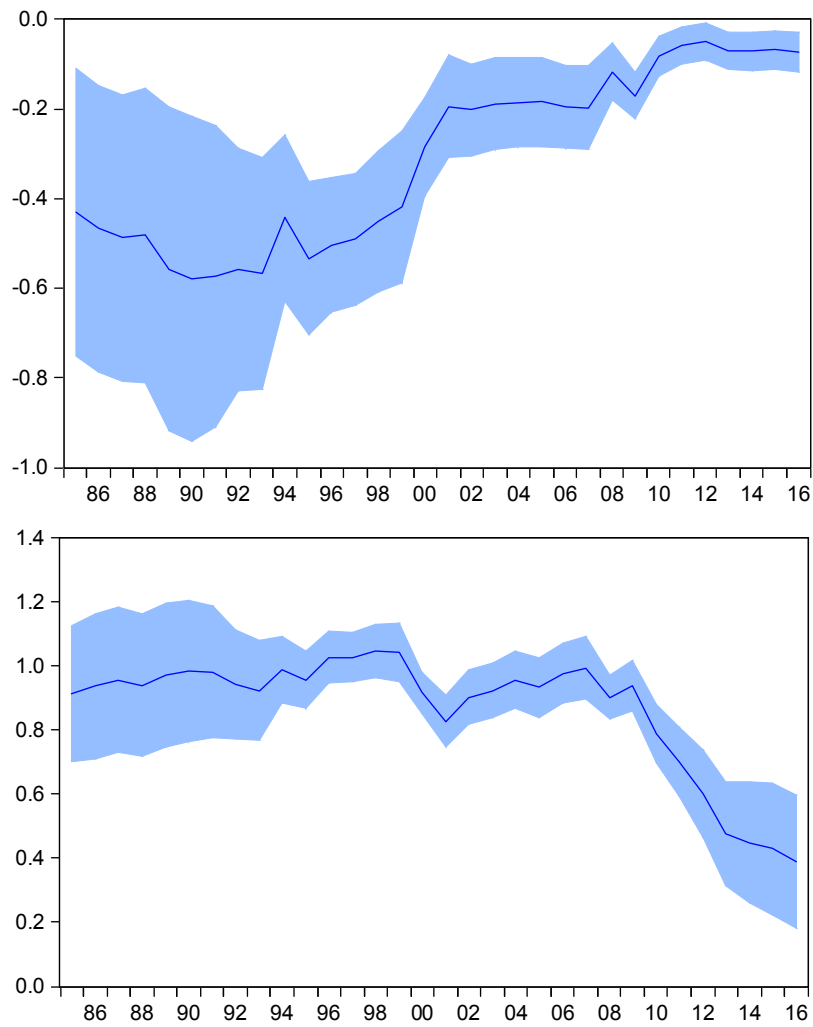
Svensson, Lars E.O. (2017) “What Rule for the Federal Reserve?: Forecast Targeting” NBER working paper no. 23993, Cambridge, MA.

Svensson, Lars E.O. and Robert J. Tetlow (2005) “Optimal Policy Projections” *International Journal of Central Banking* 1(3), pp. 177-207.

Swanson, Eric T. (2006) “Optimal Nonlinear Policy: Signal Extraction with a Non-normal Prior,” *Journal of Economic Dynamics and Control*, 30, pp. 185-203.

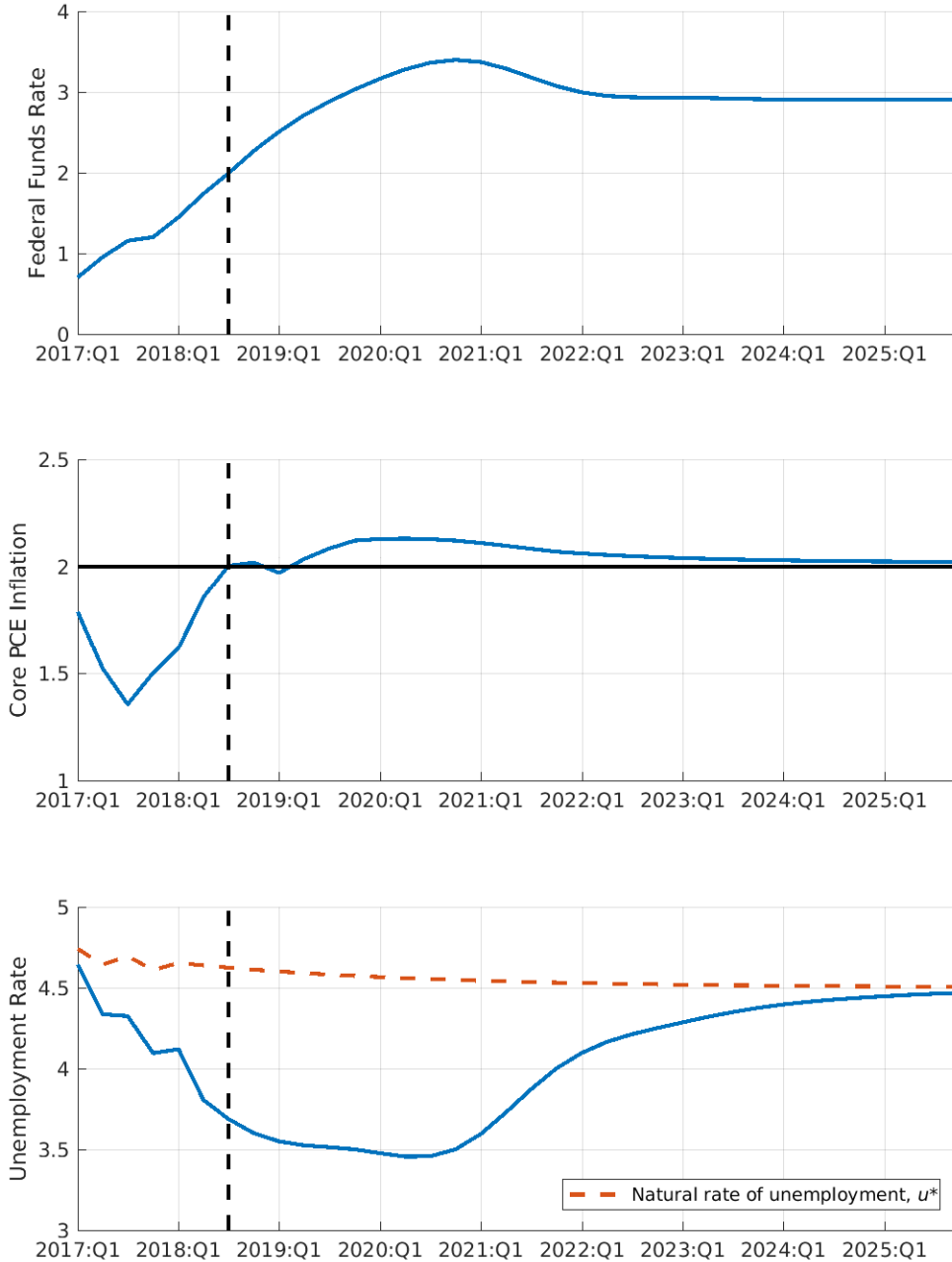
Taylor, John B. (1999) “A Historical Analysis of Monetary Policy Rules” in John B. Taylor (ed.) *Monetary Policy Rules* Chicago: University of Chicago Press, pp. 319-341.

**Figure 1: Evolution of the Phillips Curve Coefficients**



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

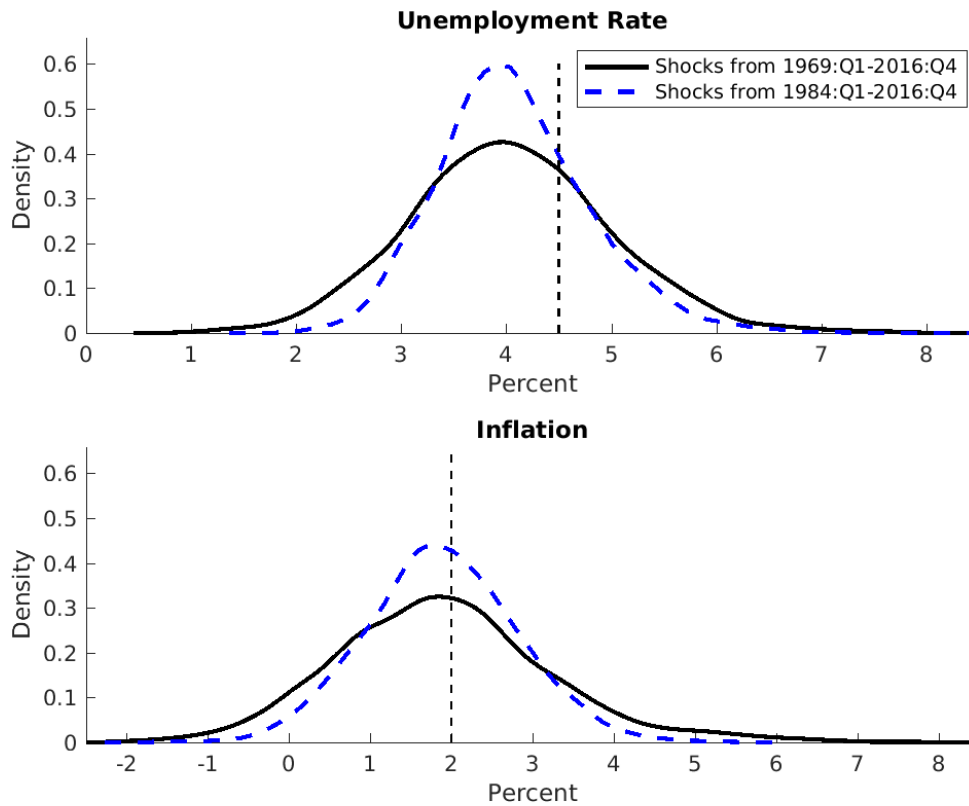
**Figure 2: Features of the SEP-Consistent Baseline  
(as constructed by Federal Reserve Board staff)**



Note: The figure shows the baseline paths of the federal funds rate, four-quarter core PCE inflation, and the unemployment rate. The dashed vertical line marks 2018:Q3, the quarter the simulations begin.

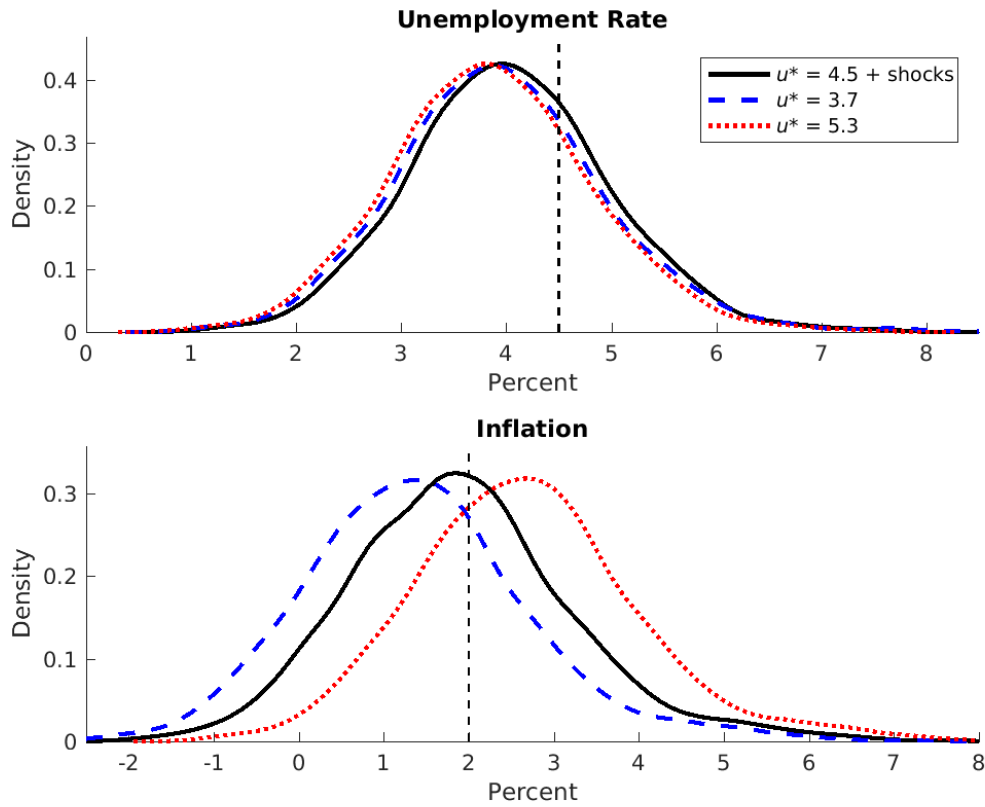


**Figure 3: Distributions of Unemployment and Inflation in 2020:Q4**



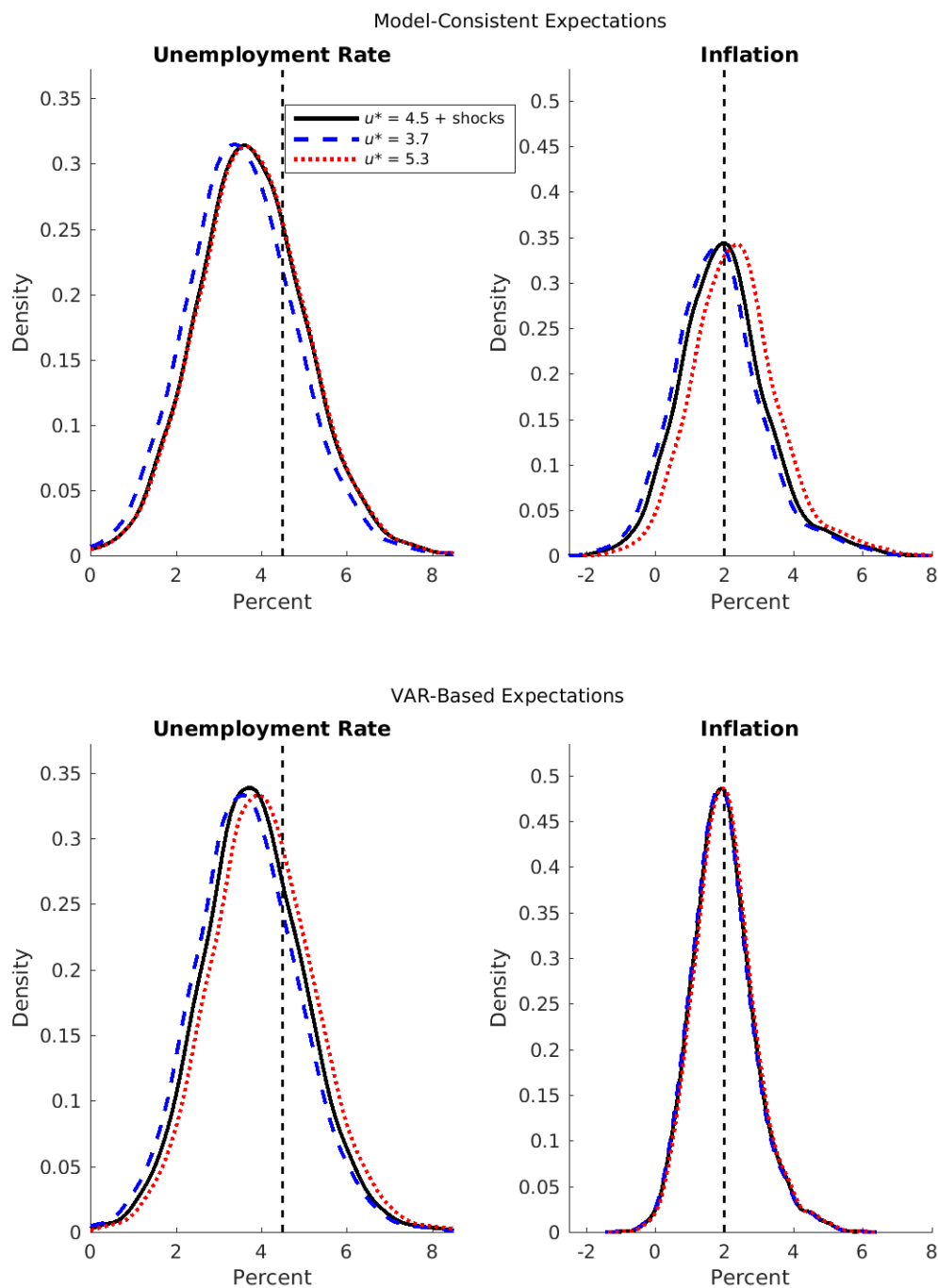
Note: The figure summarizes two sets of 5000 stochastic simulations in sFRB around the baseline, beginning in 2018:Q3, under model-consistent expectations (MCE). The solid black lines show the distributions of outcomes when shocks are resampled, demeaned model residuals from 1969:Q1 to 2016:Q4, while the dashed blue lines show the distributions of outcomes when shocks are resampled, demeaned residuals from 1984:Q1 to 2016:Q4.

**Figure 4: Outcomes in 2020:Q4 for Alternative  $u^*$  When Policymakers Believe  $u^* = 4.5$  Percent and Follow a Balanced-Approach Rule**



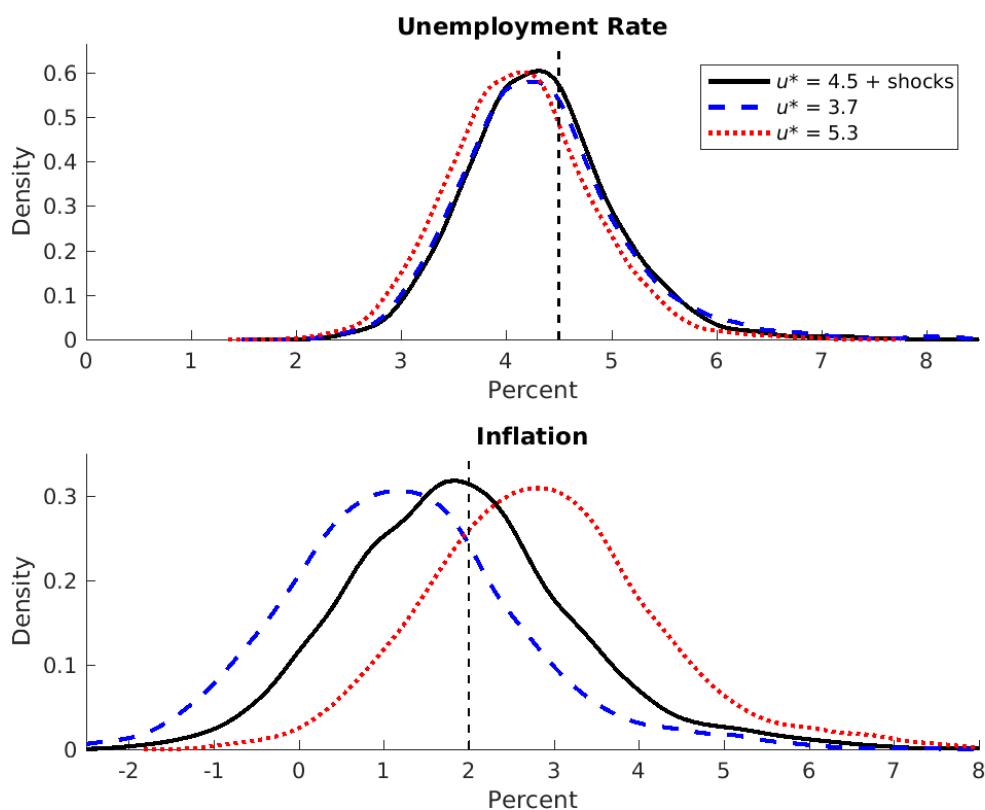
Note: The figure summarizes three sets of 5000 stochastic simulations in sFRB around three deterministic scenarios with different assumptions about  $u^*$ . Each simulation begins in 2018:Q3 and is under model-consistent expectations (MCE). Shocks are resampled, demeaned model residuals from 1969:Q1 to 2016:Q4.

**Figure 5: Outcomes in 2020:Q4 for Alternative  $u^*$  When Policymakers Believe  $u^* = 4.5$  Percent and Follow a Rule That Responds More Aggressively to Inflation**



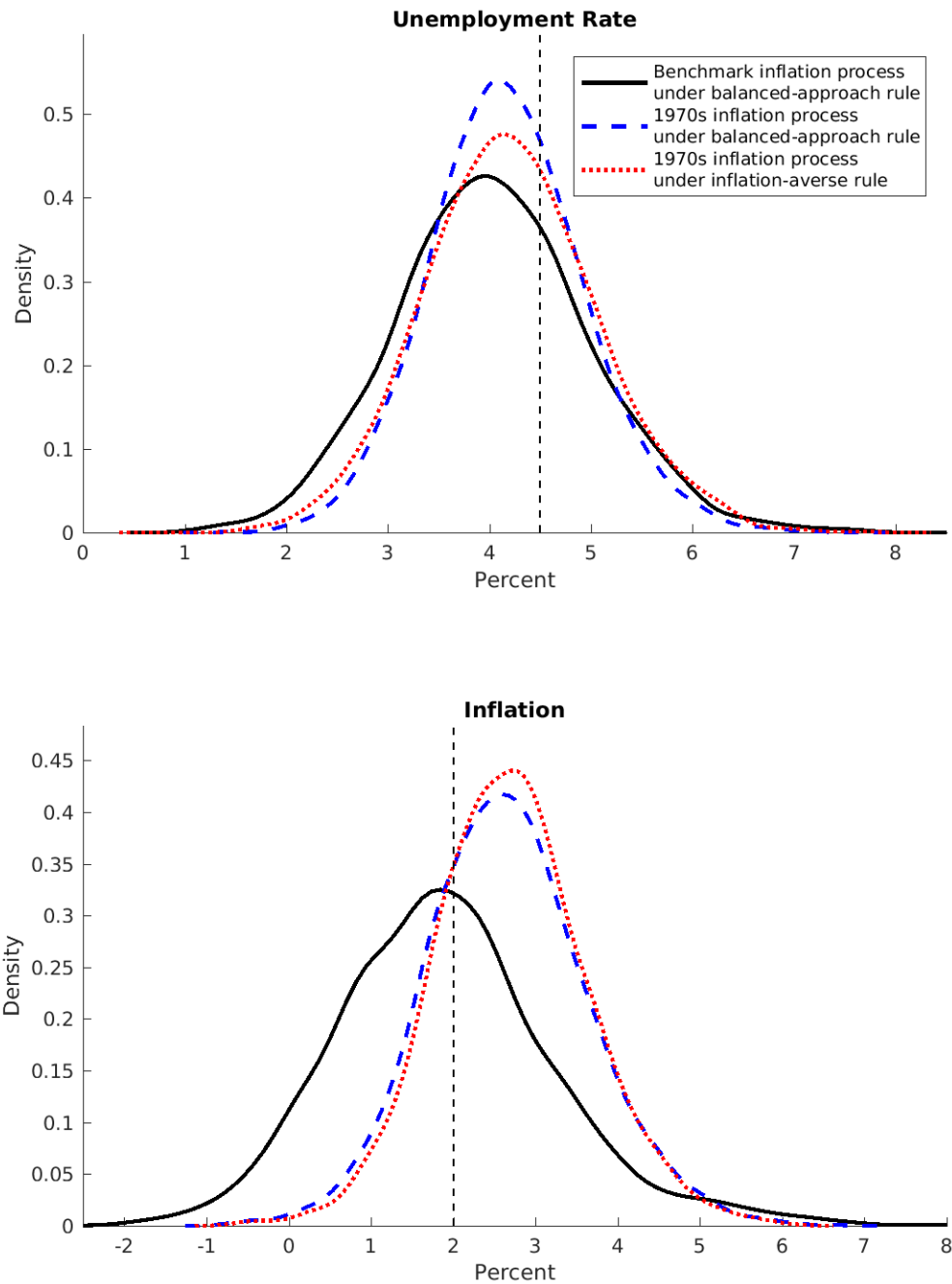
Note: The top two panels show the distributions of outcomes under model-consistent expectations (MCE), while the bottom two panels show the distributions of outcomes under VAR-based expectations. Under both MCE and VAR-based expectations, there are three sets of 5000 stochastic simulations in sFRB around three deterministic scenarios with different assumptions about  $u^*$ . Each simulation begins in 2018:Q3. Shocks are resampled, demeaned model residuals from 1969:Q1 to 2016:Q4.

**Figure 6: Outcomes for Alternative  $u^*$  When Policymakers Believe  $u^* = 4.5$  Percent and Follow a Rule That Responds More Aggressively to Unemployment in 2020:Q4**



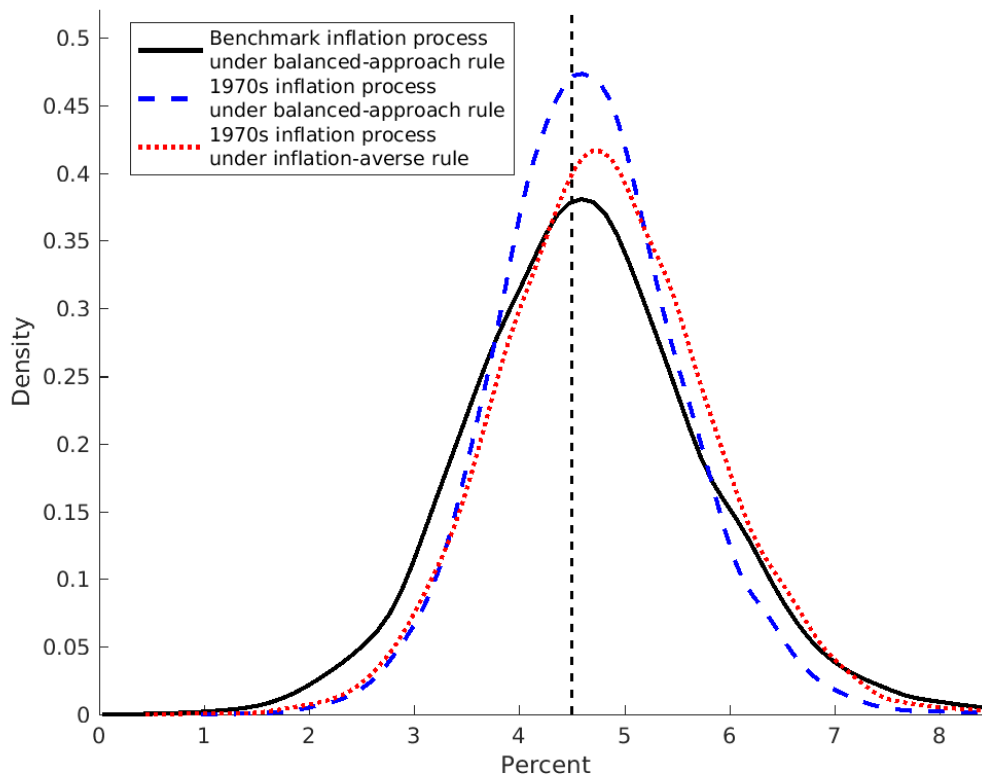
Note: The figure shows three sets of 5000 stochastic simulations in sFRB around three deterministic scenarios with different assumptions about  $u^*$ . Each simulation begins in 2018:Q3 and is under model-consistent expectations (MCE). Shocks are resampled, demeaned model residuals from 1969:Q1 to 2016:Q4.

**Figure 7: Outcomes for Steeper and Near Accelerationist Phillips Curve Under Alternative Policy Approaches in 2020: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 2018:Q3 and is under model-consistent expectations (MCE). Shocks are resampled, demeaned model residuals from 1969:Q1 to 2016:Q4.

**Figure 8: Unemployment Distributions over Longer Run (2022: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 2018:Q3 and is under model-consistent expectations (MCE). Shocks are resampled, demeaned model residuals from 1969:Q1 to 2016:Q4.

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

<i>Model Feature</i>	<i>Benchmark</i>	<i>Alternative Assumptions</i>
1 <b>Expectations</b>	MCE in asset pricing wages & price determination VAR-based for expenditures	VAR-based expectations for all agents
2 <b>Monetary policy</b>	Balanced approach (Taylor (1999))	Inflation-averse rule Unemployment-averse rule
3 <b>Shocks</b>	1969:Q1 to 2016:Q4 Includes the Great Inflation period	1984:Q1 to 2016:Q4 Great moderation and GFC
4 <b>Baseline forecast</b>	June 2018 SEP (median)	
5 <b>Model structure</b>	Known	Selected misperceived features
6 <b>Simulation period</b>	2018:Q3 to 2025:Q4 (30 quarters of shocked dates)	

**Table 2. Macroeconomic Performance in 2020****Under Monetary Policy Strategies**(policymaker believes  $u^* = 4.5 + \text{shocks}$ )

True $u^*$ Process:	[A]	[B]	[C]	[D]	
	$u < 3.5\%$ and $\pi < 1.75\%$		$u < 3.5\%$ and $\pi > 2.5\%$		
	<u>Probability</u>	<u>Q4 FFR</u>	<u>Probability</u>	<u>Q4 FFR</u>	
<b><math>u^* = 4.5 + \text{shocks}</math></b>					
1	Balanced approach	17.4	5.0	4.9	8.6
2	Inflation averse	23.9	2.2	8.2	8.0
3	Unemployment averse	5.4	10.2	1.2	12.8
<b><math>u^* = 3.7</math></b>					
4	Balanced approach	24.2	4.7	3.6	8.5
5	Inflation averse	29.7	2.1	8.3	8.0
6	Unemployment averse	7.6	9.9	0.8	12.5
<b><math>u^* = 5.3</math></b>					
7	Balanced approach	11.1	5.8	15.8	9.00
8	Inflation averse	17.4	2.4	13.6	8.2
9	Unemployment averse	4.3	11.5	7.0	13.2

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 ( $\pi$ ) over the year 2020. The federal funds rate reported is the mean 2020: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 $u^* = 4.5 + \text{shocks}$ )					
		[A]	[B]	[C]	[D]	[E]	[F]
		Standard Deviation		Normalized Losses			Welfare
				Percentiles			Improvement
True $u^*$ Process:		$\pi$	$ugap$	10	50	90	Share
<b><math>u^* = 4.5 + \text{shocks}</math></b>							
1	Balanced approach	1.33	1.01	0.52	1.00	1.93	0.0
2	Inflation averse	1.25	1.37	0.60	1.20	2.33	11.1
3	Unemployment averse	1.35	0.78	0.43	0.87	1.80	90.4
<b><math>u^* = 3.7</math></b>							
4	Balanced approach	1.37	1.22	0.67	1.35	2.80	21.2
5	Inflation averse	1.26	1.42	0.59	1.23	2.54	19.7
6	Unemployment averse	1.43	1.15	0.70	1.48	3.38	21.9
<b><math>u^* = 5.3</math></b>							
7	Balanced approach	1.34	1.17	0.83	1.47	2.61	12.2
8	Inflation averse	1.25	1.60	0.87	1.59	2.91	4.5
9	Unemployment averse	1.38	0.88	0.74	1.33	2.52	24.2

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 2018:Q3 and go through 2025:Q4, and are under model-consistent expectations (MCE). Columns A and B show the standard deviation of the four-quarter core PCE inflation rate ( $\pi$ ) 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 table below shows the specifications and parameterizations of the monetary policy rules where  $R_t$  denotes the nominal federal funds rate prescribed by a strategy for quarter  $t$ ;  $r_t$  is the real rate of interest;  $r_t^{LR}$  is a medium-term concept of the equilibrium real interest rate;  $ugap_t = u_t - u_t^*$  is the unemployment gap, and  $\pi_t$  is four-quarter core PCE inflation.

### The Rules

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

## 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,  $\pi_t^{PCE}$ , 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,  $\beta = 0.99$ :

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

with  $\lambda_\pi = \lambda_u = 1$  with  $t = 2018:Q3$  and  $T = 29$  (quarters).

### 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:

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

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

where  $\pi^c$  is core PCE inflation,  $\pi^{LT}$  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  $\pi^{LR}$ , and a low value for  $\alpha$ , 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 2020  
Under Steeper, Near-Accelerationist Inflation Process**

(policymaker believes  $u^* = 4.5 + \text{shocks}$ )

	[A]	[B]	[C]	[D]
	u < 3.5% and $\pi$ < 1.75%		u < 3.5% and $\pi$ > 2.5%	
	Probability	Q4 FFR	Probability	Q4 FFR
True $u^*$ Process:				
<b><math>u^* = 4.5 + \text{shocks}</math></b>				
1. Base $\pi$ process, balanced approach	17.4	5.0	4.9	8.6
2. 1970s $\pi$ process, balanced approach	2.5	4.7	9.5	7.9
3. 1970s $\pi$ process, inflation averse	2.7	2.1	11.3	7.4

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 ( $\pi$ ) over the year 2020. The federal funds rate reported is the mean 2020: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 3.7 percent or 5.3 percent, as applicable, but policymakers perceive that  $u^*$  is initially 4.5 percent and drifts over time according to a process:  $u_t^* = 0.98u_{t-1}^* + \sigma v_t$ ,  $v_t \sim N(0,1)$  where  $\sigma = 0.10$ . Table D1 below shows results for the opposite case where the true data generating process is that  $u^*$  begins on its baseline level of about 4.5 percent and is subject to shocks as described immediately above, but policymakers mistakenly take  $u^*$  to be constant at a value of either 3.7 or 5.3 percent, as applicable.

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

Policymaker Beliefs $Eu^*$ :	(various policymaker beliefs for $u^*$ ; true $u^* = 4.5 + \text{shocks}$ )						
	[A]	[B]	[C]	[D]	[E]	[F]	
	Standard Deviation		Normalized Losses			Welfare Improvement Share	
	$\pi$	$ugap$	Percentiles				
			10	50	90		
<b><math>Eu^* = 4.5 + \text{shocks}</math></b>							
1	Balanced approach	1.33	1.01	0.52	1.00	1.93	0.0
2	Inflation averse	1.25	1.37	0.60	1.20	2.33	11.1
3	Unemployment averse	1.35	0.78	0.43	0.87	1.80	90.4
<b><math>Eu^* = 3.7</math></b>							
4	Balanced approach	1.35	0.94	0.68	1.24	2.31	25.0
5	Inflation averse	1.25	1.34	0.63	1.25	2.40	15.6
6	Unemployment averse	1.40	0.71	0.66	1.21	2.41	32.9
<b><math>Eu^* = 5.3</math></b>							
7	Balanced approach	1.37	1.15	0.69	1.34	2.60	18.4
8	Inflation averse	1.26	1.39	0.62	1.22	2.38	7.4
9	Unemployment averse	1.42	1.02	0.73	1.48	3.08	18.9

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 2018:Q3 and go through 2025:Q4, and are under model-consistent expectations (MCE). Columns A and B show the standard deviation of the four-quarter core PCE inflation rate ( $\pi$ ) 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  $u^* = 4.5 + \text{shocks}$ . 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 2020:Q4**

(sFRB model, alternative shock sets and bootstrapping methods)

	$u > 7\%$	Value of $u$ at percentile:		ELB <sup>+</sup>	$\pi > 2.5^*$
		90 <sup>th</sup>	99 <sup>th</sup>		(4Q Avg)
benchmark	0.4	5.3	6.6	3.8	28.6
1984-2016 shocks	0.1	5.0	6.1	2.9	23.0
MS bootstrap <sup>**</sup>	6.1	5.5	9.1	5.8	25.9

\* Percentage of draws in which four-quarter rate of core PCE inflation average more than 2½ percent in the four quarters ending 2020: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 in 2020:Q4

## Appendix F. Results Under VAR-Based Expectations

**Table F.1. Macroeconomic Performance in 2020  
Under Monetary Policy Strategies (VAR-Based Expectations)**

(policymaker believes  $u^* = 4.5 + \text{shocks}$ )

True $u^*$ Process:	[A]	[B]	[C]	[D]	
	$u < 3.5\%$ and $\pi < 1.75\%$		$u < 3.5\%$ and $\pi > 2.5\%$		
	<u>Probability</u>	<u>Q4 FFR</u>	<u>Probability</u>	<u>Q4 FFR</u>	
<b><math>u^* = 4.5 + \text{shocks}</math></b>					
1	Balanced approach	13.0	5.2	3.5	8.0
2	Inflation averse	18.1	2.4	7.2	7.3
3	Unemployment averse	2.3	9.0	0.2	12.3
<b><math>u^* = 3.7</math></b>					
4	Balanced approach	15.5	5.3	4.1	8.1
5	Inflation averse	20.9	2.4	7.9	7.4
6	Unemployment averse	3.2	9.2	0.3	11.7
<b><math>u^* = 5.3</math></b>					
7	Balanced approach	10.2	5.1	3.0	7.9
8	Inflation averse	15.5	2.4	6.4	7.3
9	Unemployment averse	1.8	8.7	0.2	11.6

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 ( $\pi$ ) over the year 2020. The federal funds rate reported is the mean 2020:Q4 funds rate in simulations satisfying the respective criteria.

**Table F.2. Policymaker Loss Under Alternative Monetary Policy Strategies For Selected (Mis)perceptions of  $u^*$  (VAR-Based Expectations)**

True $u^*$ Process:	(policymaker believes $u^* = 4.5 + \text{shocks}$ )						
	[A]	[B]	[C]	[D]	[E]	[F]	
	Standard Deviation		Normalized Losses			Welfare Improvement Share	
	$\pi$	$ugap$	Percentiles				
		10	50	90			
<b><math>u^* = 4.5 + \text{shocks}</math></b>							
1	Balanced approach	1.09	1.03	0.50	1.00	2.23	0.0
2	Inflation averse	1.00	1.41	0.61	1.28	2.79	17.9
3	Unemployment averse	1.16	0.80	0.40	0.88	2.25	65.5
<b><math>u^* = 3.7</math></b>							
4	Balanced approach	1.10	1.10	0.55	1.20	2.65	30.3
5	Inflation averse	1.01	1.46	0.55	1.28	3.07	29.1
6	Unemployment averse	1.18	0.87	0.62	1.28	2.91	21.7
<b><math>u^* = 5.3</math></b>							
7	Balanced approach	1.08	1.17	0.74	1.34	2.55	18.9
8	Inflation averse	0.99	1.57	0.86	1.66	3.43	10.4
9	Unemployment averse	1.16	0.95	0.63	1.12	2.25	33.3

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 2018:Q3 and go through 2025:Q4, and are under VAR-based expectations. Columns A and B show the standard deviation of the four-quarter core PCE inflation rate ( $\pi$ ) 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.