What Is the Optimal Inflation Rate?

By Roberto M. Billi and George A. Kahn

In the late 1970s and early 1980s, many countries, including the United States, experienced high inflation. A broad consensus emerged that this performance was unacceptable, and monetary policymakers around the world adopted policies designed to bring inflation down. With inflation undesirably high, policymakers knew what direction they needed to push inflation even if they were uncertain of its ultimate destination.

Now, with inflation much lower in the United States and elsewhere, the question of what inflation rate to aim for has moved front and center. Most policymakers agree they should not allow inflation to fall below zero because the costs of deflation are thought to be high. The decade-long economic slump that accompanied deflation in Japan in the 1990s provides an example of deflation's potential for harm.

Policymakers and economists disagree, however, about how much above zero, if any, central banks should aim to keep inflation. One reason for keeping inflation above zero stems from the fact that nominal interest rates cannot fall below zero. When inflation is low and expected

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to remain low, investors are willing to accept a low inflation premium when purchasing nominal debt instruments. As a result, nominal interest rates will tend to be low. And because central banks counteract slowing economic activity by lowering short-term interest rates, a very low-inflation environment limits the extent to which policymakers can respond to an economic slowdown. Once short-term rates fall to zero, conventional monetary policy tools no longer work to stimulate economic activity.

Knowing what inflation rate to aim for is also critically important because many central banks have adopted formal numerical inflation objectives over the last couple of decades. Setting an appropriate target for inflation requires understanding how alternative inflation objectives impact economic stability and overall economic well-being. Ideally, policymakers should aim for an inflation rate that maximizes the economic well-being of the public. Unfortunately, rigorous estimates of such an "optimal inflation rate" have not been available in the economics literature.

This article provides estimates of the optimal inflation rate. The first section describes why the optimal inflation rate might be somewhat above zero. The second section examines the relationship between alternative inflation objectives and macroeconomic stability, showing quantitatively how the likelihood of hitting the zero nominal interest rate bound is higher for lower inflation objectives. The third section provides estimates of the optimal inflation rate for the U.S. economy.

Based on a standard, modern macroeconomic model calibrated to U.S. data, the inflation rate that is optimal after accounting for the zero bound—but not necessarily all other relevant factors—is estimated to be 0.7 to 1.4 percent per year as measured by the PCE price index. This estimate is the first to be based on an economic model in which policymakers are assumed explicitly to maximize the economic well-being of the public. Further research is required to confirm or refine these results in models that incorporate a richer array of possible interactions between the long-run inflation objective and economic stability.

I. WHY MIGHT THE OPTIMAL INFLATION RATE BE LOW AND POSITIVE?

There is widespread agreement among the public, economists, and policymakers that inflation is bad for the economy. As a result, in recent decades, central banks have adopted policies first to fight inflation and then to keep inflation low. But, for a number of reasons, inflation can be too low. Accordingly, while policymakers want to keep inflation low, they have not typically aimed for zero inflation.

Why should inflation be kept low?

Inflation is costly. When it is unanticipated, it arbitrarily benefits debtors and hurts creditors by decreasing the nominal value of outstanding debt. It discourages saving and investment by creating uncertainty about future prices. And, it forces businesses and individuals to spend time and resources predicting future prices and hedging against the risk of unexpected changes in the price level.

Inflation is also costly even when it is fully anticipated. Through its interaction with the tax system, it can increase tax burdens by artificially raising incomes and profits.[1] For example, one study estimates that, because of this tax distortion, permanently lowering inflation by two percentage points could generate as much as an extra 1 percent of GDP per year (Feldstein). In addition, inflation causes firms to incur costs of changing prices. And, to the extent firms only infrequently change prices, inflation can distort relative prices and undermine the efficiency of the market's pricing mechanism. Finally, inflation causes individuals to hold less cash and make more trips to the bank because inflation lowers the relative value of money holdings. All of these factors cause the economy to operate less efficiently, hampering economic growth and ultimately reducing standards of living. As a result, policymakers want to keep inflation low.[2]

Why should inflation be above zero?

Although inflation is costly, for a number of reasons, inflation can be too low. First, available measures of inflation are imperfect and tend to overstate "true" inflation. Second, a little inflation may make it easier for firms to reduce real wages when necessary to maintain employment. Third, a negative inflation rate—deflation—could be even more costly than a similar rate of inflation, suggesting that a low rate of inflation might be desirable to insure against falling prices. Finally, at very low levels of inflation, nominal interest rates may be close to zero, limiting a central bank's ability to ease policy in response to economic weakness.

Measurement error. One reason policymakers may want to aim for a low but positive inflation rate is that available measures of inflation are imperfect and tend to be biased upward. For the U.S. economy, two closely watched measures of inflation are the consumer price index (CPI) and the personal consumption expenditure (PCE) price index.[3] Both indexes are designed to measure, in different ways, the average change in the prices of goods and services purchased by consumers.[4]

For a number of reasons, both indexes likely overstate "true" inflation. One reason is that adjustments for improvement in the quality of goods and services are inadequate. If the price of a good remains fixed but its quality improves, the consumer gets a better product for the same price. In effect, on a constant-quality basis, the price of the good has fallen. Statistical agencies try to adjust for such quality change in computing the price indexes but, to the extent quality improvements are understated, the indexes overstate inflation. Other factors that may introduce small upward biases of varying degrees into the inflation measures include difficulties in incorporating new goods into the indexes, changes in consumers' shopping patterns that may favor discount retailers, and, at least in the case of the CPI, consumer willingness to substitute cheaper goods and services for similar products that have seen price increases.

The Boskin Commission—appointed by the Senate Finance Committee to study the role of the CPI in government benefits programs—estimated that in 1996 the CPI overstated inflation by roughly 1.1 percentage points per year (with a "plausible range" of 0.8 to 1.6 percentage points). Since then, methodological improvements in computing the CPI have reduced to some extent the size of the measurement bias. Lebow and Rudd estimate a bias in the CPI in 2003 of about 0.9 percentage points per year (with a range of 0.3 to 1.4 percentage points). And, Gordon estimates a bias in 2006 of 0.8 percentage points per year.

The bias in inflation as measured by the PCE price index is thought to be somewhat less than the bias in the CPI. The main reason for this difference is that the PCE price index is less subject to substitution bias. While the CPI is based on a "market basket" of goods and services that is updated every two years, the PCE price index is "chain weighted," meaning that the market basket is updated each period based on the actual purchases consumers make. Thus, the PCE price index allows for continuous shifts across general categories of goods (such as from oranges to apples). Because consumer substitution of cheaper goods for higher-priced goods is more quickly captured in the PCE price index than the CPI, the bias in the PCE price index is thought to be somewhat lower. Recent estimates of the bias in the PCE price index run about 0.3 to 0.4 percentage point per year lower than that for the CPI.[5]

Because of measurement error in inflation, "true" price stability is associated with a low, positive rate of measured inflation. Moreover, a measured inflation rate of 0 percent would not correspond to price stability, but rather would imply a decline in the price level over time. Recent estimates suggest price stability would be associated with an inflation rate of just under 1 percent per year as measured by the CPI or 0.4 to 0.6 percent per year as measured by the PCE price index.

Downward wage rigidity. Another reason policymakers may want to aim for a low, positive rate of inflation is that nominal wages may be downwardly rigid. Wages are downwardly rigid if firms are unable to make nominal wage cuts because workers are unwilling to accept them. In a zero-inflation environment with downward wage rigidity, firms would find it difficult or impossible to lower workers' real wages in the face of declining demand. They may instead adjust labor costs by laying off workers, resulting in a higher unemployment rate. With a little inflation, however, firms can lower workers' real wages without lowering nominal wages simply by keeping nominal wage increases below the rate of inflation. Thus, as conjectured by Tobin, in the presence of such downward wage rigidities, inflation may "grease the wheels" of the labor market by allowing relative wages to fall even when nominal wages are downwardly rigid.

The effects of downward rigidities in wages and prices have been investigated by several authors—for example Akerlof, Dickens, and Perry (1996, 2000) and Akerlof and Dickens. The findings of this line of research have received some attention among policymakers, both in the United States and elsewhere. So far, however, the empirical evidence is inconclusive whether the macroeconomic effects of such rigidities are important. One reason is that most evidence on downward wage rigidity comes from periods of moderate to high, as opposed to low, inflation. Furthermore, it is plausible that downward rigidities, if present, would decline over time as monetary policy achieves credibility for maintaining a low-inflation regime. As a result, central banks tend not to emphasize downward wage rigidities in their monetary policy frameworks.

Debt-deflation. Another reason policymakers may choose to aim for a low, positive inflation rate is that they view the cost of deflation as particularly severe compared to inflation.[6] Aiming for a low, positive rate of inflation may reduce the risk of the economy ever experiencing deflation and its consequences.

Deflation is potentially a more serious problem than inflation because deflation lowers nominal asset values but typically not the nominal value of debt. To the extent assets are debt-financed, deflation raises the real cost of servicing debt. Servicing costs rise because debtors must make payments in dollars that are steadily increasing in real value. With asset values falling and real debt burdens increasing, debtors may be forced to sell assets, putting further downward pressure on prices. Or, they may default on their loans, causing problems for banks and other lenders. Thus, falling prices create a vicious cycle of rising real debt burdens and financial distress, leading in turn to more downward pressure on prices.[7]

Periods of debt-deflation have occurred in U.S. economic history and in modern Japan. As documented for example by Bernanke (2004b), deflation caused considerable economic stress in the period following the return to the gold standard after the Civil War and again during the Great Depression. More recently, in the 1990s the Japanese economy confronted deflation in the aftermath of a real estate price bubble. A prolonged period of falling prices in Japan led to steady increases in the real value of outstanding debt, a banking crisis, and a decade of economic stagnation.

Especially in light of the modern-day Japanese experience with deflation, policymakers want to prevent deflation. As a result, they may view a low, positive inflation rate as a "buffer" protecting the economy against adverse shocks that could push the inflation rate below zero and the economy into stagnation or recession.

Zero lower bound. The problem of debt-deflation is further exacerbated by the zero lower bound on nominal interest rates. Over the long run as inflation falls, nominal interest rates generally fall as well. Once nominal rates reach zero, they can fall no further, rendering the conventional instrument of monetary policy for stabilizing the economy ineffective.

Today, most central banks conduct monetary policy by setting a target for a short-term interest rate. In the case of the Federal Reserve, the Federal Open Market Committee (FOMC) targets the federal funds rate—the rate banks charge each other for overnight loans of reserves. Under normal circumstances, policymakers adjust the funds rate to achieve their objectives for output and inflation. To stimulate output, policymakers lower the target for the nominal funds rate. For a given rate of inflation, lowering the nominal funds rate leads to a lower real funds rate, which, over time, stimulates economic activity. Occasionally, policymakers can even achieve a negative real funds rate, if needed to offset the risk of recession, by setting the nominal funds rate below the expected rate of inflation.

In a very low-inflation environment, however, the federal funds rate is likely to be close to zero.[8] In such a circumstance, if the economy is hit by an adverse shock, leading to a fall in aggregate spending, monetary policymakers will have limited scope to stimulate the economy by lowering the funds rate. Once the funds rate reaches zero, conventional monetary policy no longer works.[9] Moreover, if the inflation rate is expected to fall below zero, the real funds rate will rise, resulting in an effective tightening of monetary policy. As a result, without conventional monetary policy tools, the economy may be less stable when inflation is kept very close to zero than when kept a little above zero.

As with debt-deflation, the possibility of hitting the zero bound is not simply a theoretical construct, but rather a real-world concern. In the United States, the federal funds rate fell to 1 percent in 2003 as policymakers eased policy to insure against the unlikely, but highly worrisome, possibility of deflation. Had the economy weakened further or inflation fallen further, policymakers would have had little additional room to maneuver before potentially having to resort to "nonconventional" monetary policy to stabilize the economy (Sellon). More alarmingly, Japanese policymakers actually confronted the zero bound as the policy rate in Japan fell to zero in the late 1990s. Eventually, policymakers in Japan were forced to adopt a number of nonconventional policies to further stimulate economic growth.[10] Despite these actions, economic activity remained stagnant in Japan through most of the 1990s and into the next decade.

The possibility of hitting the zero bound, along with measurement error, are the key reasons policymakers give for aiming for an inflation rate above zero. Although policymakers recognize the risks associated with debt-deflation, most macro models—including those examined in the remainder of this article—do not incorporate a debt-deflation channel. And, downward wage rigidity is absent from most macro models since its relevance is not clear.[11] Moreover, to some extent, by addressing the zero bound problem through a low, positive inflation objective, policymakers may simultaneously insure against the consequences of debt-deflation and downward wage rigidity.

The remainder of this article examines how, after accounting for measurement error, the zero interest rate bound gives rise to a low, positive inflation objective in standard macro models. The key question is how far above zero is enough to address these issues, given that inflation also has its own set of costs.

II. HOW DOES THE LONG-RUN INFLATION OBJECTIVE IMPACT MACROECONOMIC STABILITY?

Economists have used a variety of economic models to estimate the relationship between the central bank's long-run inflation objective and the likelihood of hitting the zero bound. In these models, a lower inflation objective leads to a higher incidence of hitting the zero bound. And a higher incidence of hitting the zero bound is associated with greater variance in real output and inflation since monetary policy becomes less effective at stabilizing the economy. Thus, these models provide an estimate of the tradeoff between the central bank's long-run inflation objective and the associated variation in real output and inflation.

Typically, models that account for the zero bound reach similar conclusions. The incidence of hitting the zero bound falls quickly as the inflation objective rises from 0 to roughly 4 percent. Moreover, the variation of output and inflation falls steadily, but at a decreasing rate, as the inflation objective rises. Policymakers have viewed this evidence with considerable interest but remain somewhat uncertain how much above zero their long-run inflation objective should be.

Empirical evidence

One type of evidence on the tradeoff between the long-run inflation objective and the variability of output and inflation stemming from the zero bound comes from simulating an econometric model. In one such study, Reifschneider and Williams examine the consequences of the zero bound in the FRB/US model—a large-scale structural model employed at the Federal Reserve Board for forecasting and policy analysis.[12]

In its basic structure, the FRB/US model follows a standard macroeconomic assumption that firms cannot instantaneously adjust nominal prices and wages. While wages in the model adjust slowly, they do not exhibit downward nominal rigidity. Nevertheless, because of nominal price and wage stickiness, changes in household demand and spending affect the amount firms produce for a given level of prices. As a result, monetary policy, which affects demand, can cause changes in employment and output before prices have time to fully adjust. Thus, sluggish nominal adjustment creates a channel through which monetary policy has temporary real effects on the economy. In the long run, however, when prices fully adjust, monetary policy induces changes only to the level of prices. In other words, monetary policy determines the long-run inflation rate.

Following the general practice of modern macroeconomics, monetary policy is characterized in the FRB/US model in terms of a "Taylor rule." The main feature of such a rule is that policymakers adjust the level of a short-term interest rate—the federal funds rate in the case of the Federal Reserve—to stabilize inflation at a given objective and hold output near the level consistent with full employment. Policymakers are assumed to follow such a rule systematically over time, even when faced with the occasional temptation to depart from it. Thus, the public perceives the policy as perfectly credible. That is, the public knows the policy rule and expects policymakers to abide by it systematically.[13]

When setting the funds rate according to a Taylor rule, policymakers may find themselves confronted with the zero interest rate bound. In particular, in a very low-inflation environment, where on average the funds rate is close to zero, policymakers may lack room to lower rates enough to stabilize the economy in an economic downturn. In contrast, in a high-inflation, high-interest rate environment, the zero bound is unlikely to bind, leaving policymakers ample room to lower the funds rate downward in response to falling output or inflation.

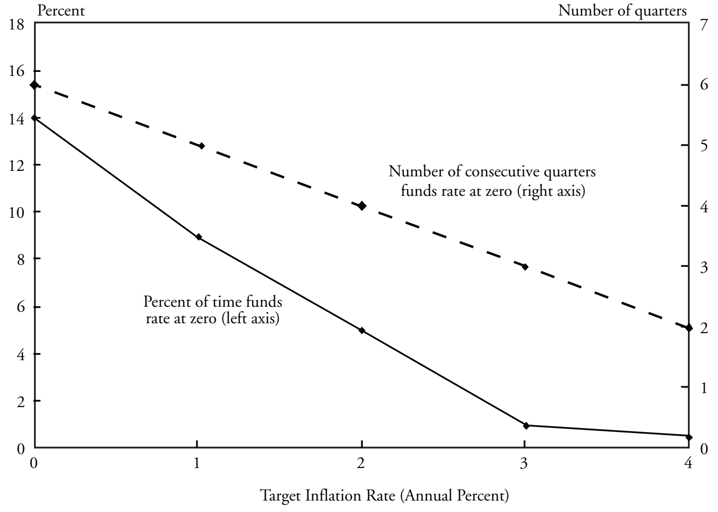
To examine the severity of the zero bound problem, Reifschneider and Williams simulate the FRB/US model under alternative assumptions about the long-run inflation objective. In performing the simulations, the authors assume the shocks buffeting the model economy are similar in magnitude to those that have actually hit the U.S. economy in recent decades. Since the size of the shocks is not unusual in a historical perspective, the simulations can be used to judge the extent of the zero bound as a problem for economic stability.

Chart 1 illustrates the importance of alternative long-run inflation objectives for monetary policy in the FRB/US model. As shown, with an inflation objective of 4 percent per year, as measured by the personal consumption expenditure (PCE) price index, the funds rate reaches the zero bound less than 1 percent of the time (bold line, left axis). In other words, the federal funds rate would be expected to fall to zero less than once every 100 quarters or, equivalently, less than four times every 100 years. And when it did hit the zero bound, the funds rate would be expected to remain at 0 percent on average for only two consecutive quarters (dashed line, right axis). As the inflation objective is lowered and the funds rate is on average closer to zero, however, policy is increasingly more constrained. For a zero-inflation objective, in fact, the funds rate would be expected to hit the zero bound 14 percent of the time (bold line, left axis) and stay there for six consecutive quarters (dashed line, right axis).

An increased incidence of hitting the zero bound leads to greater macroeconomic instability. Chart 2 illustrates this implication. As seen in the previous chart, in a low-inflation environment, where interest rates are closer to zero on average, the ability of policymakers to sta-

Chart 1

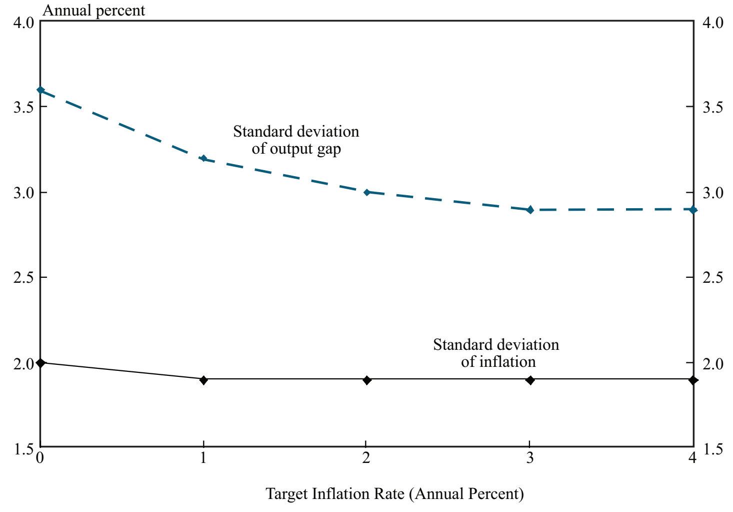
INFLATION TARGETS AND THE ZERO BOUND IN THE FRB/US MODEL



Notes: The chart illustrates results of Reifschneider and Williams (top panel of table 1) for the FRB/US model. Monetary policy follows a simple Taylor rule, estimated for the period 1980 to 1997 using quarterly U.S. data, where the funds rate depends on the CBO measure of the output gap—given by the difference between actual real GDP and the CBO estimate of potential real GDP—and the PCE price index over the past four quarters.

Chart 2

INFLATION AND ECONOMIC STABILITY IN THE FRB/US MODEL



Note: See Chart 1.

bilize the economy is limited. As a result, the lower the objective for inflation, the less stable output, inflation, or both, will be. And indeed, the model suggests output stabilization is problematic in a very low-inflation regime. For example, if the inflation objective is lowered from 4 to 0 percent, the variability of the output gap (dashed line) —defined as the difference between actual and potential real GDP—would rise 20 percent (when measured in terms of standard deviation). In contrast, the choice of inflation objective, even one close to zero, has little effect on inflation stability (bold line).

According to Reifschneider and Williams:

> Overall, these results suggest that macroeconomic stability would likely deteriorate somewhat if the target rate of inflation were to fall below 1 or 2 percent... Under these conditions, the zero bound gives rise to a trade-off between the average rate of inflation and the variability of output; however, there is no significant trade-off between the average rate of inflation and inflation variability, at least for the range of inflation targets considered here (p. 956).

Another study using a different model but similar approach reached very similar conclusions. Coenen, Orphanides, and Wieland quantify the importance of the zero bound in a structural model of the U.S. economy that is much smaller and simpler than the FRB/US model used by Reifschneider and Williams.[14]

Despite differences in size and complexity, the Coenen, Orphanides, and Wieland model shares the same basic features of the FRB/US model—namely, monetary policy affects output and employment in the short run due to price stickiness and determines the level of inflation in the long run when prices have time to fully adjust. In addition, like the FRB/US model, the small model characterizes monetary policy with a Taylor-type rule that the public perceives as perfectly credible.

Similar to the results obtained in the FRB/US model, the simulations of the small structural model show that inflation objectives as low as 2 percent per year place only limited constraints on monetary policy in stabilizing the economy. Specifically, with a 2 percent inflation objective as measured by the chain-weighted GDP price index—a broader measure of inflation than either the PCE price index or the CPI—

policymakers are estimated to confront the zero bound 7 percent of the time. In contrast, with an inflation objective of 0 percent, the funds rate hits the zero bound 18 percent of the time. Coenen, Orphanides and Wieland conclude:

> Our analysis for the United States indicates that if the economy is subjected to stochastic shocks similar in magnitude to those experienced over the 1980s and 1990s, the consequences of the zero bound are negligible for target inflation rates as low as 2 percent. However, the effects of the constraint become increasingly important for determining the effectiveness of policy with inflation targets between 0 and 1 percent (p. 14).

Policymaker views

Empirical estimates of the effects of the zero bound on macroeconomic stability under alternative inflation objectives suggest policymakers should be cautious in pursuing an inflation objective much below 2 percent per year, as measured by either the PCE or GDP price index. But is such a concern shared by the policymakers with responsibility for setting U.S. monetary policy?

Commenting on these empirical studies in 2004 as a Federal Reserve Board governor two years prior to his appointment as chairman, Ben Bernanke expressed support for more research to determine what he called the "optimal long-run inflation rate," or OLIR. While he noted that the 2 percent figure may seem to be robust to a "variety of assumptions about the costs of inflation, the structure of the economy, the distribution of shocks, etc.," he recommended more research to clarify the range of uncertainty surrounding it. He also suggested more research into a variety of details, including the specification of the inflation index and the assumptions made about the long-run properties of the models. He concluded that:

> ...having an estimate of the OLIR likewise seems crucial to making good policy in the next few years. The issue is one that, in my view, the FOMC and the staff should be looking at carefully. ...Of course, the value of the OLIR would only be a rough approximation to the "truth," but one cannot avoid making such

> approximations in policymaking, whether implicitly or explicitly (Bernanke 2004a, p. 166).

More recently, in the minutes of its October 2007 meeting, the FOMC began publishing quarterly economic projections for inflation and other key macroeconomic variables over an extended forecast horizon of around three years.[15] The projections for inflation are expressed in terms of the PCE price index—the FOMC's preferred measure of inflation. The longer-run projections—which are derived under the assumption of "appropriate" monetary policy—give an indication of the Committee's medium- to long-run goals for inflation. According to the October 2007 minutes:

> Participants' projections for PCE inflation in 2009 and 2010 were importantly influenced by their judgments about the measured rates of inflation consistent with the Federal Reserve's dual mandate to promote maximum employment and price stability and about the time frame over which policy should aim to attain those rates given current economic conditions. The central tendency of participants' projections for both core and total inflation in 2010 ranged from 1.6 to 1.9 percent.

At the January 2008 meeting, the most recent meeting for which projections have been published, the central tendency of participants' projections for overall inflation was unchanged in 2009, but revised up slightly in 2010 to a range of 1.7 to 2.0 percent. However, the minutes also noted that given recent adverse shocks to inflation, some participants' projections of inflation in 2010 were likely still "a bit above" levels judged consistent with the Federal Reserve's dual mandate.

Thus, the central tendency of FOMC participants' January 2008 projections for annual inflation of 1.7 to 2.0 percent (as measured by the PCE price index) three years into the future were equal to or slightly below the 2 percent threshold identified in the empirical studies of the effects of the zero bound. While FOMC members appear to favor a small inflation buffer, they have differing estimates of what it should be and perhaps different reasons for thinking a buffer is required. The central tendencies of participants' inflation projections may reflect concern about the zero bound, or they may reflect other concerns about the best way to balance the Federal Reserve's dual mandate. Either way, policymakers may find it useful to have a model-based estimate of the optimal inflation rate that accounts for the zero interest rate bound.

III. HOW LOW IS THE OPTIMAL INFLATION RATE?

The studies summarized in the previous section describe a tradeoff between the long-run inflation objective and the frequency of hitting the zero bound. This tradeoff implies a related tradeoff between the inflation objective and the variability of real output and inflation. But what point along the tradeoff represents the inflation rate that maximizes the overall macroeconomic well-being of the public?

In a recent study, Billi provides the first direct estimates of the optimal inflation rate, showing that the previous research somewhat overstates the consequences of the zero interest rate bound. The approach of Reifschneider and Williams and of Coenen, Orphanides, and Wieland does not provide policymakers a method for choosing which inflation rate to target. It only identifies the tradeoff they face between the inflation objective and macroeconomic stability. In addition, the approach fails to account for the direct costs of inflation on the macroeconomic performance of the U.S. economy. Indeed, their model simulations show that as the inflation objective rises, the variability of both output *and inflation* falls (Chart 2). As a result, higher inflation objectives would appear to be unambiguously better.

To address limitations in earlier studies, Billi simulates a small New-Keynesian model often used for monetary policy analysis. Unlike earlier studies, which impose an arbitrary inflation objective and analyze its effects, Billi assumes policymakers aim directly for the level of inflation that maximizes the economic well-being of the public. This direct approach is possible because the New-Keynesian model is developed from explicit microeconomic foundations in which firms and consumers maximize profits and utility, respectively, subject to their budget constraints. As a result, a measure of economic well-being can be obtained from the utility function of the consumer—who, as is customary in the economics literature, is assumed to derive utility from consumption and disutility from working rather than enjoying leisure.

The main channel through which inflation is costly in the New-Keynesian framework is through "relative-price distortions." As observed in the data, the prices of many goods and services tend to adjust infrequently even though the general price level is rising over time. Thus, under general price inflation, many prices do not fully reflect the relative costs of production. And, the higher the inflation rate, the greater the distortion caused by price stickiness. As a result, absent other factors of influence, such as the zero bound problem, zero inflation would appear optimal as it limits the distortions in relative prices due to inflation.[16]

The costs of inflation in the New-Keynesian model are somewhat different from those often described in the literature and summarized in Section I. For example, the model lacks a full description of government spending and taxation and thus ignores the distortions that inflation causes in a tax system that is not fully indexed. Moreover, because economic agents in the model know the central bank's long-run inflation objective, uncertainty about the long-run inflation rate is not an issue. The model does, however, account for the inefficiencies inflation causes when it distorts relative prices and leads consumers and firms to make suboptimal decisions.

In addition to concern about inflation, policymakers in the New-Keynesian model are assumed to care about output stability.[17] Thus, they face a dual mandate, similar to that of the Federal Reserve. Concern about inflation and output stability implies that literal price stability, or zero inflation, is not the optimal goal for monetary policy because of the zero interest rate bound. To obtain estimates of the optimal inflation rate accounting for the zero bound, the model is simulated assuming that the public perceives the monetary policy strategy as perfectly credible.[18]

The model provides estimates of the optimal inflation rate based on a hypothetical measure of inflation with no measurement error. As a result, the model-based estimates are independent of any specific measure of inflation (CPI, PCE and GDP price index, or others). As described in Section I, however, available inflation measures tend to be biased upward. Thus, to convert the model-based estimate of the optimal inflation rate into an actual, measured inflation rate, an estimate of the bias has to be added. In what follows, the results will be discussed in terms of the PCE price index for which the bias is thought to be roughly 0.5 percent per year.

The baseline estimate of the optimal inflation rate is constructed to buffer the economy from the consequences of the zero bound, given adverse shocks comparable in size to shocks that have hit the U.S. economy in recent decades. Assuming the model provides a correct description of the U.S. economy, the optimal inflation rate as measured by the PCE price index is 0.7 percent per year. At that level of inflation, nominal interest rates hit the zero bound roughly 3.5 percent of the time and stay there for just under two consecutive quarters. In addition, at the optimal inflation rate, the standard deviation of output is roughly 1.2 percent, and the standard deviation of inflation is just below 2 percent.[19]

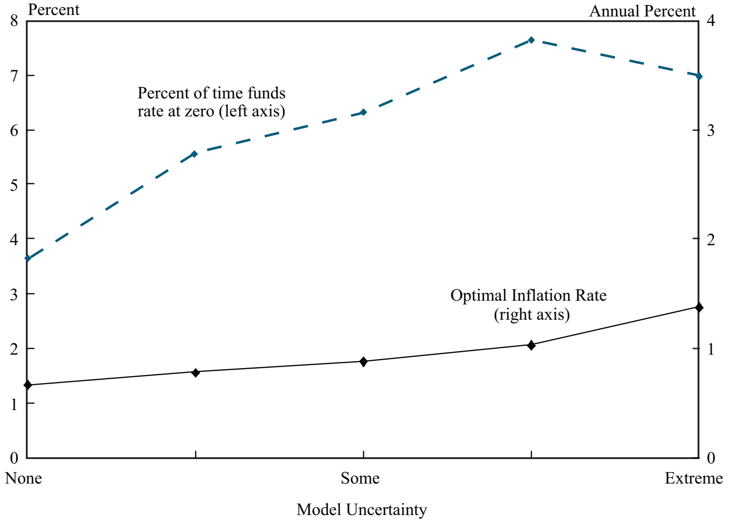
When "model uncertainty"—uncertainty about the parameters of the model—is taken into account, the optimal inflation rate rises. With greater uncertainty surrounding the parameters of the model, uncertainty about the actual response of the economy to shocks increases. At the same time, this uncertainty about the structure of the economy leads to uncertainty about the effects of monetary policy on the economy. Hence, a higher inflation rate is required to buffer the economy from the consequences of the zero bound.

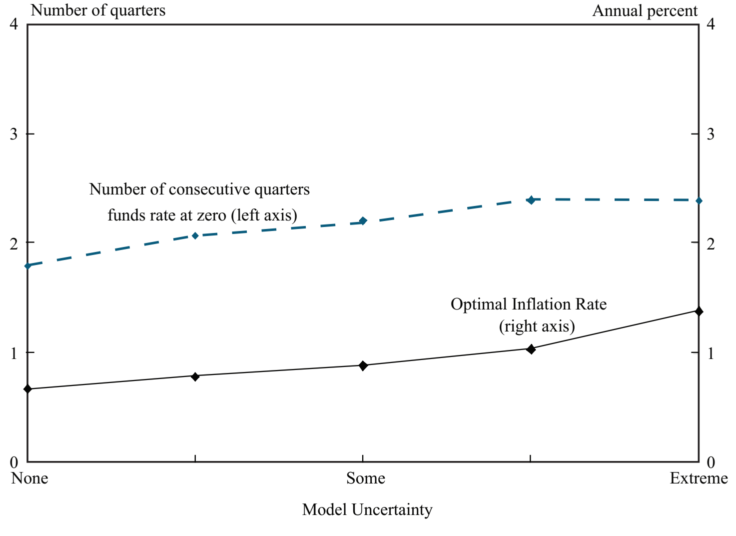
As shown in Chart 3, the optimal inflation rate (solid lines, right axis) for the PCE price index—accounting for 0.5 percent per year measurement error—ranges from 0.7 percent per year without model uncertainty to 1.4 percent per year with extreme model uncertainty. In this context, extreme model uncertainty is the greatest uncertainty surrounding the parameters of the model for which long-run inflation expectations remain anchored. Under optimal policy, the federal funds rate (dashed line, left axis in top panel) is expected to reach the zero bound from 3.5 to 7.5 percent of the time, depending on the degree of model uncertainty, and to remain there for only about two consecutive quarters (dashed line, left axis in bottom panel) regardless of the degree of model uncertainty.

Chart 4 examines the implications of model uncertainty on output and inflation variability. It shows that for a considerable increase in model uncertainty, the variability of output and inflation increases steadily. Indeed, with extreme model uncertainty, the variability of inflation (dashed line) and output (dashed-dotted line) are both 50 per-

Chart 3

OPTIMAL INFLATION AND MONETARY POLICY IN THE SMALL NEW-KEYNESIAN MODEL

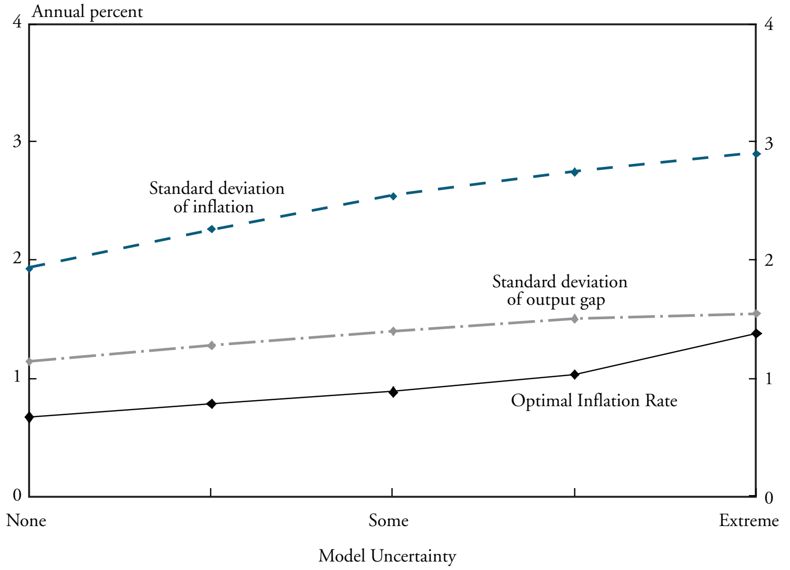




Notes: The chart illustrates results of Billi for a small New-Keynesian model calibrated for the period 1983 to 2002 using quarterly U.S. data. Monetary policy maximizes social welfare by selecting the optimal paths for the funds rate, the model-based measure of the output gap—given by the difference between actual real GDP and the potential level of real GDP that would arise under perfect price flexibility—and a correctly measured inflation rate. The OIR accounts for 0.5 percent per year measurement error based on estimates of the bias in the PCE price index.

Chart 4

OPTIMAL INFLATION AND ECONOMIC STABILITY IN THE SMALL NEW-KEYNESIAN MODEL



Note: See Chart 3.

cent higher (when measured in terms of standard deviation) than that experienced in recent decades. Yet the optimal inflation rate (solid line) rises only to 1.4 percent per year.

The two charts, together, suggest that the previous research to some extent overstates the consequences of the zero bound. Indeed, the range of estimates for the optimal inflation rate in the New-Keynesian model—0.7 to 1.4 percent per year for the PCE price index—falls somewhat below the 2 percent threshold as identified by Reifschneider and Williams and Coenen, Orphanides, and Wieland. The range of estimates of the optimal inflation rate also falls slightly below the central tendency of FOMC participants' projections for annual inflation as measured by the PCE price index three years into the future (1.7 to 2.0 percent per year).

IV. CONCLUSIONS

Inflation is costly, but it can also be too low. A key reason why inflation can be too low is the zero interest rate bound. When inflation gets too low, nominal interest rates may approach zero, limiting a central bank's ability to stabilize the economy by lowering its policy rate.

Researchers who have analyzed this issue have estimated a tradeoff between the central bank's long-run inflation objective and the likelihood of hitting the zero rate bound. They find that the incidence of hitting the zero bound falls quickly as the inflation objective rises from 0 percent to roughly 4 percent. Moreover, the variation of output and inflation falls steadily, but at a decreasing rate, as the inflation objective rises.

While this line of research provides information policymakers can use in formulating an inflation objective, it does not provide a direct estimate of the optimal inflation rate. Such an estimate can be obtained by simulating a small New-Keynesian model. In the model described in this article, the optimal inflation rate as measured by the PCE price index is estimated to range from 0.7 to 1.4 percent per year, depending on the assumed degree of model uncertainty. This range of estimates is lower than that suggested by previous researchers and slightly lower than the central tendency of FOMC projections three years into the future.

In interpreting these results, a number of caveats must be kept in mind. First, the costs of inflation in the models described in this article are based on relative price distortions caused by price stickiness. Other costs such as distortions from the interaction of inflation and the tax system are ignored. Second, the model focuses on the effects of the zero interest rate bound, ignoring other potential factors that might lead policymakers to target a positive inflation rate. These factors include downward wage rigidity and the potential severe costs of debt-deflation. Third, the results are derived from a very simple model that abstracts from many real-world features. Finally, the estimates of measurement error in the various price indexes are themselves subject to error, creating some uncertainty around the optimal inflation rate as would be measured using available price indexes.

Even with these caveats, the results suggest that the zero lower bound for nominal interest rates may not warrant quite the concern that economists and policymakers have attributed to it. Still, further research is needed to confirm or refine these results in models that incorporate a more realistic and complete description of the economy.

ENDNOTES

[1]Inflation distorts the tax system because taxes are often applied to nominal income. As a result, inflation can raise the effective tax rate on capital income and negatively affect firms' incentives to invest in capital formation, as argued by Feldstein.

[2]See Fischer (1984, 1996) for a more complete discussion of the costs of inflation.

[3]While policymakers often focus on "core" measures of inflation—which exclude food and energy prices—in assessing short- to medium-term inflation pressures, this article focuses on overall inflation, including food and energy. As a long-run objective of policy, the public and policymakers are concerned about overall inflation, including food and energy, because these components are important in consumer purchases. Moreover, overall and core inflation should tend to move together over the long run. Because this article is about the long-run inflation objective, its focus is on overall inflation.

[4]Clark reviews the differences between the CPI and the PCE price index.

[5]See for example the remarks by former FOMC Governor Gramlich, as well as Stockton's comments at an FOMC meeting in 1997 quoting a paper by Lebow, Lindner, Sichel, and Tetlow.

[6]That said, in some monetary models the optimal inflation rate is the inflation rate that results when the nominal interest rate is zero. At zero nominal interest rates, the opportunity cost of holding money is zero and, hence, there is no need to conserve on holdings of money balances, as argued by Friedman. By definition, the nominal interest rate is equal to the real interest rate plus expected inflation (the so-called Fisher identity). Thus, at zero nominal interest rates, inflation is expected to be close to the negative of the real interest rate. Since real interest rates are usually low and positive, the optimal inflation rate will be low and negative when the nominal interest rate is zero.

[7]An early analysis of the debt-deflation problem is in Fisher. See Bernanke (2004b) for a modern treatment of the subject.

[8]By definition, as described in endnote 6, the nominal funds rate is equal to the real funds rate plus expected inflation. Thus, when inflation is low and thereby expected to be low, the nominal funds rate will be close to the real funds rate.

[9]Sellon reviews "nonconventional" methods of implementing monetary policy that may be effective even when short-term rates reach zero.

[10]See for example Sellon or Orphanides for an account of the policy actions taken by the Bank of Japan once the policy rate had hit zero.

[11]Wage "stickiness," as opposed to downward wage rigidity, is a feature of many macro models. With wage stickiness, nominal wages are slow to adjust in either direction, but eventually do adjust to their long-run equilibrium level.

[12]For further discussion of the FRB/US model, see Brayton and Tinsley; Brayton, Levin, et al; Brayton, Mauskopf, et al; and Reifschneider, Tetlow and Williams.

[13]Perfect credibility is a reasonable assumption when a policy has been in place for some time, but perhaps less so for a newly announced policy, as argued for example by Reifschneider and Roberts. Indeed, in equilibrium—after the transitional period following a new policy—perfect credibility is the most relevant case for analyzing how policy can be designed to minimize the effects of the zero bound on macroeconomic stabilization, or conversely to maximize the economic well-being of the public. It is important to note, however, that significant output costs might be associated with a transition from one inflation objective to a lower one. These costs are not analyzed in this article.

[14]Coenen, Orphanides, and Wieland were among the first to simulate a structural model to estimate the impact of the zero bound on macroeconomic stability. The small structural model they use has about a dozen equations and therefore less sectoral detail than the FRB/US model, which comprises a few hundred equations.

[15]Prior to October 2007, the FOMC reported projections twice a year over a horizon of one-and-a-half to two years.

[16]See Woodford or Galí for further discussion of the small New-Keynesian model.

[17]Since the New-Keynesian model is developed from explicit microfoundations, the welfare criterion for the monetary policymakers is derived by taking a quadratic approximation of the utility function of the representative individual. The resulting welfare-based loss function is quadratic in deviations of output from the socially efficient level and deviations of inflation from zero, where the latter term captures the costs of inflation from relative-price distortions.

[18]One could also investigate a "suboptimal" inflation rate under the alternative assumption of imperfect policy credibility; however, the optimal inflation rate is the natural benchmark for analyzing how policy can be designed to fully maximize the economic well-being of the public.

[19]Billi's results would thus suggest lower output and inflation variability than the other studies because the other studies assume monetary policy follows a standard Taylor rule. As they show, a standard Taylor rule delivers higher variability of output and inflation in the presence of the zero bound than alternative Taylor rules that incorporate, for example, interest rate inertia.

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