Designing Monetary Policy Rules in an Uncertain Economic Environment*

BY MICHAEL DOTSEY AND CHARLES I. PLOSSER

A well-designed monetary policy can help the economy respond efficiently to economic disturbances by limiting the deviation of economic activity from its potential while keeping inflation close to its desired rate. But successful implementation of such strategies must confront significant challenges arising from various forms of economic uncertainty. In this article, Michael Dotsey and Charles Plosser discuss the design of monetary policy rules in an environment in which policymakers face two distinct forms of uncertainty: the uncertainty surrounding the precise values of key policy variables that often appear as determinants in such rules, and learning uncertainty, which arises when people have only an incomplete knowledge of the economy itself.

A well-designed monetary policy can help the economy respond efficiently to economic disturbances by limiting the deviation of economic activity from its potential while keeping inflation close to its desired rate. But successful implementation of such strategies must confront significant challenges arising from various forms of economic uncertainty. This article discusses the design of monetary policy rules in an environment in which policymakers face two distinct forms of uncertainty. The first involves the uncertainty surrounding the precise values of key policy variables that often appear as determinants in such rules. These variables are typically measures of resource utilization relative to some concept of potential. This data uncertainty can arise because the relevant conceptual definition of potential may be uncertain and even if it is clearly defined, it may not be observable and thus measurement error becomes an important consideration. The second form of uncertainty we refer to is learning uncertainty, which arises when people have only an incomplete knowledge of the economy itself.

Regarding the first source of uncertainty, it is well documented that the key policy variables mentioned above are measured with considerable error. Thus, the true value of these variables is uncertain at the time policy is made. With respect to the second source of uncertainty, we believe that most people do not possess complete knowledge of the economy and that their behavior is characterized by a continual learning process in which their views about the economy evolve over time. Policymakers must recognize these uncertainties when designing policy. Throughout our discussion, we take as given the desirability of rule-like behavior for policy.[1] It is widely accepted in the economics profession that rule-like behavior is preferable to discretion because more desirable economic outcomes can be obtained with commitment.[2] We will

[1] For example, see the following: Michael Dotsey and Charles Plosser (2007), Michael Dotsey (2008), and Charles Plosser (2007).

[2] In the monetary setting, this has been made abundantly clear by, among others, Richard Clarida, Jordi Gali, and Mark Gertler, and Michael Woodford.

*The views expressed here are those of the authors and do not necessarily represent the views of the Federal Reserve Bank of Philadelphia or the Federal Reserve System.

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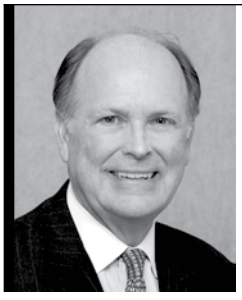

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also concentrate on the conduct of monetary policy in normal times and will, therefore, not address the special problems brought about by the zero lower bound on nominal interest rates.[3]

The basic conclusion from the literature is that when policymakers are trying to achieve the best outcomes in terms of economic welfare, these types of uncertainty make it desirable for the central bank to respond relatively aggressively to deviations of inflation from target and to rely less on measured deviations of either output or unemployment from their natural or potential values. Rather, the central bank should also respond to economic growth irrespective of where economic activity is with regard to potential or trend.[4]

USEFULNESS OF INTEREST-RATE RULES

In analyzing the design of beneficial ways in which to conduct monetary policy under uncertainty, we will concentrate on the use of an interest-rate rule. The types of rules we will discuss are fairly simple ones and ones that have been shown to be useful for policymaking. These rules are generally designed to stabilize some measure of economic activity and inflation, because doing so leads to more efficient economic performance. Simple interest-rate rules tend to perform well in many different economic models, a fact that suggests they can be useful in practice. Thus, it is no accident that the behavior of most central banks in developed economies can be reasonably approximated by a simple interest-rate rule.[5]

However, the formulation of monetary policy rules must take into account the uncertainty that policymakers face, since rules designed under the assumption of no uncertainty are often disastrous when one explicitly considers uncertainty. In particular, a rule may, in theory, perform quite well when data are measured accurately but be quite bad when data are subject to severe measurement errors. Also, rules that work well under the assumption that individuals fully understand their economic environment may not do so well when individuals are constantly learning about economic circumstances.

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AN OVERVIEW OF UNCERTAINTY

Many of the variables that a central bank reacts to in the course of setting its interest-rate instrument are in fact poorly measured. In particular, statistical measures of potential output or natural rates of unemployment are measured with great imprecision.[6] Thus, relying on these types of measures can potentially lead policy astray. By a statistical measure we mean an estimate of potential output or unemployment that is based solely on data and, therefore, is independent of any particular theoretical model. For example, a common measure of potential output involves extracting a trend rate of output growth or some other relatively smooth measure of output growth that removes much of the short-run variation in output.[7]

There is also a concern that statistical measures are not likely to correspond to the conceptual metrics most relevant for monetary policy. Indeed, it is difficult to assign any theoretical justification for the use of these purely statistical constructs.[8] Thus, when deciding on which measure of economic activity is important for formulating monetary policy, central banks operate under a large degree of uncertainty. Much recent research has shown that ignoring this uncertainty can create problems.

We will first discuss the problems that data uncertainty poses for designing monetary policy. A strong conclusion from the literature on data

[3] For a discussion of the problems the zero lower bound presents for monetary policy, see Dotsey's 2010 article.

[4] Potential output is the output that could be produced with the labor, capital, and technology available in the absence of economic distortions arising from stickiness in prices and wages. A more complete description of potential can be found in the *Business Review* article by Roc Armenter. Trend is the long-term growth path of an economic variable.

[5] For a review of simple interest-rate rules, see the article by John Taylor and John Williams. See also the article by Marc Giannoni and Michael Woodford and the one by Stephanie Schmitt-Grohe and Martin Uribe for a discussion of their optimality.

[6] The natural rate of unemployment is the rate of unemployment that would arise if there were no stickiness in the setting of wages and prices. That is, it is the rate of unemployment that would occur if prices and wages were completely flexible. It is also the rate of unemployment that the economy would converge to in the long run after all price and wage rates had time to fully adjust to economic disturbances. The concept is thus tightly related to potential output (see footnote 4).

[7] Common statistical methods involve the use of band-pass filters, Hodrick-Prescott filters, or fitting polynomials of time to the data.

[8] See the 2010 speech by Charles Plosser and Roc Armenter's and Keith Sill's *Business Review* articles. All three point out that there is no agreed-upon way of measuring potential and that various measures may differ. In addition, Sill emphasizes that in setting prices, firms are most concerned with the evolution of their marginal cost and that marginal cost is not highly correlated with unemployment rates.

uncertainty is that "gap-type measures," especially statistical measures of gaps, are not reliable enough to base policy on, a conclusion that is shared by the literature on learning.

Most of our attention will be focused on the topic of data uncertainty for two reasons. First, the effects of data uncertainty on policy design have been more fully studied, and second, the work done by the Philadelphia Fed's Real-Time Data Research Center underscores the importance of measurement issues.

We then turn to some issues associated with the likely possibility that people may not possess a fully articulated understanding of the economy.

CONCEPT UNCERTAINTY

In most modern macroeconomic models used to study monetary policy, minimizing the theoretical gap between actual output and potential output improves economic welfare. Thus, the notion of potential output plays a key role in setting monetary policy. However, theory-based concepts of potential often differ from the statistical concepts that many people believe belong in policy rules. We refer to the lack of coherence between statistical and theoretical measures of gaps as "concept uncertainty."

The theoretical gaps are also specific to the particular theory or model being used to study the economy. Because each model is different, the gaps in each model are different. For example, the way that one models firms' pricing decisions can theoretically affect the value of an output gap.[9] This lack of an agreed-upon macroeconomic model indicates that designing monetary policy rules that help achieve reasonably good economic performance is a challenging undertaking. How one goes about doing this represents an ongoing part of economists' research agenda and is beyond the scope of this paper. What we will try to do here is to emphasize certain lessons that appear to be consistent across many economic models and for which there is a growing consensus regarding their implications for policy.

One lesson from the literature is that the statistical gaps often prescribe policies opposite to those obtained from the theory-based gap.[10] For example, an unanticipated improvement in productivity often leads potential output to increase by more than actual output and hence generates a negative theoretical output gap. This outcome occurs because various inflexibilities built into operational models of the U.S. economy imply that economic variables move more slowly than they would if they could adjust without cost and with complete flexibility and potential output is the output that would arise if there were, in fact, no inflexibilities.

In contrast, potential output based on some statistical trend does not increase as much as actual output in response to a positive productivity shock, leading to a positive output gap (see the article by Roc Armenter).[11] This occurs because when output increases in response to an increase in productivity, only part of that increase is initially attributed to a change in trend, and thus, statistically constructed potential output is always smoother than actual output. Therefore, the two different measures would lead to opposite monetary policy responses, and the response based on the statistical measure would be in the wrong direction.

Furthermore, levels of statistical gaps may not be good indicators of inflationary pressures in the economy. Empirically, they do not help to forecast inflation and that has been especially true over the last 25 years.[12] Keith Sill analyzes some of the reasons for this failure, namely, that measures of various gaps are not very correlated with the costs of producing goods, and it is the underlying behavior of costs that governs firms' pricing decisions in most modern macroeconomic models.

These conceptual problems call into question the usefulness of statistically based gaps in designing monetary policy. Furthermore, it is far from evident that monetary policy has always been conducted with regard to statistically based measures, and when it has, the results have at times been disastrous. We will return to this point after discussing the measurement issues more fully, but the 2002 study by Athanasios Orphanides has made a compelling argument that part of the

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[9] In fact, as things stand theoretically, the situation is even a bit more muddled. It turns out that it may not be the level of the gap that is most relevant for policy; it may be the change in the gap that should influence monetary policy. For example, Woodford's model shows that changes in the theoretical gap, not the gap's level, are the relevant variable for welfare and hence the relevant variable that the interest rate should respond to.

[10] We wish to point out that there is also no agreed-upon model of the macro economy and that theoretical gaps differ across models. Our discussion, however, pertains to results that are consistent across a wide range of economic models.

[11] A positive output gap occurs when actual output is greater than potential output. A negative output gap occurs when actual output is less than potential output.

[12] For a detailed description of this failure, see the studies by James Stock and Mark Watson.

Great Inflation of the 1970s was due to misperceptions about the unemployment gap.

UNCERTAINTY SURROUNDING STATISTICAL MEASURES

Even though statistical output gaps have not universally guided U.S. monetary policy, it does appear that they have periodically played a role in influencing U.S. monetary policy. Thus, it is worth looking into the measurement issues and the implications that these measurement issues have for using statistical gaps.

Essentially, constructing an output or unemployment gap requires breaking down output or unemployment into a trend component and a cyclical component. From a policy perspective, we are interested in how much current output or unemployment is deviating from the current measure of trend.

There are two primary reasons why both statistical output gaps and unemployment gaps may be poorly measured from the perspective of implementing monetary policy. The first is that the data from which they are constructed are significantly revised, and the second is that future data also significantly affect our estimates of the current and past measures of trend and hence potential. That is, it helps to know the entire path of output or unemployment, both past and future, when figuring out what part of their current values reflect a general trend.

For example, consider a simple exercise that estimates trend unemployment and the deviation of unemployment from trend. The figure shows the difference between estimates of trend unemployment using all of the available data, which we denote as the final estimate, and its estimate when only data available at each point in time are used to construct the trend. We will refer to this as a real-time estimate.[13] (See *Constructing the Figure*.)

Although we have used a very simple statistical technique to calculate trend unemployment, the basic thrust of our results would carry over if more sophisticated statistical techniques were used.[14] In addition, we have performed the analysis using the latest estimates of unemployment and so have ignored the effects of data revisions. In general, although revisions do contribute to measurement error in estimating the unemployment gap in real time, this channel is less important than the inability to see future unemployment rates when estimating trend unemployment.

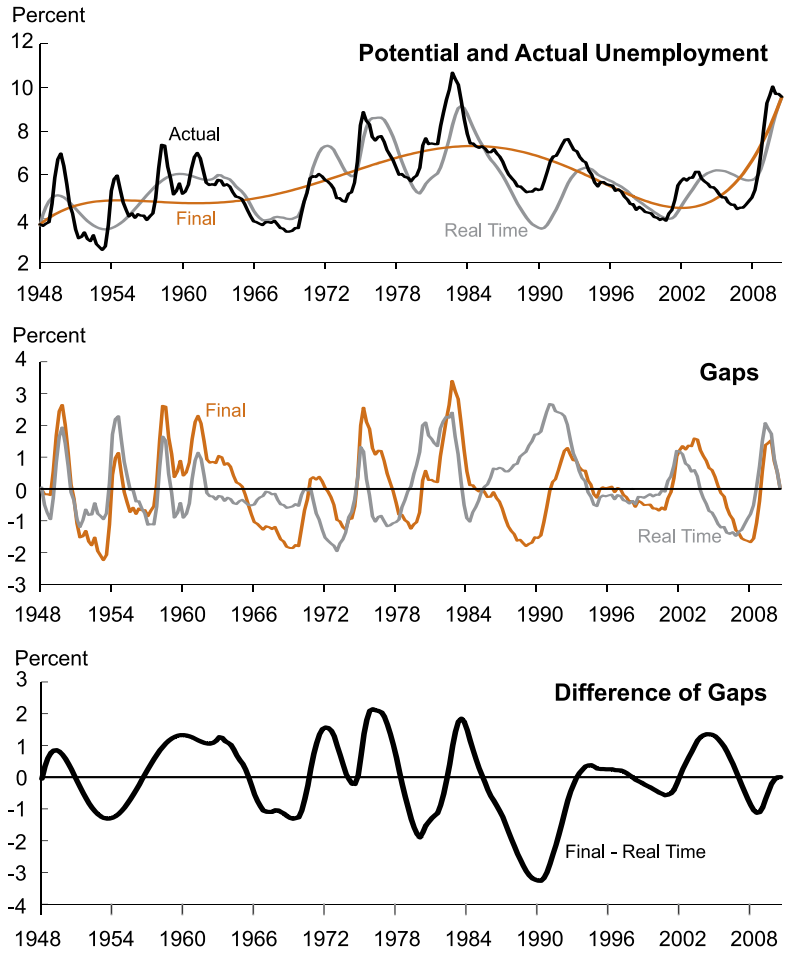
The evidence regarding the statistical uncertainty in measuring unemployment gaps is also present when one examines output gaps. A detailed examination of the measurement problems in calculating output gaps is provided in a paper by Athanasios Orphanides and Simon van Norden. Their basic findings are similar to what

[13] A true real-time estimate would use only the data as they were reported at the time. Therefore, we ignore measurement error issues associated with initial data that are subsequently revised, but it turns out that estimation errors associated with data revisions are a relatively small problem.

[14] For a detailed comparison of different statistical measures of trend unemployment, see the 2002 study by Athanasios Orphanides and John Williams.

FIGURE

Potential and Actual Unemployment



Source: Estimates constructed by authors using data from the Bureau of Labor Statistics.

we have just shown for the unemployment gap. Using various statistical estimates that are more sophisticated than the one used in our example (there are many ways to estimate a trend), Orphanides and van Norden arrive at very different estimates of the gap, especially the real-time gap. The different estimates in real time can vary by more than 6 percentage points and by more than 3 percentage points when final data are used. Furthermore, for various measures the revisions between real-time and final estimates are frequently larger than 4 percentage points in absolute value. Thus, the revisions are often nearly the same size as the output gap measures themselves. Also, the revisions are persistent, implying that measurement errors are long-lived.[15] Finally, the estimated gaps in real time are often of the opposite sign when compared with the final estimates.

In general, data revisions also contribute a small share to the difference in the real-time and final estimates of the output gap. Most of the revision is due to the fact that the final estimates use all of the data over the full sample and that data are useful in establishing the estimated trend.

We should mention that there are also data revisions of many inflation series and that inflation, therefore, suffers from measurement issues. However, because the data uncertainty surrounding inflation is affected only by data revisions to inflation itself and not by imprecise estimates of an inflation gap, the data uncertainty surrounding inflation is generally minor when compared to the uncertainty surrounding the unemployment or output gap. Therefore, we ignore the uncertainty associated with inflation and treat inflation as an accurately measured variable in real time.[16]

After reviewing the measurement problems, we conclude they are severe. The question then is what role these measurement problems should play in the way we design monetary policy.

IMPLICATIONS OF DATA UNCERTAINTY FOR MONETARY POLICY DESIGN

The general message from the literature is that basing policy on gap-type concepts is problematic and that it pays to respond fairly aggressively to movements in inflation from target. It also appears that responding to economic activity itself, as opposed to "gaps," is quite helpful when design-

[15] Autocorrelation coefficients range from 0.80 to 0.96. Autocorrelations show the correlation between two values of the same variable at different times, rather than the correlation between two different variables.

[16] However, there have been episodes in which core personal consumption expenditures (PCE) have been substantially revised. One particularly large episode occurred in 2001 when inflation, as measured by the core PCE, was revised up by approximately 1 percent and what was initially observed as declining inflation actually became a period of rising inflation. For more details, see the study by Dean Croushore.

Constructing the Figure

In this example, the trend is constructed using a common statistical technique of fitting the unemployment rate to an equation based on time.* For the final estimate, the equation is estimated on data from the first quarter of 1948 to the fourth quarter of 2010, and the orange line in the top panel represents the fitted curve. The real-time estimates are constructed by estimating the same equation using data only up to the period in question and calculating the trend value at that time. We start in 1963 so that our initial real-time estimate is made using 15 years of data. In particular, for the estimate of the trend in the first quarter of 1963, we use data from the first quarter of 1948 to the first quarter of 1963 and calculate the trend for the first quarter of 1963. We then update our estimation of the trend by using an additional quarter of data and make the analogous calculation of the trend for the second quarter of 1963. We continue this procedure until the fourth quarter of 2010. As we approach the end of the sample period, the two trend measures begin to converge. They do so because the data used in constructing each measure become similar as the end of the sample is approached, and they are exactly the same for the last data point. This happens not because the real-time estimates are getting better but because the final-time estimates no longer have the advantage of information contained in unemployment rates that have yet to occur.

The actual unemployment rate is shown by the black line in the top panel of the figure, and estimates of the real-time trend are displayed by the grey line. The final-time estimates are depicted by the orange line. It is obvious that the real-time and final-time estimates are very different. In the middle panel, we plot the unemployment gaps, which are the difference between the unemployment rate and the estimated trends. The average absolute values of the gaps are 0.83 for the real-time gap and 0.93 for the final-time gap. The differences between the two gaps are large, with an absolute average value of 0.95. Thus, the differences in the gap measures are bigger than the estimates of the gaps themselves. Furthermore, the gaps are often of opposite sign and the differences in their values are persistent.

* In particular, we postulate that the unemployment rate is a particular function of time. In particular we estimate $u = a_0 + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 + a_5 t^5 + e$ using data from 1948Q1 to 2010Q4, where t is the number of periods from the beginning of our data sample. We use the estimate of this function to calculate the trend.

ing policy under data uncertainty. Basically, one should not base policy on poorly estimated measures, and economic activity is much better measured than gaps.

A useful paper that articulates this message is the 2002 study by Orphanides and Williams that investigates the effects of mismeasurement of the natural rate of unemployment, which is also easy to translate into a similar message regarding the use of statistically based output gaps.

Orphanides and Williams calibrate misperceptions of these natural rates using U.S. data from the first quarter of 1970 to the second quarter of 2002. As in our analysis above, they measure misperceptions by the difference between potential measured in real time and potential when measured using the data over the entire sample. For these authors as well, the additional data provided by the full sample turn out to be very important for breaking down unemployment into its true trend and cyclical movements. Hence, the limitation of not observing the future potentially creates a lot of uncertainty about the trend in unemployment. As in the study by Orphanides and van Norden, the authors show that the misperceptions about the natural rate of unemployment are large and highly persistent.

Given this uncertainty, Orphanides and Williams analyze what types of monetary policy rules work in their fairly simple environment. Although it is natural to question whether results in such a simple setting can be generalized to more realistic and complex models of the economy, we believe that qualitatively, at least, the lessons learned from their exercise are informative for designing policy.

The basic result is that under data uncertainty, the monetary authority wants to minimize the degree to which that uncertainty affects policy. That conclusion seems quite intuitive. Furthermore, the more uncertain the central bank is at any given point in time, the more it should reduce the potential effect that misperceptions may have on policy. This is certainly a message that should resonate with policymakers in the current economic environment.

The central bank minimizes uncertainty's effect on monetary policy by moderating its response to the gap compared to what it would do if it knew the gap with certainty. The central bank also increases its response to inflation and is somewhat inertial, changing interest rates gradually. This inertial behavior reduces the effects of uncertainty. The results go further and indicate that central bank policy is improved when it responds to changes in unemployment (or output growth) rather than only responding to gaps.[17]

Furthermore, the optimal policy derived under uncertainty does not perform badly in a world that hypothetically has no uncertainty, while policies formulated as if there were no uncertainty can be quite disastrous when, in fact, there are measurement issues. In part, that feature, as Janet Yellen has pointed out, is due to the fact that rules based on natural rate concepts tolerate significant departures of inflation from target when natural rates are badly measured. For example, if the monetary authority incorrectly thought that current output was well below potential, it would ease monetary policy and tolerate additional inflation. The rules that instead respond to changes in economic activity are not as forgiving because economic activity is much more precisely measured, and inflation is, therefore, less likely to drift from target.

The 2003 study by Orphanides provides additional intuition as to why gap-type rules perform badly when both inflation and gaps are mismeasured in real time. With mismeasurement, these types of rules essentially introduce a policy error into monetary policy. The interest rate set by the central bank responds to measurement error because the interest rate is not only responding to the true gap but also to the error in measuring that gap. The induced policy error, in turn, affects the economy, increasing the variance of both output and inflation.

The exercises in the 2002 study by Orphanides and Williams and the 2003 study by Orphanides are, to our minds, not just mere theoretical curiosities but are indicative of actual problems that have occurred when policy has been based on gaps and when these gaps have been badly measured. A particularly powerful example is given in the 2002 study by Orphanides, in which he discusses the Great Inflation of the 1970s. While we don't believe that mismeasurement is the sole reason for the stagflation of that era, we do believe it was a contributing factor.[18]

The economic experience of the 1970s was indeed a disaster, and monetary policy played a role in the decade's dismal economic performance. Part of the problem appears to have its foundation in basing monetary policy on unemployment gaps. Persistent errors in measurement lead to persistent errors in policy.

Over much of the 1970s real-time estimates of the natural rate of unemployment indicated that the economy was operating below its full-employment potential when in fact the opposite was true. This misperce-

[17] The substitution of responding to changes in economic activity rather than responding to the level of some gap is also reminiscent of the study by Bennett McCallum and Edward Nelson, who reach this conclusion using a model that is different from that of Orphanides and Williams.

[18] Another potentially important aspect was that individuals began to believe that the Fed had raised its inflation target. We will return to this feature when we discuss the role of learning.

tion lent an inflationary bias to policy over that period. Thus, had the Fed been responding to inflation and the unemployment gap by following a classic Taylor rule over this period, the misperceptions about both potential unemployment and forecasts of current inflation would have led to funds rate settings that were very close to what actually occurred.[19] Thus, the FOMC might have believed it was operating according to a well-designed policy rule, when in fact the errors induced by misperceptions about key variables implied a policy that acted as if the inflation target was increasing.

On the other hand, the 2002 study by Orphanides and Williams also indicates that during the strong growth of the late 1990s, the Fed was not responding to gaps but was following policy rules that incorporated economic growth. By adhering to this alternative type of rule, which responds aggressively to deviations of inflation from target and to economic growth, the Fed averted a large deflation that would have occurred if it had, in fact, been paying attention to unemployment gaps. According to the book by Robert Hetzel, former Fed Chairman Alan Greenspan's dismissal of the relevance of gaps as a basis for setting monetary policy had its precursor under the regime of William McChesney Martin. During most of Martin's tenure as Chairman, the Fed raised interest rates early on in recoveries, responding to economic growth rather than gaps.[20]

To summarize, the lessons from this literature for policymakers when responding to statistical measures of a gap are (1) statistical gaps should not be a major contributing factor in implementing policy, (2) policy should aggressively respond to inflation when it moves away from target, (3) it is appropriate to take measures of economic growth into account when deciding on the level of short-term interest rates, and (4) there is a role for gradualism or inertia in policy.

UNCERTAINTY DUE TO LEARNING

Another type of uncertainty arises because individuals may not be fully aware of the underlying theoretical model that explains the economy, even when such a model exists. In this case, individuals may look at actual data and try to infer from the data what will happen in the future. That is, their economic forecasts will depend on statistical inference based on historical data and not on a deep theoretical understanding of the economy. In this case, the central bank's own actions affect what individuals believe about the actions the central bank will take in the future and cause individuals to update their beliefs about the future.

It turns out that in such a situation, the best monetary policy will be substantially different from the best policy that would arise if everyone knew how the economy operated. The effects of this type of uncertainty are dealt with in the 2006 and 2007 papers by Orphanides and Williams. A striking feature of their results is that the best policy designed under the assumption that individuals know the true model of the economy performs very poorly when, in reality, individuals don't know the model and forecast the future based solely on historical data.

To set the stage more precisely, we examine their analysis in a bit more depth. Their model, like most models used for policy analysis, is one in which there is a trade-off between stabilizing inflation and stabilizing unemployment. One cannot fully stabilize both inflation and unemployment. The central bank can stabilize inflation to a greater extent, but doing so leads to more economic volatility. The reverse is also true, so the central bank tries to stabilize both variables as best it can.

Doing so requires the central bank to react to deviations of inflation from target and unemployment from its natural rate, raising the interest rate when inflation is too high and lowering the interest rate if unemployment is above its natural rate. Thus, their economic model embeds important real-world characteristics.

To understand how policy design is affected by learning when individuals have an imperfect understanding of the economy, we need to first understand how the presence of learning affects economic outcomes.

To understand how policy design is affected by learning when individuals have an imperfect understanding of the economy, we need to first understand how the presence of learning affects economic outcomes. Basically, learning gives rise to more volatility and persistence in the economy. Relative to knowing exactly how the economy works, individuals are less informed and, therefore, make mistakes. Thus, economic activity is influenced not only by fundamental shocks to

[19] Stanford economist John Taylor developed a formula to suggest how a central bank should set short-term interest rates as economic conditions change to achieve both its short-run goal for stabilizing the economy and its long-run goal for inflation.

[20] William McChesney Martin served as Chairman of the Federal Reserve from April 1951 to January 1970.

the economy but also by misperceptions due to learning. The effect of economic disturbances becomes more prolonged because it takes time for individuals to learn.

For example, if inflation goes up in response to some economic disturbance, inflation will be higher than individuals originally thought. This higher inflation will lead them to make a forecasting error: They will forecast higher inflation in the future, and importantly, they may reassess the value of the central bank's inflation target. Their misperceptions will, to some extent, be realized. Firms, whose expectations of future inflation rise, raise their prices and inflation does, in fact, rise. As the effect of the economic disturbance wears off, individuals' forecasts of inflation will become more closely aligned with what they would have forecast if they had perfect knowledge of the economy. However, the deviation of the forecast under imperfect knowledge from that under perfect knowledge persists for a while, and that deviation leads to more persistence in unemployment and inflation.

The effects of learning on the actual behavior of inflation can be even more dramatic and more harmful if changes in inflation lead individuals to reassess the central bank's inflation target. In those circumstances, individual expectations of inflation and the goals of the central bank can become unhinged. The result can be economic instability.

Understanding that individuals are learning, the monetary authority can improve economic performance by taking these features into account when designing policy. For example, the central bank should be more aggressive when reacting to deviations of inflation from target. By doing so, it reduces the persistence of inflation and reduces the consequences that arise when individuals gradually learn about the economy. It also reduces the probability that individuals will reassess the underlying goal for inflation. For example, if the monetary authority reacted so vigorously to changes in inflation that inflation never changed, then individuals would have no problem forecasting inflation. It would always be at the target. Individuals would make no forecasting mistakes with respect to inflation, and there would be no deleterious effects from learning on economic activity – at least with regard to inflation.

Perfectly targeting inflation, however, is not desirable because it would create too much volatility in unemployment. Recall the trade-off. However, there is now an added cost of inflation volatility in an environment where individuals learn. Volatility in inflation makes it harder to learn and hence to forecast future inflation. It is now beneficial for the central bank to react more strongly to changes in inflation. Also, as in the previous discussion, it is worthwhile to react to changes in unemployment and to not rely solely on output gaps when conducting policy.

Not reacting aggressively to inflation and responding vigorously to output gaps may have played a significant role in the rising inflation and stagflation of the 1970s. This thesis is persuasively argued in a 2005 paper by Orphanides and Williams and serves to validate the thesis set forth in Orphanides' 2002 paper. In their study, Orphanides and Williams postulate that during the large oil-price shocks in the 1970s, it is reasonable to assume that individuals were constantly learning and updating their beliefs about the economy. In addition, the authors re-document the extreme real-time mismeasurement of the natural rate of unemployment in official estimates. In particular, real-time measures of the natural rate greatly underestimated the true natural rate. Further, the FOMC at the time was aggressively responding to unemployment gaps in an effort to stabilize the economy. The misperception of the unemployment gap led to persistent, overly expansionary monetary policy to the extent that public perceptions of the Fed's desired inflation rate began to rise and inflation expectations became unhinged. In other words, the Fed lost credibility for maintaining price stability. The result was stagflation: rising inflation and a severe economic contraction.

Orphanides and Williams then analyze two interesting hypothetical situations in a model economy similar to the one alluded to above. The first hypothetical question is: What if the FOMC had responded to the economy more like the subsequent policy instituted by Paul Volcker, where less weight was placed on stabilizing unemployment or, more generally, economic activity? The answer is that both unemployment and inflation would have been considerably lower. The second hypothetical question is: What if the FOMC had paid no attention at all to the unemployment gap? In that case, both inflation and unemployment would have been even lower still. Thus, an overemphasis on economic stabilization can in practice have serious economic consequences, which, in theory, can be avoided by responding aggressively to deviations of inflation from target and placing less emphasis on economic stabilization in the policy rule.

SUMMARY

In this article, we have examined how two types of uncertainty — uncertainty from badly measured variables and uncertainty that arises because individuals do not fully understand how the economy operates — affect the design of monetary policy. The message from both examples is qualitatively the same. The central bank should acknowledge the existence of the uncertainty and formulate

its response to the economy accordingly. Ignoring the uncertainty generally leads to policies that do rather poorly and can be significantly improved.

Taking account of the types of uncertainty that we describe in this article and which we think are significant sources of uncertainty in reality leads to monetary policies that aggressively respond to inflation and that also respond to economic growth. Of interest is that policy should downplay the role of output and unemployment gaps and that policy should be very inertial, reacting gradually to economic disturbances. In the current economic environment, we believe the overriding message for future policy is that an overreliance on the magnitude of any particular gap is likely to yield results that could be greatly improved.

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