# Was Monetary Policy Optimal During Past Deflation Scares?

*By Roberto M. Billi*

Countries around the world have fallen into one of the deepest recessions since the Great Depression—a recession exacerbated by a severe financial crisis. Among the challenges that face monetary policymakers in such uncertain times is the danger economies worldwide, including the United States, Japan, and the euro area, may enter a period of deflation, in which the prices of goods and services fall relentlessly.

Policymakers and economists agree that sustained deflation would likely worsen the already fragile economic and financial environment. Past episodes of deflation in the wake of financial crises have included falling asset values, collapsing business and consumer confidence, credit crunches, widespread bankruptcies, long-lasting surges in unemployment, and other adverse conditions. Moreover, a deflationary environment has the potential to complicate the conduct of monetary policy. Central banks typically counteract slowing economic activity by lowering short-term nominal interest rates. But as policy rates approach zero, conventional tools of monetary policy are no longer available to stimulate economic activity.

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Policymakers have responded vigorously to the current crisis to prevent deflation. Some analysts warn that the U.S. policy response might be too proactive and cause a subsequent surge in inflation. At the same time, other analysts advise that the policy response in many other countries might not be active enough to fend off deflation. Of course, it is too early to judge the success of the different policies in the current episode. Still, it is possible to learn from past attempts by policymakers to fend off deflation under similar economic circumstances. One episode occurred in Japan during the early 1990s, when the collapse of an asset-price bubble severely weakened the economy. Another episode occurred in the United States during the early 2000s, when its stock-price bubble burst and the terrorist attacks of September 11, 2001 shocked the economy.

One way to evaluate monetary policy is to compare it with the recommendations of Taylor rules. A Taylor rule prescribes a setting for a central bank's policy rate based on observed inflation and output. At a number of central banks, policymakers use Taylor rules, along with other types of guidelines, as inputs into their evaluation of the appropriate stance of monetary policy.

This article shows how Taylor rules can be used to evaluate monetary policy. It then compares actual policy during the Japanese and U.S. deflation scares with how policy would have been conducted using Taylor rules based, to the extent possible, on data available at the time. The rule-based evidence suggests that Japan's monetary policy response during the early 1990s might have been too weak, while the U.S. response during the early 2000s might have been too strong.

The first section of the article describes the policy rule proposed by Taylor as well as different versions, which collectively are called Taylor rules. The second section uses Taylor rules to evaluate Japan's monetary policy from 1990 to 1995. The third section uses the rules to evaluate U.S. monetary policy from 2000 to 2005.

## I. WHAT ARE TAYLOR RULES?

In 1993, at the Carnegie Rochester conference, John Taylor first proposed the Taylor rule. The rule was a simple equation for central banks to use as a guideline for systematically changing the level of the policy rate in response to changes in inflation and output. Since then, economists have modified Taylor's original proposal. One type of modification was aimed at achieving optimal economic performance. This section describes the original and optimal Taylor rules, as well as their limitations.

## *General description*

Taylor rules provide guidelines for central banks setting policy rates in response to changes in a small number of factors that broadly summarize the state of the economy. Taylor rules often take the form:

$$i_t = \alpha(\pi_t - \pi^*) + \gamma(y_t - y^*) + i_t^*. \tag{1}$$

On the left side of this equation, $i_t$ is the recommended level of the policy rate in period *t*. The policy rate, which is the conventional tool of monetary policy, is a short-term nominal interest rate. The rate is expected to be zero or positive because, under normal circumstances, nominal interest rates cannot fall below zero.[1]

On the right side of the equation, three factors influence the prescription of the policy rate. The first factor is the *inflation gap*, or the gap between the inflation rate and the central bank's long-run inflation goal $(\pi_t - \pi^*)$. The inflation goal is thought to be low but above zero. Policymakers and economists agree that inflation is bad for the economy, but it can also be too low (Billi and Kahn).

The second factor is the *real output gap*, or the gap between the real output of the economy and its potential output $(y_t - y^*)$. Potential output is the highest level of real output that can be sustained in the long run. The real output gap reflects the view that in the short run policy should lean against cyclical winds. In addition, the gap may signal future inflation developments. When real output rises and stays above potential, inflation also tends to rise as aggregate demand exceeds supply. By contrast, when real output persists below potential, inflation tends to fall as aggregate demand falls short of supply.

The third factor is the *equilibrium nominal interest rate*. It, in turn, has two components: the equilibrium real interest rate and the central bank's inflation goal $(i_t^* = r_t^* + \pi_t^*)$. Both components can change over time. The equilibrium real interest rate is determined by factors relevant for the growth of the economy, such as trends of productivity and employment, which are subject to change.[2] Similarly, a central bank can change its inflation goal. As a consequence, the equilibrium nominal interest rate can also change over time.

As rule (1) implies, the policy rate should equal the equilibrium nominal interest rate when both the inflation gap and real output gap are at zero. When the gaps deviate from zero, dampening fluctuations of inflation and real output requires that the response coefficients, $\alpha$ and $\gamma$, in front of the gap terms be positive.[3] Thus, for example, a central bank using the rule will ease policy by lowering the policy rate when inflation falls below the inflation goal or real output falls below potential. By lowering the policy rate, monetary policy can guide other interest rates in the economy toward lower levels, which then encourages spending and investment and discourages savings. Such an increase in aggregate demand puts upward pressure on prices, countering deflation. Conversely, a central bank will tighten policy by raising the policy rate when either inflation or real output is too high, so as to discourage spending and investment and promote saving. Such a decrease in aggregate demand relieves inflationary price pressures.

### *Original Taylor rule*

Several details must be specified when implementing rule (1). In Taylor's original proposal, for example, the response coefficient on the inflation gap is assumed to be 1.5, while that on the real output gap is assumed to be 0.5. In addition, both the inflation goal and the equilibrium real interest rate are assumed to be 2 percent annually, without changing over time. The implied equilibrium nominal interest rate is 4 percent annually. In addition, Taylor estimated the real output gap as the difference between real gross domestic product (GDP) in the current quarter and a series for potential real GDP that grows at a constant rate.[4] Finally, Taylor measured inflation as the GDP deflator in the current quarter over the past four quarters.

Taylor showed that his policy rule proposal, despite its simplicity, explained remarkably well the actual path of the federal funds rate (the Federal Reserve's policy rate) from 1987 to 1992. This period is generally regarded as a successful one for monetary policy in the United States. As a result, Taylor rules are viewed by many as a good prescription for monetary policy.

Supporting this view, Taylor rules are also appealing on theoretical grounds. Economists have proposed a number of variations on Taylor's proposal, and the performance of these alternatives has been tested extensively with economic models (that is, simplified theoretical frameworks designed to illustrate key features of actual economies). Several studies have found that Taylor rules perform well on average—that is, they achieve relatively low variability of inflation and output across a wide variety of models.[5] Because there is considerable debate among economists on which models better replicate actual economies, basing policies on rules that work well within a range of models is desirable.

Although Taylor commented first on the U.S. economy, Taylor rules have also been broadly adopted as guidelines for setting policy rates in other economies (Bernanke; Clarida, Galí, and Gertler). In addition, Taylor rules have been modified by economists to account for differences in policy frameworks among countries. One difference is that central banks may focus on different measures of inflation. For example, in recent decades the Federal Reserve has shifted attention toward the personal consumption expenditures (PCE) price index, while other central banks, including the Bank of Japan, have focused on the consumer price index (CPI). In addition, many central banks closely monitor a core measure of inflation, which excludes from a headline measure the volatile food and energy components. Research shows that core measures may be better predictors than headline measures of future inflation developments.

### *Optimal Taylor rule*

The response coefficients, $\alpha$ and $\gamma$, on the gap terms in rule (1) can be chosen based on a number of criteria. One criterion proposed by economists is whether the coefficients achieve optimal performance—that is, whether they minimize variability of inflation and output in an economic model. To the extent that the model can help policymakers and economists explain actual economies and inform policy decisions, the "optimal" Taylor rule implied by the model is an appealing alternative to the original Taylor rule.

One class of models, commonly known as the "New-Keynesian" framework, has emerged in recent decades as the benchmark for analyzing monetary policy (Galí; Woodford). The New-Keynesian framework describes the behavior of households, firms, and a central bank. Households choose how much they wish to work, purchase goods, and save. Firms decide how much labor to hire and how to price their goods. And the central bank sets its policy rate to dampen the variability of inflation and real output, because research has shown that minimizing such fluctuations promotes maximum sustainable economic growth in the long run.[6] The central bank also aims to achieve low variability of the policy rate, because doing so helps reduce the chance that policy rates will fall to zero. Cutting the policy rate to stimulate economic activity is clearly no longer feasible once policy rates have reached zero.[7]

The response coefficients of the optimal Taylor rule are chosen using a simple New-Keynesian model (Appendix). This analysis applies the model to both the U.S. and Japanese economies. Certainly, the model is too simple to capture all of the differences between these economies. Still, it can account for important features for policymaking, such as the sensitivity of inflation to business cycles.

Research shows that inflation appears less sensitive to business cycles in Japan than in the United States (Higo and Nakada). One explanation is that Japanese firms have less control over prices as a result of rising competition due to deregulation and globalization (Fukui). Accordingly, more competition among firms is incorporated into the model when applied to Japan's economy. Still, allowing for more competition leads to no substantial differences between the two countries' response coefficients of the optimal Taylor rule.[8]

Table 1 compares the original Taylor rule with the optimal Taylor rule implied by the model, with the response coefficients shown in Panel A. The *response coefficient on the inflation gap* is close to 1 in the optimal Taylor rule (33 percent smaller than in the original Taylor rule). The *response coefficient on the real output gap* is close to 0.5 in the optimal Taylor rule (equal to the original Taylor rule).[9] According to this evidence, the policy rate would move with inflation only slightly less with the optimal Taylor rule than with the original Taylor rule. As a consequence, the economy would be expected to behave in a fairly similar way under both rules.

Still, there are some differences in the behavior of the model economy. The differences are captured by three sets of measures of economic performance (Table 1). The first set consists of the variability (as mea-

*Table 1*
## ORIGINAL AND OPTIMAL TAYLOR RULES

*Panel A*

| | Original rule: | Optimal rule: | Difference: |
|---|---|---|---|
| Response coefficient on: | | | |
| Inflation gap | 1.5 | 1.0 | -33% |
| Real output gap | 0.5 | 0.5 | 0 |

*Panel B*

| | Original rule: | | Optimal rule: | | Difference: | |
|---|---|---|---|---|---|---|
| | U.S. | Japan | U.S. | Japan | U.S. | Japan |
| Standard deviation of: | | | | | | |
| Inflation | 0.19 | 0.16 | 0.20 | 0.17 | +5% | +6% |
| Real output gap | 5.12 | 5.30 | 5.48 | 5.60 | +7% | +6% |
| Nominal interest rate | 0.92 | 0.90 | 0.89 | 0.87 | -3% | -3% |

Notes: The *original* response coefficients are from Taylor. The *optimal* response coefficients and unconditional standard deviations are from a quarterly model calibrated to the U.S. or Japanese economy (Appendix). The standard deviations are shown in percentage points at a quarterly rate. The *difference* between the rules is calculated as follows: (optimal rule) / (original rule) – 1.

Source: Author's calculations

sured by the unconditional standard deviation) of inflation, the real output gap, and the nominal interest rate when the original Taylor rule is followed. The second set consists of the variability when the optimal Taylor rule is followed. The third set consists of the percent difference in the variability between the two.

As shown in Panel B, the optimal Taylor rule results in lower variability of the nominal interest rate and higher variability of inflation and the real output gap compared with the original Taylor rule. With the optimal Taylor rule, the nominal interest rate is 3 percent less variable, inflation is 5 to 6 percent more variable, and the real output gap is 6 to 7 percent more variable, depending on which economy is considered. In other words, there is a tradeoff between stabilizing the nominal interest rate on one hand and inflation and the real output gap on the other.

This tradeoff occurs because, in the model, a policy that moves interest rates more aggressively results in greater stability of inflation and the real output gap—as long as the zero lower bound (ZLB) on nominal interest rates does not pose too great of a constraint. The ZLB constraint arises because the more aggressively a central bank stabilizes inflation and the real output gap, the more frequently policy rates will fall to zero. The response coefficients of the optimal Taylor rule take into account the limits on policy imposed by the ZLB. In contrast, the response coefficients of the original Taylor rule were chosen to be round numbers that were generally consistent with earlier research on policy rules (Taylor 1993). Because the original Taylor rule responds more aggressively than the optimal rule, it implies more frequent encounters with the ZLB.[10] Clearly, since Taylor proposed his policy rule in 1993, near-zero policy rates have become a more common phenomenon worldwide.

### *Limitations*

Taylor rules have a number of limitations as guidelines for setting policy rates. One limitation is that economists must specify several details when implementing Taylor rules, but there is no consensus regarding such details. In addition, Taylor rules with different specifications may deliver conflicting policy recommendations (Kozicki). For instance, historical analysis shows that typical measures of inflation (such as CPI, PCE and GDP price index, core or headline measures) may diverge significantly for long stretches (Kohn). Thus, Taylor rules using alternative inflation measures, all else equal, can lead to conflicting conclusions. Consequently, policymakers and economists usually compare several Taylor rules, as well as other types of guidelines, to inform policy decisions.

Second, economists must rely on incomplete or "noisy" economic data that cannot measure the economy precisely. Most data series are revised substantially one or more times following their initial release, as more complete information becomes available and as methodologies improve. For example, some measures of potential output and the implied output gap are subject to large and highly persistent errors (Orphanides and van Norden). Thus, policymakers may encounter ongoing problems in achieving their intended goals if they rely on Taylor rules using such flawed measures. Moreover, historical analysis of monetary policy makes relying on information that was actually available to policymakers essential. Indeed, interpretation of past episodes may change when viewed through the "distorted glass" of revised data (Orphanides).

Third, Taylor rules typically involve only a small number of factors, which may not always adequately summarize the state of the economy. For this reason, economists have proposed variations on Taylor rules by incorporating other factors to help measure the economy. For example, some Taylor rules assume that policy rates also respond to asset prices, reflecting the view that monetary policy should lean against asset-price bubbles (Lansing).[11] Moreover, central banks also monitor many other indicators to gauge conditions in all segments of the economy. When information beyond that incorporated in the rules is available, departing from Taylor rules from time to time can make good sense.

These limitations apply to both the original and optimal Taylor rules. A further set of caveats is specific to the optimal Taylor rule. The response coefficients of the optimal Taylor rule were chosen using a simple model that abstracts from many real-world features. For example, it assumes that financial markets are "perfect" and credit is available without restrictions to households and firms.[12] In many situations, this approximation may be reasonable. In other situations, financial market imperfections may be relevant. Historical analysis shows that many households and firms have no access to credit during a financial crisis. To counteract the effects of credit constraints, central banks might ease policy more vigorously than typically implied by Taylor rules. In other words, the optimal policy response may be stronger when monetary policy has to restore the flow of credit in the economy.

Furthermore, the model does not account directly for other policy options that may be available to policymakers to affect the economy. Besides easing monetary policy, policymakers in a downturn can loosen fiscal policy to stimulate economic activity. For example, tax cuts may encourage private-sector spending and investment, even when some of a tax cut will be saved. Such an increase in aggregate demand can also be achieved with government expenditures.[13] Monetary and fiscal policies can be used simultaneously in various combinations. When fiscal policy is expansionary, central banks might be able to achieve the same desired effects on economic activity by easing policy less intensely. As a consequence, the optimal response of monetary policy during recessions may be weaker when fiscal policy plays an active role by leaning against cyclical winds. But when fiscal policy is pro-cyclical, the optimal response of monetary policy in a downturn may be stronger. All things considered, therefore, the response coefficients that attain optimal economic performance may be larger or smaller in models that incorporate a rich array of market imperfections and policy instruments.

## II. WAS JAPAN'S MONETARY POLICY OPTIMAL DURING THE EARLY 1990s?

Taylor rules can be used to evaluate monetary policy in historical episodes. Specifically, Taylor rules provide a standard for judging whether historical policy actions were appropriate given economic conditions at the time. As discussed above, the original Taylor rule—which has been shown to produce good economic performance across a range of models—is one possible standard, while an optimal Taylor rule—which produces optimal economic performance in a simple, workhorse model—is another possible standard.

Ideally, historical actions should be evaluated based on data available to policymakers at the time decisions were made. But it is also of interest to see how policies might have been different than those prescribed by Taylor rules with the benefit of hindsight. The difference between a "real-time" and an ex-post evaluation of policy provides a measure of the extent to which policies were based on incomplete or inaccurate data as opposed to deviations from rule-like behavior.

One historical episode was Japan's deflation scare in the early 1990s. This section first illustrates the difficult economic environment that policymakers encountered during this period. It then evaluates Japan's monetary policy during its deflation scare. The evidence suggests that the stance of monetary policy might have been too tight.

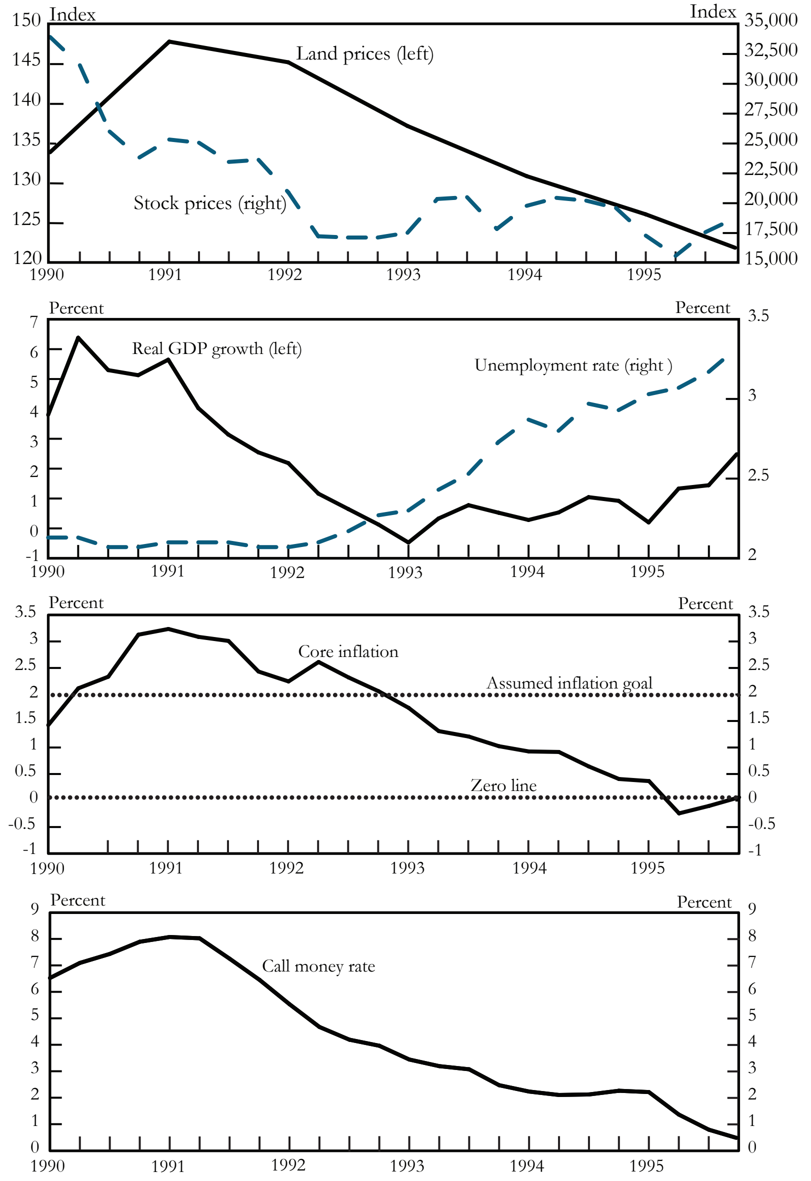
### *Economic environment*

In the aftermath of the collapse of an asset-price bubble in early 1990, Japan's economy abruptly lost its strength of previous decades. Major problems arose in the financial sector, and inflation fell toward zero. Over this period, the Bank of Japan eased policy, and overnight interest rates approached zero by late 1995. Because Japan entered a period of very slow economic growth and deflation—its "lost decade" of the 1990s—many analysts have argued that policymakers provided too little stimulus to the economy.

Chart 1 illustrates Japan's economic situation throughout its deflation scare.[14] Stock market prices (dashed line in the top panel) fell 50 percent by early 1992. The collapse of equity prices led to severe balance-sheet problems for households and firms and made it difficult to pay back loans. Such deterioration in loan performance substantially

*Chart 1*

## JAPANESE ECONOMY AND MONETARY POLICY




Notes: Stock prices are quarterly averages of the Nikkei index. Real GDP growth is the four-quarter rate of change of real GDP. The unemployment rate is seasonally adjusted. Core inflation is the four-quarter rate of change of core CPI, adjusted to exclude the temporary effects of the consumption tax hikes in 1989Q2 and 1997Q2 (Ahearne et al.).

Sources: Bank of Japan (overnight call money rate), Cabinet Office (GDP 68SNA and 93SNA), Ministry of Internal Affairs and Communications (CPI and unemployment rate), Real Estate Institute (Urban Land Price Index), and author's calculations.

eroded the financial health of banks and other financial institutions. In addition, declining real estate prices (solid line in the top panel) undercut the value of collateral used to secure new loans. As a consequence, the growth of bank credit fell to near zero by 1993.[15] The result of these financial "headwinds" was a falloff of economic activity and further downward pressure on prices. Real GDP growth (solid line in the second panel) fell from 6 percent to zero by early 1993. As the decline reached a bottom, firms started to lay off workers and the unemployment rate (dashed line in the second panel) moved upward.[16] Over the same period, core consumer price inflation (solid line in the third panel) plunged from 3 percent in early 1991 to 1 percent by early 1993.

The Bank of Japan began to ease policy in mid-1991, shortly after real estate prices began to decline. Overnight interest rates (bottom panel of Chart 1) fell from 8 percent to 3.5 percent by early 1993. Until then, Bank of Japan officials were apparently optimistic about the economy's prospects, judging that CPI inflation between 0 and 2 percent was consistent with their objective for inflation. During 1993, however, the Bank's quarterly economic outlook report stated that in January "the stabilization of consumer prices has become evident" and then in April that "consumer prices have stabilized considerably."[17] In the following years, the Bank continued to ease policy, and overnight interest rates fell to 2 percent by early 1995 and to 0.5 percent by late 1995.

In retrospect, several commentators criticize the Bank of Japan for not easing the stance of policy faster. But, in actuality, most observers at the time were slow to appreciate how deep and protracted Japan's economic slowdown would be (Ahearne et al.).[18] A question thus arises as to whether policy was eased quickly enough in light of information available to policymakers at the time.

## *Measuring the economy*

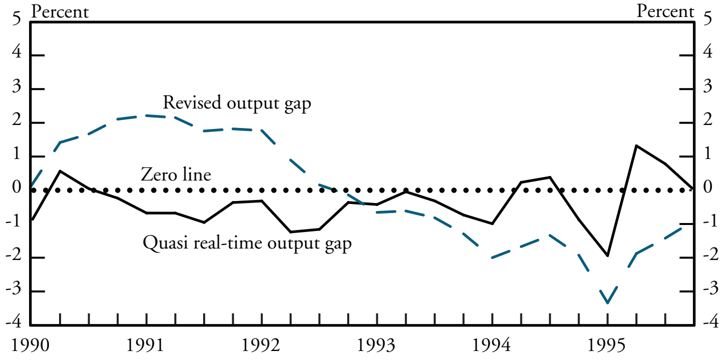
Some of the economic data published since Japan's deflation scare suggest that policymakers should have reacted more vigorously to counter deflationary forces. Based on information available at the time, though, such a conclusion may be less clear. Most data series, in Japan and elsewhere, are revised over time as more information becomes available. These revisions can sometimes be quite large. As a consequence, real-time and revised data for the same economy can depict considerably different economic conditions.

Two issues associated with real-time data complicate the historical analysis of this episode. First, official statistical sources (such as Bank of Japan, BIS, IMF, and OECD, among others) provide revised data, as observed today; but Japan's real-time data, as observed in the 1990s, are not available in electronic format. For this reason, the analysis will rely on revised data.[19] The second issue is that potential output, and the implied output gap, are not directly observed and instead must be estimated. For historical analysis of policy, potential output should be estimated at each point in time without reliance on future data. Though real-time data are not available, potential output can still be measured at each point in time without relying on post-sample data. The result is a "quasi real-time" estimate of potential output.

One way to estimate potential output is by applying a statistical filter (Hodrick-Prescott filter). The filter can extract from real GDP a smooth trend, which is a measure of potential output. For instance, the quasi real-time estimate of potential output in 1990:Q1 is the trend measured with revised real GDP up until 1990:Q1, disregarding post-sample data. The real output gap is the difference between revised real GDP and potential output. Research shows that potential output measured in real time may not be particularly reliable; however, economists have developed methods to improve the reliability of the resulting output gap estimates.[20]

Chart 2 shows quasi real-time (solid line) and revised (dashed line) measures of the real output gap. As can be seen, the effects of the revisions (the distance between the two lines), which in early 1991 is roughly 3 percentage points, alters the assessment of the economy. Before 1993, the quasi real-time data signal downward pressures on prices (real GDP below potential), while the revised data indicate inflationary pressures (real GDP above potential). By contrast, both measures reveal downward pressures on prices from 1993 onward, and the revised data do so to a greater extent (revised below quasi real-time measure).[21] Based on this evidence, therefore, downward price pressures in 1993-95 may have been stronger than thought at the time.

*Chart 2*
MEASURING THE JAPANESE ECONOMY




Notes: The output gaps are log-differences between revised real GDP and an estimated trend. The trend is estimated with the Hodrick-Prescott filter, using a smoothing parameter of 1,600. The revised trend is based on quarterly data for 1955-2008. The quasi real-time trend is based on quarterly data starting in 1955 and extended from the real-time quarter for 10 years with forecasts formed from AR(4) models. Extending the data with forecasts reduces the imprecision of the Hodrick-Prescott filter at the endpoints (Mise, Kim, and Newbold).

Sources: Cabinet Office (GDP 68SNA and 93SNA) and author's calculations

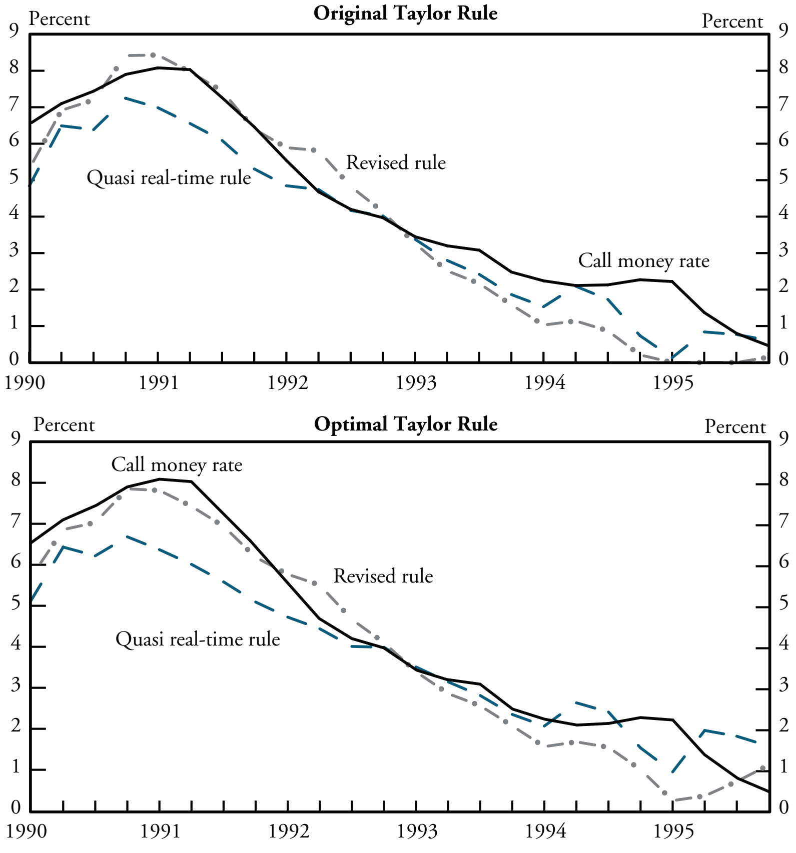
## *Evidence from Taylor rules*

Quasi real-time and revised measures of the real output gap can be used to evaluate Japan's monetary policy during its deflation scare. This evaluation relies on revised inflation (core CPI inflation). Chart 3 compares actual policy with the recommendations of original and optimal Taylor rules.[22] These optimal Taylor rules (derived in Section I from a simple New-Keynesian model) incorporate a less aggressive policy response to inflation than the original Taylor rule.

The top panel of the chart compares actual policy with the original Taylor rule's prescriptions.[23] Based on quasi real-time data, policy in 1990-91 was too tight—that is, above the prescription. In 1992, it was roughly appropriate. And, from 1993 onward, it again became gradually too tight. Overnight interest rates (solid line) in early 1991 were 1.5 percentage points too high; they were 2 percentage points too high by early 1995. Based on revised data, policy in 1990-92 was roughly appropriate. From 1993 onward, it became rapidly too tight. Overnight interest rates were 2 percentage points too high by late 1994. The discrepancy between the prescriptions is a result of the large effects of the data revisions on the estimate of the output gap (Chart 2).

*Chart 3*

## EVALUATING JAPANESE MONETARY POLICY




Notes: The calibration of the Taylor rules follows Taylor's original proposal, but the optimal Taylor rule is assumed to have a response coefficient on the inflation gap equal to 1. In addition, the equilibrium real policy rate is estimated as the four-quarter rate of change of revised trend real GDP (Okina and Shiratsuka; Yamaguchi). The Taylor rules are based on core CPI inflation from Chart 1 and output gaps from Chart 2.

Sources: Bank of Japan (overnight call money rate) and author's calculations

The bottom panel of the chart compares actual policy with the optimal Taylor rule's prescriptions. Based on quasi real-time data, policy in 1990-92 was too tight. Overnight interest rates in early 1991 were 2 percentage points too high. From 1993 to mid-1994, policy was roughly appropriate. In 1994:Q4 and 1995:Q1, however, the quasi real-time Taylor rule called for lower rates than were actually set by the Bank of Japan. Later in 1995, the Bank of Japan lowered rates below the prescription of the quasi real-time Taylor rule. Based on revised data, policy in 1990-92 was roughly appropriate. From 1993 onward, it became gradually too tight. Overnight interest rates were 2 percentage points too high by early 1995. On balance, therefore, the original and optimal Taylor rules both conclude that Japan's monetary policy over much of this episode was too tight.

Other studies reach similar conclusions. However, they do not always agree on the exact periods over which the Bank of Japan kept policy too tight. In addition, the extent to which policy was too tight may differ, depending on the measures of inflation and the real output gap, and on other details that must be specified when implementing Taylor rules (Kuttner and Posen; Kamada).[24] Though none of these studies shows how optimal Taylor rules can be used to appraise policy, the bottom line is that the Bank of Japan's policy response might have been too weak.

In this context, many analysts have argued both monetary and fiscal policy could have done more to help avoid the deflation and economic stagnation that set in during the 1990s.[25] But, at the time, considerable uncertainty existed as to how financial markets and the real economy would develop. Indeed, the timing and magnitude of the financial headwinds were largely unanticipated by policymakers and observers alike. In 2002, commenting on the economic environment in which the Bank of Japan had to conduct monetary policy, Deputy Governor Yamaguchi clarified that at the early stage of Japan's financial crisis "there was a presumption that shocks would be contained within the financial sector and would not spread to the real side of the economy." Therefore, there was a widespread belief that the situation would turn around, thus making the case for additional policy stimulus less clear at the time.

## III. WAS U.S. MONETARY POLICY OPTIMAL DURING THE EARLY 2000s?

Another deflation scare occurred in the early 2000s in the United States. This section evaluates U.S. monetary policy during its deflation scare. In contrast to Japan's episode, the evidence suggests that the stance of monetary policy might have been too accommodative.

### *Economic environment*

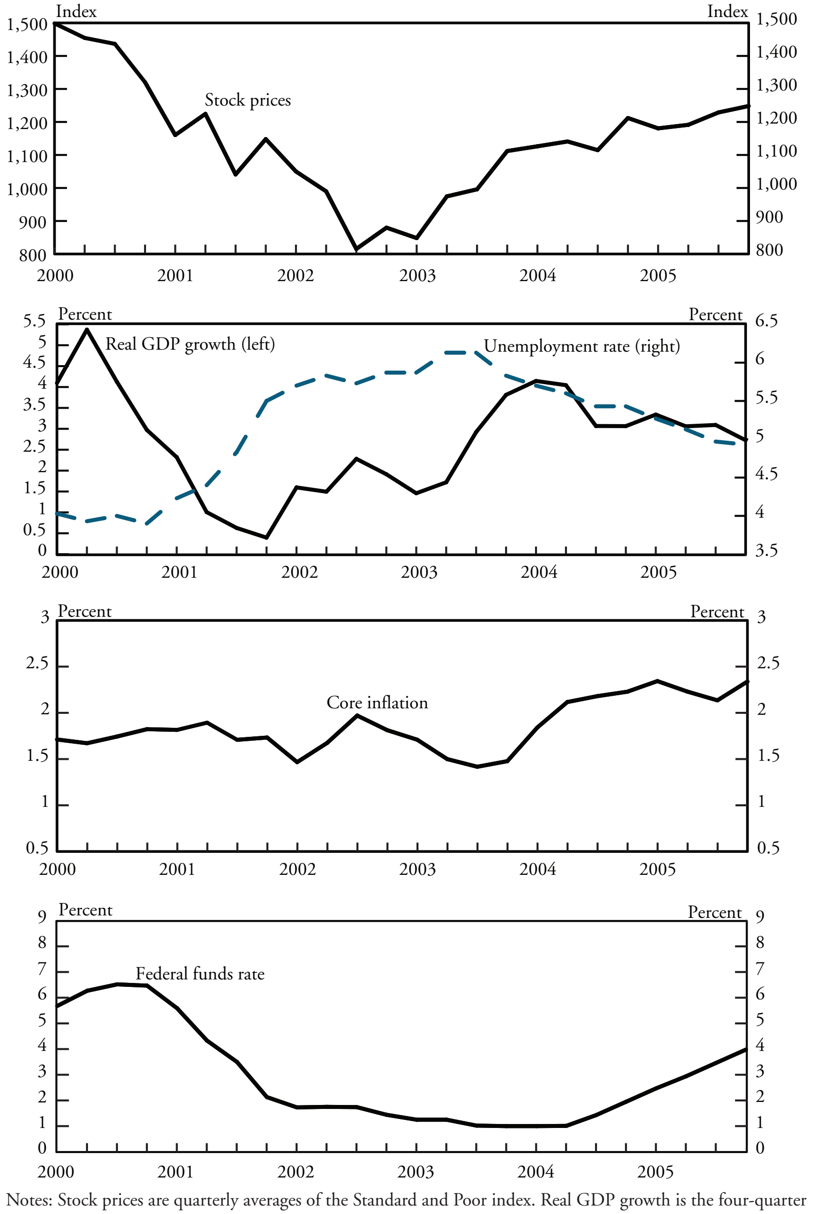
In early 2000, the collapse of a technology stock-price bubble in the United States shocked the economy. In addition, geopolitical risks heightened following the terrorist attacks of September 11, 2001. As a result, economic activity slowed and inflation edged down. In response to policymakers' concerns about the possibility of deflation, the Federal Reserve eased policy, lowering the federal funds rate to nearly 1 percent by mid-2003. The United States avoided deflation. But housing demand and price imbalances worsened significantly, leading some analysts to argue that policymakers gave the economy too much stimulus (Taylor 2007).

A number of other conditions contributed to the episode. Following the investment boom of the 1990s, many firms reassessed their need for physical capital and cut back on investment spending. By 2002, in the wake of corporate governance and accounting scandals, access to external funding diminished, causing the financial conditions of many firms to deteriorate substantially. As investor confidence eroded, stock market prices (top panel of Chart 4) fell almost 50 percent by late 2002. In the meantime, real GDP growth (solid line in the second panel) fell from 5.5 percent to zero. As the economic situation worsened, firms scaled back workforces, pushing up the unemployment rate (dashed line in the second panel). Owing to these restraints on economic activity, core PCE-price inflation (third panel) edged down from 2 percent in mid-2002 to 1.5 percent by mid-2003.

During the fall of 2002 and summer of 2003, some participants of the Federal Open Market Committee (FOMC), the body responsible for the conduct of monetary policy, openly voiced concerns of a "remote" possibility of deflation going forward.[26] Commenting on these events in 2004, Federal Reserve Chairman Greenspan explained that FOMC members were leaning toward an "easier stance of policy aimed at limiting the risk of deflation even though baseline forecasts from most conventional models at that time did not project deflation." In May 2003, with inflation already uncomfortably low, the FOMC statement pointed to the risk of an "unwelcome substantial fall in inflation." Addressing such concerns, the Federal Reserve continued to ease policy, pushing the federal funds rate (bottom panel of Chart 4) to 1 percent by mid-2003, its lowest level in over 40 years.

*Chart 4*

## U.S. ECONOMY AND MONETARY POLICY




Notes: Stock prices are quarterly averages of the Standard and Poor index. Real GDP growth is the four-quarter rate of change of real GDP. The unemployment rate is seasonally adjusted. Core inflation is the four-quarter rate of change of core PCE.

Sources: Bureau of Economic Analysis (GDP and PCE), Bureau of Labor Statistics (unemployment rate), Federal Reserve Board of Governors (target federal funds rate), and author's calculations

*Measuring the economy*

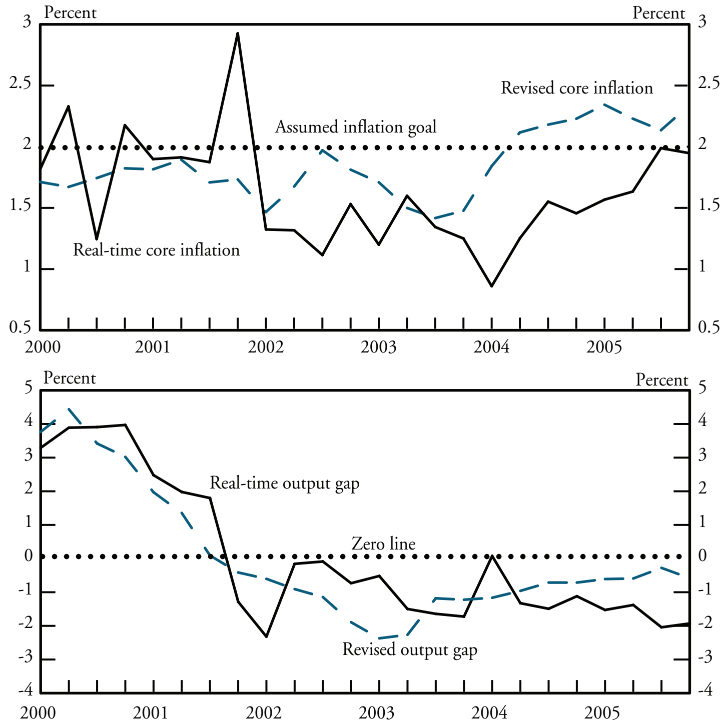
From a measurement standpoint, evaluating the Federal Reserve's policy during this episode is easier than the evaluation of the Bank of Japan's policy (Section II). The analysis of the Bank of Japan's policy relies on the latest vintage of data. By contrast, real-time data for the U.S. economy is readily available.[27] In addition, some of the information available to the FOMC at the time of each meeting is publicly available. Hence, policy can be evaluated using much of the same real-time data that may have been used in the Federal Reserve's policy decisions.

Some of the real-time data comes from the "Greenbook" report prepared by the staff of the Board of Governors of the Federal Reserve System and distributed to FOMC participants before each meeting. The Greenbook contains the Board staff's in-depth analysis of current economic and financial conditions in the U.S. and international economy, as well as forecasts of the evolution of the economy over a couple of years and assessments of the risks to those forecasts. Such information is viewed by committee members as a valuable input during policy discussions at the FOMC meeting (Poole). In addition, research shows that Greenbook forecasts, especially for inflation, contain valuable information on current and future economic developments and outperform private-sector surveys (Romer and Romer).

The Greenbook forecasts can be used in this analysis to construct a real-time series for inflation. Through 2003, the inflation measure is the current-quarter forecast of core PCE-price inflation at the time of each FOMC meeting.[28] Because subsequent Greenbooks are yet not publicly available, the inflation measure for the post-2003 period is the real-time data from the Bureau of Economic Analysis (BEA).[29] In addition, the real output gap is constructed with a standard estimate of potential output from the Congressional Budget Office (CBO). The CBO's estimates of potential output are available both as real-time and revised series.

Chart 5 shows the real-time (solid lines) and revised (dashed lines) data. Based on information available at the time, inflation plunged from 3 percent in late 2001 to 1 percent by mid-2002 and fell below 1 percent by early 2004 (top panel). With the benefit of hindsight, inflation was not as low as appeared at the time but still quite low.

*Chart 5*
## MEASURING THE U.S. ECONOMY




Notes: Revised core PCE inflation is from Chart 4. The real-time core inflation series shows Greenbook current-quarter forecasts through 2003Q4 (latest release publicly available) and then BEA data for the post-2003 period. The output gaps are log-differences between revised real GDP and the CBO measures of, revised or real-time, potential GDP.

Sources: Bureau of Economic Analysis (GDP and PCE), Congressional Budget Office (potential GDP), Federal Reserve Board of Governors (Greenbook forecasts), and author's calculations

Also based on information available at the time, the real output gap dropped below zero in late 2001 and continued to signal downward pressures on prices over the following years (bottom panel). The revised data indicate, however, that downward price pressures may have been stronger than thought in 2002-03, although not quite so strong from 2004 onwards.

### *Evidence from Taylor rules*

Real-time and revised measures of the economy can be used to evaluate U.S. monetary policy during its deflation scare. Chart 6 compares actual policy with the recommendations of original and optimal Taylor rules. These optimal Taylor rules incorporate a less vigorous policy response to inflation than the original Taylor rule (Section I).

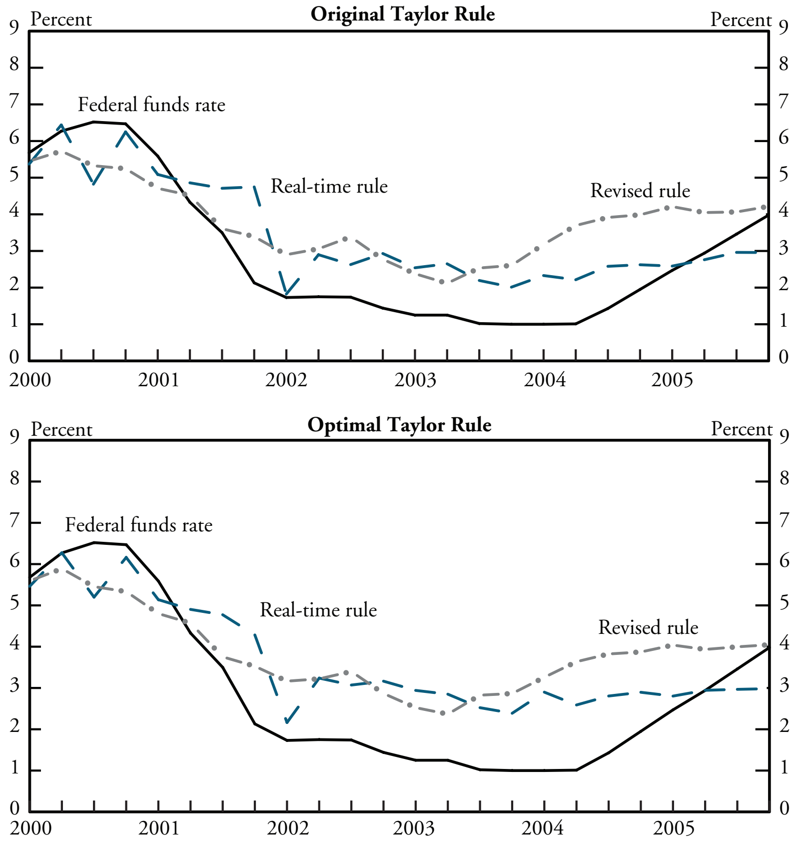
The top panel of the chart compares actual policy with the original Taylor rule's prescriptions. Based on information available at the time, policy in 2000 was too tight—that is, above the prescription. In 2001-04, it was too accommodative. Over this period, the federal funds rate (solid line) on average was 1 percentage point too low. And, in 2005, policy again became too tight. The federal funds rate was 1 percentage point too high by late 2005. With the benefit of hindsight, policy in 2000 was too tight. From 2001 onward, it became increasingly too accommodative. The federal funds rate on average was 1 percentage point too low in 2001-03 and 1.75 percentage points too low in 2004-05. The discrepancy between the prescriptions is mainly due to a substantial wedge between Greenbook forecasts and revised inflation, and to a lesser extent to the effects of the data revisions on the estimate of the output gap (Chart 5).

The bottom panel of the chart compares actual policy with the optimal Taylor rule's prescriptions. Based on information available at the time, policy in 2001-04 was too accommodative. Over this period, the federal funds rate was on average 1.25 percentage points too low. With the benefit of hindsight, policy became increasingly too accommodative from 2001 onwards. The federal funds rate on average was 1.25 percentage points too low in 2001-03 and 1.5 percentage points too low in 2004-05. In short, the original and optimal Taylor rules essentially both conclude that U.S. monetary policy over most of this episode was too accommodative.

Though many commentators have argued that the Federal Reserve's policy response might have been too strong, other factors not captured by Taylor rules may have contributed to policy decisions. Above all, however, the U.S. situation in the early 2000s resembled remarkably Japan's experience in the early 1990s. After carefully analyzing Japan's experience, a study prepared by staff at the Federal Reserve concluded that "Japan's sustained deflationary slump was very much unanticipated" and that "this was a key factor in the authorities' failure to provide sufficient stimulus." With the benefit of hindsight, however,

*Chart 6*

EVALUATING U.S. MONETARY POLICY




Notes: The calibration of the Taylor rules follows Taylor's original proposal, but the optimal Taylor rule is assumed to have a response coefficient on the inflation gap equal to 1. The Taylor rules are based on core PCE inflation and output gaps from Chart 5.

Sources: Federal Reserve Board of Governors (target federal funds rate) and author's calculations

the main concern is that policymakers "did not take out sufficient insurance against downside risks through a precautionary further loosening of monetary policy" (Ahearne et al.).

Based on these considerations, Federal Reserve policymakers concluded that, as inflation and short-term interest rates were approaching zero and the possibility of deflation could not be ruled out, policy stimulus should go beyond levels conventionally implied by baseline forecasts of inflation and economic activity. "Aggressively moving against the risk of deflation would pay dividends by reducing the odds on needing to deal with the zero bound on nominal interest rates should the economy be hit with another negative shock" (Kohn).

## IV. SUMMARY

This article explains how Taylor rules can be used to evaluate monetary policy. It compares actual policy during the Japanese and U.S. deflation scares with how policy would have been conducted using Taylor rules based, to the extent possible, on data available at the time.

The rule-based evidence suggests that Japan's monetary policy response during its deflation scare in the early 1990s might have been too weak. Yet Japan's sustained deflationary slump was largely unanticipated by policymakers and observers alike.

By contrast, U.S. monetary policy in the early 2000s might have been too accommodative, because policymakers kept the policy rate at historically low levels to limit the risk of deflation. Although the United States avoided deflation, some analysts claim housing market imbalances worsened significantly over this period. Thus, as the economy recovered from its crisis and the risk of deflation subsided, perhaps the stance of monetary policy should have been "normalized" faster. Admittedly, though, policymakers may have had reason to respond to other factors in the economy not captured by simple Taylor rules.

## APPENDIX—DESCRIPTION OF THE MODEL

This appendix describes the simple economic model used to design the optimal Taylor rule discussed in the text. It first provides the equations of the model. It then calibrates the model to the U.S. and Japanese economies.

### *Simple economic model*

The simple New-Keynesian model embodies three equations that explain the behavior over time of nominal interest rates, inflation, and output. In addition, a fourth equation summarizes the central bank's policy goals (Galí; Woodford).

The first equation is a *Taylor rule*, equation (1) in the text. The central bank is assumed to use equation (1) to decide the level of its policy rate.[30] The policy rate decision is a function of three factors. The first is the inflation gap. The second is the real output gap. And the third is the equilibrium nominal interest rate (the equilibrium real interest rate plus the inflation goal, $i_t^* = r_t^* + \pi_t^*$). For convenience, this equation is reproduced here:

$$i_t = \alpha(\pi_t - \pi^*) + \gamma(y_t - y^*) + i_t^*. \qquad \text{(A1)}$$

The second equation is a *Phillips curve*, which is based on firms' pricing decisions. It has two parts. It states that inflation today rises when expectations of inflation tomorrow rise. Inflation also rises when high household consumption pushes real output above its potential level. (To simplify notation, the real output gap is denoted below as $x_t = y_t - y^*$.) This equation takes the form:

$$\pi_t = \beta E_t \pi_{t+1} + \kappa x_t . \qquad \text{(A2)}$$

The third equation is an *Euler equation*, which is based on households' spending decisions. It has three parts. Household consumption today rises when expectations of consumption tomorrow rise. Household consumption also rises when there is a fall in the real interest rate (the nominal interest rate less expectations of inflation). And it might rise in response to "shocks" that hit the economy and positively affect consumption.[31] Such a shock might derive from numerous factors, such as changes in consumer preferences, productivity, government expenditures, or other temporary factors. This equation takes the form:

$$x_t = E_t x_{t+1} - \varphi(i_t - E_t \pi_{t+1}) + \varphi \eta_t . \tag{A3}$$

At the same time, the central bank is assumed to minimize a *loss function.* Doing so is thought to be equivalent to maximizing household welfare.[32] The loss function has three squared terms, one each for inflation, the real output gap, and the nominal interest rate.[33] It states that the loss rises when inflation is more variable. The loss also rises when the real output gap is more variable. And it might rise when the nominal interest rate is more variable (higher chance that policy rates approach zero).[34] The loss function takes the form:

$$\min E_0 \sum_{t=0}^{\infty} \beta^t (\lambda_\pi \pi_t^2 + \lambda_x x_t^2 + \lambda_i i_t^2) . \tag{A4}$$

Designing an optimal Taylor rule thus boils down to finding the response coefficients, $\alpha$ and $\gamma$, in rule (A1) that minimize the loss function (A4). To do so, the other parameters of the model must be assigned a numerical value or "calibrated."

## *Calibration*

Table A1 shows the calibration of the model. The values of the parameters in the rule ($r^*$ and $\pi^*$) are derived from Taylor's original proposal. The other parameter values are derived from Woodford's Tables 5.1, 6.1, and 6.2 based on U.S. data. The calibration abstracts from transactions frictions but accounts for the zero lower bound on nominal interest rates by imposing a penalty on its variability (the squared nominal interest rate in the loss function).[35]

The calibration has to be modified for Japan's economy. For the reasons explained in the text, the calibration is modified to incorporate more competition among firms. More competition has two implications on the calibration. It makes inflation less sensitive to the real output gap, or reduces $\kappa$. In other words, the Phillips curve will be "flatter." More competition also makes the variability of the real output gap less impor-

*Table A1*
## CALIBRATION OF THE MODEL

| Parameter | Numerical Value: | |
|---|---|---|
| | U.S. | Japan |
| $r^*$ | 0.5% | 0.5% |
| $\pi^*$ | 0.5% | 0.5% |
| $\beta$ | 0.99 | 0.99 |
| $\kappa$ | 0.024 | 0.02 |
| $\varphi$ | 6.25 | 6.25 |
| $\rho$ | 0.35 | 0.35 |
| s.d.($\varepsilon$) | 3.72% | 3.72% |
| $\lambda_\pi$ | 1 | 1 |
| $\lambda_x$ | 0.003 | 0.002 |
| $\lambda_i$ | 0.236 | 0.236 |

Notes: Because in the model the time period is one quarter, the parameter values correspond to inflation and interest rates measured at a *quarterly* rate.

Sources: Taylor, Woodford, and author's calculations

tant for household welfare. Thus, the loss function will have a smaller weight, $\lambda_x$, on the squared real output gap.[36]

To incorporate into the calibration more competition among firms, the price elasticity of demand, or $\theta$ in Woodford's notation, not shown in the table, is raised to 10 from 7.66. This higher level of competition reduces the slope of the Phillips curve, $\kappa$, by roughly 20 percent; it also reduces the loss-function weight, $\lambda_x$, on the squared real output gap by roughly 30 percent (Table A1). This choice may appear arbitrary. Nonetheless, the response coefficients in the optimal Taylor rule, as discussed in the text, appear robust to fairly more competition and a flatter Phillips curve.

## ENDNOTES

[1]In theory, nominal interest rates could fall below zero if money holdings were taxed or financial assets were not freely convertible into cash.

[2]For instance, during periods of especially high productivity growth, the equilibrium real interest rate will be high so that additional savings can be encouraged to meet high investment demand. During such a period, the equilibrium policy rate will tend to be high as well.

[3] In addition, good monetary policy typically requires that the response coefficient on the inflation gap be bigger than 1. In other words, the policy rate should rise more than one-for-one with increases in inflation. This requirement is known as the "Taylor principle." According to a number of theories and historical analysis, failure to meet the principle may allow inflation over time to become unanchored from the goal. However, recent research suggests that even a response coefficient on the inflation gap slightly smaller than 1 may keep inflation anchored to the goal, if at the same time the response coefficient on the real output gap is positive. Because the real output gap signals future inflation, this weaker condition ensures that in the long run the policy rate rises by more than the increase in inflation (Woodford).

[4]Specifically, Taylor used a series for potential real GDP that grows at an annual rate of 2.2 percent.

[5]By contrast, other types of rules may be tailored to exploit specific properties of a given model, but those properties are likely to be different in another model. For instance, "optimal inflation targeting rules" are tied directly to the first-order, or optimality, conditions of a model. Research shows that these rules perform poorly in models with different properties (Taylor 1999).

[6]The ability of the central bank to dampen economic fluctuations depends on the "stickiness" of firm's price setting. Firms are able to adjust their prices only gradually to changes in economic circumstances. As a result, monetary policy can cause changes in aggregated demand before prices have time to fully adjust. But in the long run, when prices fully adjust, monetary policy induces changes only to prices. In other words, monetary policy determines the long-run inflation rate.

[7]Clouse at al. and Sellon examine "nonconventional" methods of implementing monetary policy that may be effective even when short-term nominal interest rates reach zero.

[8]More competition has two roughly offsetting effects in a simple New-Keynesian model. First, it makes inflation less sensitive to the real output gap. The real output gap measures business cycles in the model. As a consequence, the central bank has to move the policy rate, and aggregate demand, more to affect inflation. Because the central bank is less effective controlling inflation, policy has to lean more against inflation. Second, more competition encourages the central bank to put less emphasis or "weight" on limiting fluctuations in the real output

gap, relative to its other goals—stabilizing inflation and the policy rate. If product markets are perfectly competitive, as in standard real business cycle models, there is no rationale in a simple New-Keynesian model for monetary policy to stabilize the real economy. Because the central bank puts more weight on stabilizing inflation, policy can lean less against inflation. In practice, these two opposing effects roughly offset in the model.

[9]The optimal response coefficients—$\alpha$ close to 1 and $\gamma$ close to 0.5—were found searching over values of $\alpha$ and $\gamma$ bigger than zero. The step size of the search was 0.5 with variables measured at an annual rate. The unconditional value of the central bank's loss function, equation (A4) in the Appendix, turns out to be fairly similar under the original and optimal Taylor rules. The reduction in the loss is less than 1 percent under the optimal Taylor rule. Thus, households enjoy a fairly similar level of welfare in the long run under both rules. But welfare can be far from optimal if $\alpha$ and $\gamma$ are far from their optimal values. In addition, in a simple New-Keynesian model, the Taylor principle requires that $\alpha + \gamma(1 - \beta)/(4\kappa) > 1$, where $\beta$ is the discount rate and $\kappa$ is the slope of the Phillips curve (Appendix). It can be verified easily that the response coefficients of both rules satisfy this condition.

[10]The unconditional likelihood of hitting the ZLB is 14 percent quarterly under the original Taylor rule and 13 percent quarterly under the optimal Taylor rule. Thus, under the optimal rule, the nominal interest rate would be expected to fall to zero one quarter less often every 100 quarters or, equivalently, four quarters less often every 100 years.

[11]Some Taylor rules assume policy rates depend directly on their past level, reflecting the view that interest-rate smoothing may be a beneficial way to conduct monetary policy (Amato and Laubach). In addition, Taylor rules may incorporate a "residual" term accounting for all other factors that might influence actual policy. But the residual is not expected to exhibit a systematic pattern.

[12]Standard economic models assume that financial markets are frictionless, always matching buyers and sellers at prices that perfectly equate risk-adjusted returns across all types of securities. Bankruptcy and default are typically nonexistent in these models. Therefore, these models cannot explain the effects of financial market disruptions on the real economy.

[13]Feldstein discusses the role of discretionary fiscal policy to counter deflation.

[14]This article follows the common narrative approach that uses the term "deflation scare" in reference to a period characterized by low (current and expected) inflation and policy limited in its ability to counter deflationary price pressures with conventional tools. An alternative approach would be to statistically identify a deflation scare, for example, as a period characterized by a sharp decline in long-term bond yields and no reduction in the short-term policy interest rate (Kuttner and Posen). See Bordo and Filardo for a historical analysis of past episodes of deflation.

[15]See Ahearne et al. and references therein for a more detailed account of the collapse of Japan's bubble economy.

[16]The unemployment rate is typically a “lagging indicator” or starts to pick up after economic downturns are under way. One explanation is that employers are reluctant to lay off workers, because it is more difficult to hire when the economy rebounds and labor demand is rising.

[17] Fujiwara et al.’s Table 1 shows how the assessment on inflation evolved in the Bank of Japan’s quarterly economic outlook report.

[18]Analysts were generally slow to revise downward their forecasts. By 1995, however, Federal Reserve Board staff, IMF staff, and private-sector analysts surveyed by Consensus Economics were marking down significantly inflation forecasts as data showing falling prices began to trickle in.

[19]Most other analyses of this period have also relied on revised data. See Yamaguchi, for example. One exception is Kamada, who uses revised GDP in estimating a real-time output gap, but who nevertheless uses revised CPI inflation in evaluating policy.

[20]Orphanides and van Norden show that, for U.S. data, measurement error associated with real-time output gaps only in part is due to revisions in published data; the bulk of the problem is a result of the pervasive unreliability of end-of-sample estimates of the trend in output. Nonetheless, imprecision at the end-points of the sample period can be reduced by extending the output series with forecasts, and then applying the Hodrick-Prescott filter to the extended series (Mise, Kim, and Newbold). This is the procedure used in this article.

[21]Fujiwara et al. find qualitatively similar results estimating potential output and the real output gap with a production function approach. See their Figure 7.

[22]In 1995, the Bank of Japan altered its traditional operating procedures based on changes in the discount rate and adopted a formal target for the uncollateralized overnight call money rate. Nonetheless, the latter rate is typically thought to correspond with the policy rate for historical analysis of Japan’s monetary policy through the 1990s. In addition, the equilibrium policy rate is assumed to change over time to account for the dramatic structural changes in Japan’s economy (Okina and Shiratsuka; Yamaguchi).

[23]The analysis is static in that it evaluates policy at each point in time without allowing an alternative setting of the policy rate to affect future output and inflation.

[24]Kuttner and Posen’s Tables 1 and 2 summarize appraisals of the Bank of Japan’s policy in the 1990s. Some of these studies use estimated, as opposed to calibrated, Taylor rules. Clearly, an estimated Taylor rule based on a central bank’s actual behavior is not necessarily the most suitable benchmark for assessing monetary policy, particularly when the estimation sample includes the period being examined. See also Kamada.

[25]Ahearne et al. and references therein discuss the scope and effectiveness of Japan’s fiscal policy.

[26]Bernanke, Reinhart, and Sack's Table 8 shows how the concerns about deflation evolved in relevant speeches and testimonies of Federal Reserve officials.

[27]Real-time data for the U.S. economy can be downloaded free of charge at the websites of the Federal Reserve Banks of Philadelphia and St. Louis.

[28]Because the FOMC meets more than once in some quarters, the forecast is from the Greenbook of the first FOMC meeting in each quarter.

[29]Greenbooks and other FOMC meeting-related documents are generally released to the public with a five-year lag. These documents can be accessed at the website of the Federal Reserve Board. Compared with the BEA reading, the Greenbook current-quarter forecast of core PCE inflation on average is 0.5 percentage point higher in 2000-01 and 0.25 percentage point lower in 2002-03.

[30]In this simple model there is only one interest rate. That is, the central bank's policy rate and the nominal interest rates on which households and firms base their decisions are assumed to be the same.

[31]The shock $\eta_t$ is modeled as an AR(1) stochastic process, with autoregressive coefficient $\rho$, and independent and identical normally distributed innovations $\varepsilon_t$.

[32]In the New-Keynesian framework, the central bank's loss function is derived as a second-order approximation of the discounted utility function of a representative household. Because households derive utility from consumption, lower values of the loss function may obtain higher expected consumption. Thus, up to second order, minimizing the loss function is roughly the same as maximizing household's welfare.

[33]The weights ($\lambda_j$ for $j = \pi, x, i$) on each of the squared terms in the loss function reflect the emphasis the central bank puts on limiting fluctuations in each goal. In the New-Keynesian framework, the values of these weights are not chosen ad hoc by the policymaker. Rather, they are derived as a function of the underlying structure of the economy to maximize households' welfare subject to the limits on policy imposed by the zero lower bound on nominal interest rates.

[34]The squared nominal interest rate in the loss function approximates, up to second order, the limits on policy imposed by the zero lower bound on nominal interest rates. Because of this, the article can follow the typical approach of solving the system of equations (A1)-(A3) with a standard linear solution method. Instead, accounting directly for the effects of the zero lower bound would require a nonlinear solution method (Billi).

[35]The parameter values have to be adjusted, because in the model the time period is one quarter. Specifically, Taylor's response coefficient, $\gamma$, on the real output gap is equal to 0.5 with variables measured at an annual rate; this is equivalent to 0.5/4, or 0.125, at a quarterly rate. Similarly, Woodford's loss-function weight, $\lambda_x$, on the squared real output gap is equal to 0.048 at an annual rate; this is equivalent to $0.048/4^2$, or 0.003, at a quarterly rate.

[36]See Woodford's Chapter 6 for more details.

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