BOARD OF GOVERNORS OF THE FEDERAL RESERVE SYSTEM

DIVISION OF RESEARCH AND STATISTICS

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To: Federal Open Market Committee

From: Robert Tetlow and Peter Tulip

Subject: Changes in Macroeconomic Uncertainty

Introduction and Summary

The current disruptions to the financial system and the economy are unprecedented in the post-war period. While these events may simply reflect an extremely bad draw from the distribution of shocks, they also seem consistent with a much greater inherent degree of macroeconomic volatility and uncertainty than we had previously imagined. In this memo we review these developments, appraise whether we need to adjust our confidence intervals for the staff and the Committee's projections, and offer some remarks on the nature of uncertainty. In brief, our main conclusions are the following:

- Recent forecast errors for output, unemployment and the federal funds rate have been highly unusual, while the behavior of inflation has been less surprising. This experience suggests that the Great Moderation period should probably be viewed as a transitory episode, at least insofar as real and financial variables are concerned.
- Because the confidence intervals regularly reported in the Greenbook have been based on the relatively calm conditions of the past 20 years, they are likely too narrow. Accordingly, we have decided to revise our procedures and will now report uncertainty estimates based on the experience of a longer history that includes more periods of volatility.
- The case for revising the uncertainty estimates that the Committee reports in the Summary of Economic Projections is less clear, largely for communications reasons. Thus, our recommendation is to continue with the current procedure used to construct these estimates.
- Increased macroeconomic volatility and uncertainty may have important implications for the conduct of monetary policy.

Recent Evidence on Changes in Uncertainty

The economic events since the middle of 2007 have come as a surprise to everyone, the staff included. The extent of the surprise is illustrated in figure 1, which compares the outlook from June 2007 Greenbook (the solid black line) with actual outcomes (the dashed red line). The 70- and 90-percent confidence intervals shown are taken from that

Greenbook, calculated by stochastic simulation of the FRB/US model using model residuals drawn from the period from 1986 to 2005. As the figure shows, outcomes for real GDP, the unemployment rate and the federal funds rate have fallen well outside the estimated range of likely outcomes; in contrast, the evolution of core PCE inflation has not been that surprising.

Table 1 compares the June 2007 forecast errors with the range of historical Greenbook forecast errors. As the first line of the table shows, in June 2007 the staff projected that real GDP would rise 2.5 percent over 2008, versus the currently estimated decline of 0.8 percent, implying an error of 3.3 percentage points. The last two columns of the table note that prediction errors larger than this have occurred in only 3 percent of six-quarter-ahead errors, regardless of whether those errors are measured over the calm 1986-2005 period (the period used to generate the confidence intervals shown in figure 1) or the longer and more volatile 1979-2008 period. The error for unemployment, shown in the second line of the table, was the largest over the 1986-2005 sample and almost unprecedented for 1979-2008 sample. In contrast, inflation errors, shown on the third and fourth lines, have fallen near the middle of the distribution. For example, 67 percent of core PCE errors from the 1986-2005 sample were larger.

Table 1: Forecast Errors for 2008, Relative to Previous Greenbook Errors
(percentage points, annual rate)

Variable (Q4/Q4 change except *)	June 2007 forecast	Outcome	Error	Percentage of errors that have been larger**	
				1986-2005	1979-2008
Real GDP	2.5	-0.8	-3.3	3	3
Unemployment Rate*	4.8	6.9	2.1	0	1
Core PCE prices	2.1	1.8	-0.3	67	65***
CPI	2.2	1.5	-0.7	44	51

* Fourth-quarter level. ** The percentage of six-quarter-ahead Greenbook forecast errors from the periods shown that were larger in absolute value than the error shown. *** 1981-2008

The current episode is not yet complete, and based on what we now know, we expect sizable forecast errors over similar time horizons this year. For example, in June 2008, the Greenbook projected that real GDP would expand 2.4 percent in 2009 and that the unemployment rate would stand at 5.6 percent in 2009:Q4. These projections now seem likely to result in even larger errors than those shown in table 1. In addition, if the economy were to unfold as we projected in the March 2009 Greenbook, the error associated with last year's forecast of core PCE price inflation in 2009 will look outsized relative to historical experience.

That the staff did not forecast such severe economic outcomes does not by itself imply large shocks; the staff could simply have had poor judgment by overriding historical relationships. But that does not appear to have been the case. Figure 2 provides a model-based perspective on this issue by displaying equation residuals from the FRB/US model from 1965:Q1 through 2009:Q1. Panel (a) shows a share-weighted sum of the residuals from the model's spending equations; panel (b) shows residuals from the equation for

consumer prices; and panel (c) shows residuals from the equation for the Baa corporate bond rate. The severity of the current shock is evident in the extreme observations at the right of panels (a) and (c); in fact, the spending and bond rate residuals for 2008:Q4 are 4 and 7 standard deviations away from zero, respectively. The spending residual for 2009:Q1 is likely to be similarly extreme, based on the current staff projection. Outliers of this magnitude have occurred more frequently than is consistent with the normal distribution.

To provide some additional perspective on the sources of these surprises, we estimate rolling regressions of simple output-gap and inflation equations.[1] If time variation in the coefficients can absorb the variation in the data over time, "structural" shifts in the model (and hence the economy) may be a culprit. However, if the variation in the data shows up in the residuals, other sources—including chance or misspecification of the model and thus the stochastic shocks—may be responsible.

These possibilities are assessed in figure 3. In both panels, the thick gray lines show what is *unexplained* in the regressions—the standard error of the regression residuals—indexed by the end date of the regression window. The thin black lines show the *explained portion* of the variability in the data as captured by the equations' R-squared statistic. The results for the output gap equation, in panel (a), show that the unexplained part dropped precipitously in the mid-1980s and stayed low into the 1980s, with no lasting change in the explained portion over the same period.[2] Recently, however, there has been a marked run-up in the residuals, with an accompanying decline in the explained portion of the relationship. That this arises notwithstanding that the current episode is much shorter than the 5-year window over which these rolling regressions are computed is a testament to the extremity of the current cycle. In contrast, panel (b) shows that there has been no concomitant increase in unexplained part of inflation variability, and that the explained portion has increased recently.[3]

These model-based results suggest that recent large forecast errors for real output are not readily explained by shifting economic relationships, at least not insofar as such shifts can be approximated by a simple equation; rather, the forecast errors manifest themselves as large residuals in the simple model. At the same time, large model residuals for real output do not, by themselves, confirm that the current cycle has just reflected a bad draw; the residuals may instead mean that the simple model is misspecified in a way more subtle than can be captured by allowing for time variation in coefficients. For inflation, the results suggest that the record of relatively good forecasting performance over the past twenty years might not be merely a matter of chance.

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[1] The output-gap equation regresses the gap on two lags plus a long-term real interest rate variable; all data are from the FRB/US model database. The Phillips-curve equation regresses core PCE inflation on lagged inflation, changes in relative food and energy prices, and the output gap. The results are shown for rolling five-year regressions, but broadly similar results obtain for somewhat shorter and longer windows.
[2] This is the so-called Great Moderation. In fact, the chart understates the magnitude of the phenomenon in some ways: While it shows that the explained variability rose somewhat and the unexplained variability fell appreciably, it does not show that total variability fell substantially, on average, after about 1984.
[3] Total variability in core PCE inflation, the left-hand-side variable in the inflation equation, fell substantially in the mid-to-late 1980s and has remained low ever since.

Possible Interpretations of the Recent Historical Evidence

What conclusions should we draw from the staff's recent forecasting record and the other empirical evidence just considered? In particular, what are their implications for our measures of forecast uncertainty? Deciphering this information is not straightforward. After all, confidence intervals are necessarily functions of the models and procedures from which they derived. If our models are seriously misspecified or our procedures flawed—both significant risks given our limited understanding of the economy—then we could easily misstate the width of these intervals. These and other considerations suggest a range of possible interpretations of recent events:

- *Random error.* We are in the midst of a rare, once-in-a-lifetime event requiring no fundamental modification of our models or procedures for assessing the average uncertainty of the economic outlook.
- *Unrepresentative sample.* The confidence intervals we report are too narrow because we have based our analyses on a historical period that was atypically calm.
- *Misspecified procedures.* Our stochastic simulation procedures are flawed because they overlook a predictable tendency for shocks to be autocorrelated during recessions and thus make inadequate provision for rare tail events.
- *Misinterpretation.* The nature of uncertainty is simply not revealed in a simple fanchart. In particular, our estimates of uncertainty might be reliable under "normal" conditions when our models provide reasonable, local approximations of the dynamics of the economy, but are a poor guide in more extreme circumstances when the full range of properties of the economy are exposed.

The available facts are insufficient to definitively support one of these possibilities over the others; ambiguity is pervasive. Nevertheless, in our assessment, we do not think it would be prudent to proceed as if recent disturbances represent nothing more than extreme draws from the stable distribution that we have been using. Our previous estimates of uncertainty would appear to have been too sanguine about the permanence of the Great Moderation.

The recent behavior of inflation may be an exception to this. Recent forecast errors for core inflation have been modest. Moreover, an argument can be made that a permanent structural break in inflation variability occurred in the early 1980s, as monetary policy changed from leaving inflation unanchored to pursuing something more firmly directly towards maintaining price stability. In principle, it would be possible to apply different procedures to different variables to estimate uncertainty (for example, assuming an enduring Great Moderation for inflation but not for activity), but making these adjustments does not seem worth the complication. That said, this issue bears watching because, as we have already noted, the inflation forecast errors for the current episode could turn out to be large.

If the recent experience has led us to revise up our estimates of uncertainty, it should also lead us to approach such estimates more cautiously. Forecasts go awry because the

unexpected happens. And while the unexpected may be a manifestation of random events, it might also be an indicator of an incomplete understanding of the economy. The prudent policy maker needs to respect the uncertainty of uncertainty.

Implications for Confidence Intervals

The staff regularly prepares several estimates of forecast uncertainty. These estimates are derived using a variety of techniques and data sources, including FRB/US stochastic simulations, past Greenbook projection errors, and the historical accuracy of projections published by private and government forecasters (including those released by the FOMC itself). In their current implementations, all these approaches have the common feature of relying on the experience of the Great Moderation period because they all employ data drawn exclusively from the last 20 years.

Our standard practice is to roll the fixed 20-year window forward one year at the time of the April FOMC meeting. Because recent errors for real activity have been large, the corresponding uncertainty estimates would increase noticeably with the incorporation of the 2008 data, even with no change in methodology. And confidence intervals are likely to widen again in 2010 when we pick up the 2009 results. However, as discussed in the previous section, further adjustments seem warranted. In particular, we see a case for lengthening the sample period from which errors are drawn to include errors from prior to the Great Moderation. In addition to adding a period of relatively greater volatility to the current sample, this would also avoid overemphasizing the experience of 2008.

Confidence intervals based on FRB/US stochastic simulations

What do these considerations imply for our procedures? In the case of FRB/US stochastic simulations, which are used to generate the probability fancharts and some of the confidence intervals reported in the Greenbook, our intention henceforth is to draw equation residuals beginning in the late 1960s (roughly the starting date for estimation of most of the key model equations). We also believe that a reasonable approach is to lengthen our sample range by one year annually, rather than to use a fixed window.

To illustrate how confidence intervals would look under this proposal, table 2 shows standard deviations about the March forecast. A standard deviation—interpretable as the size of a typical forecast error–is approximately half the width of the 70-percent confidence intervals shown in the Greenbook or Figure 1. That is, under conventional assumptions, there is about a 70 percent probability that actual outcomes will fall within one standard deviation of the forecast.[4] For comparison, table 2 also shows standard deviations using our previous 1987-2007 sample. Lengthening the sample widens the estimated range of uncertainty about the forecast, but the changes are small: the change in

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[4] The main exception to this is the funds rate, which has an asymmetrical distribution due to the zero bound.

procedure does not alter the assessment that recent developments have been extraordinary.[5]

Table 2: Standard Deviations of FRB/US Stochastic Simulations
(percentage points, relative to March 2009 baseline)

	Forecast horizon (quarters)				
	4	8	12	16	20
Real GDP					
Previous (1987-07)	0.9	1.1	1.3	1.4	1.4
Proposed (1969-08)	1.1	1.4	1.5	1.7	1.8
Unemployment Rate[*]					
Previous (1987-07)	0.3	0.5	0.6	0.7	0.8
Proposed (1969-08)	0.4	0.7	0.8	1.0	1.0
Total PCE price					
Previous (1987-07)	0.5	0.7	0.8	0.8	0.8
Proposed (1969-08)	0.6	0.8	0.9	0.9	0.9
Core PCE price					
Previous (1987-07)	0.3	0.5	0.6	0.7	0.7
Proposed (1969-08)	0.4	0.7	0.8	0.8	0.8
Federal Funds Rate[*]					
Previous (1987-07)	0.0	0.0	0.0	0.4	1.4
Proposed (1969-08)	0.0	0.0	0.2	0.8	1.8

Notes: Four-quarter growth rates except * which are Q4 levels.

Confidence intervals based on Greenbook forecast errors

For confidence intervals derived from historical Greenbook forecast errors, similar arguments support a lengthening of the sample period. However, staff forecasts from the late 1960s (the starting point for the sample used in FRB/US stochastic simulations) had a horizon that extended no further than 4 quarters. Accordingly, we have extended the Greenbook sample back to 1979, when consumer prices were first forecast and when the horizon for all variables extended to two years. However, for core PCE prices, forecast errors are only available from 1981. Table 3 shows the standard deviation of historical Greenbook errors for the proposed long sample and the previous short sample.

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[5] We have also rethought our method for calculating uncertainty about the federal funds rate in circumstances where the zero lower bound constrains monetary policy. As a result, the funds rate remains bound near zero for all but the biggest surprises and thus is subject to much less uncertainty than implied by the confidence intervals reported in figure 1. In order to maintain methodological consistency, all results reported in table 2 reflect the new approach, and some small changes to the model.

Table 3: Standard deviation of Previous Greenbook Errors
(percentage points)

	4-quarter horizon[**]	8-quarter horizon[**]
Real GDP		
Proposed (1979-2008)	1.5	1.5
Previous (1987-2007)	1.3	1.5
Unemployment Rate[*]		
Proposed (1979-2008)	0.6	0.8
Previous (1987-2007)	0.5	0.8
Total PCE price ***		
Proposed (1979-2008)	1.0	1.2
Previous (1987-2007)	0.8	1.0
Core PCE price		
Proposed (1981-2008)	0.6	0.7
Previous (1987-2007)	0.5	0.7

Notes: Four-quarter growth rates except * which are Q4 levels.
** 4- and 8-quarter horizons are measured from the quarter preceding the forecast date.
*** Where PCE price forecasts are missing (18 percent of the sample), we use CPI errors.

Perhaps surprisingly, lengthening the sample makes negligible difference to the estimated confidence intervals, with the small exception of total PCE price inflation. The reason is that Greenbook errors in the late 1970s through the mid 1980s were not unusual, in that the staff predicted developments in this period about as well as it has predicted developments since then. Greenbook-based confidence intervals are slightly wider than intervals derived from stochastic simulations, even when the latter use a 40-year sample. This may reflect that Greenbook forecast errors reflect real-time uncertainty whereas FRB/US stochastic simulations reflect within-sample estimation residuals.

FOMC-published estimates of average uncertainty

For the "Average Historical Projection Error Ranges" presented by the FOMC in the Summary of Economic Projections, the case for change is less compelling. Arguably these estimates are not intended to be the "best" estimates of uncertainty going forward, but rather to be a benchmark against which the FOMC's qualitative assessments of uncertainty can be interpreted by the public. And while accuracy is one feature of a good benchmark, which by itself would argue in favor of a change in procedure, simplicity is also important to effective communication. Stability also matters: Revisions to existing procedures, rather than enhancing communication might instead become a focus of attention in their own right, thereby diverting attention from the main message. A "hands-off" approach has merit in this regard. Furthermore, the financial crisis may turn out to be a once-a-century event. Should tranquility return, the above arguments would call for further changes to the sample period, with consequent public backtracking.

Ordinarily, the FOMC would update its estimates to incorporate recently available forecast errors for 2008 in the next release of the Summary of Economic Projections.

Estimates on this basis are shown in Figure 4 as the green line with dots.[6] As can be seen, these are somewhat larger than previous estimates, the dashed red line.[7] Further upward revisions may be expected next year when 2009 errors become available.

Another option would be to extend the sample period for measuring the errors. At the four-year horizon currently reported, errors can be calculated back some 30 years, following the commencement of long-term projections by the Administration and CBO in 1975 and 1976, respectively.   However, the data on forecast errors are somewhat thinner in the late 1970s. For example, the FOMC did not publish any forecasts until 1979; the Greenbook and SPF did not publish CPI forecasts until 1979 and 1981, respectively; forecast horizons were somewhat shorter; and many of the early forecasts were reported on an annual-average basis, rather than for the fourth quarter. Given the high correlation between forecasters, these gaps might not be serious, though they would become so were the sample to be pushed back much further. Average RMSEs for 1979-2008 are shown in figure 4 as the blue solid line, labeled "last 30 years."

However, extending the historical sample range to 30 years has its limitations. For activity, the increase in measured variability would be slight. Were such estimates adopted as a benchmark, FOMC participants would still probably wish to describe uncertainty as greater than normal, given the current situation. And for inflation, the change to the confidence intervals would be large when, as we have already discussed, it is not clear that current estimates of uncertainty are too small.

Uncertainty about uncertainty

No conventional approach for the measurement of uncertainty would result in a restatement of the fancharts in figure 1 that would come close to producing bands wide enough to encompass the economic outcomes of the past six quarters. Why is that? One way to think about recent events is that we are confronting not just an increase in economic volatility, relative to previous estimates, but also increased uncertainty about the amount of uncertainty we face. Such an assessment could have important policy implications.

If confidence bands are only local approximations of uncertainty *around a given model*, then sequences of shocks borne in periods of vulnerability could expose policymakers to unmodeled features of the economy—nonlinearities or missing variables, for example. Viewing the current episode in this way provides a somewhat different perspective on economic shocks: Instead of being purely random events, given by "nature," large and persistent shocks could in reality be indications that the economy has left the region for which the model is a good approximation. To the extent this is true, one might expect

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[6] Estimates for the April projections have already been sent to Committee participants in Table 1 of Deborah Danker's memo of April 16, "Request for April Projections."

[7] We have made two small changes to our approach, neither of which greatly affects the estimates. First, we now have FOMC forecasts from the spring and fall, and so no longer average the summer and winter forecasts. Second, we now date by event (or error) rather than forecast. This means we can use a uniform 20-year window for all horizons, which reduces quirks and permits a simpler description of the estimates.
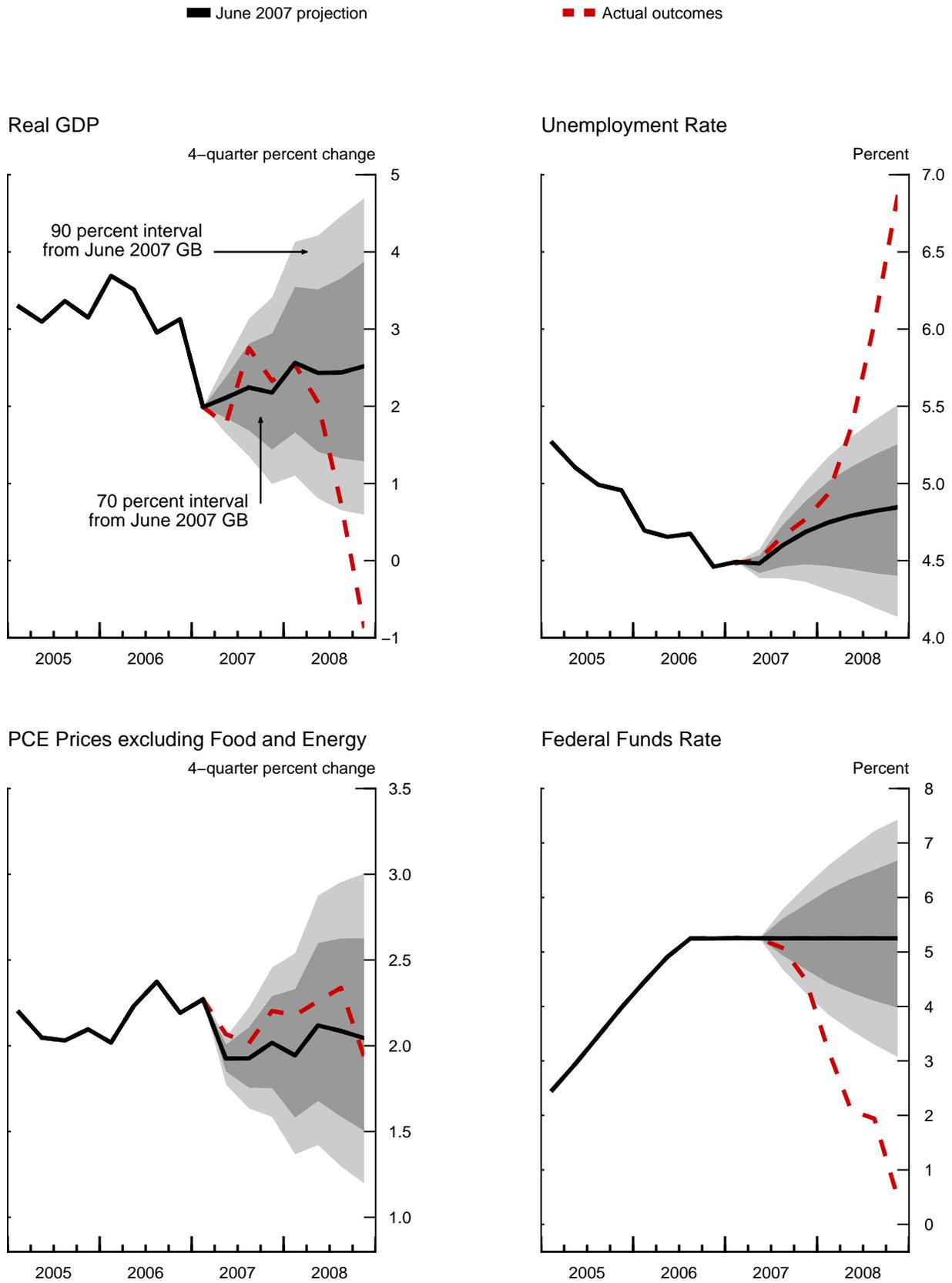
that those shocks that strain the outer boundaries of our confidence intervals might not be fleeting; reflecting, as they do, the misspecification of the underlying model, they could turn out to be more lasting—and damaging—than conventional stochastic modeling would suggest.

Increased economic variability and heightened uncertainty about the outlook have important implications for monetary policy. For example, if policymaker assessments of the inherent variability of real activity and inflation rise, concerns about the potential threat posed by the zero lower bound should increase as well. Larger and more persistent shocks increase the volatility of the economy, all else equal, and induce larger and more persistent movements in the funds rate in response. Larger swings in the funds rate, in turn, imply more risk of a binding zero-lower-bound constraint with all its consequences for economic stabilization and reliance on nonstandard policies.

As discussed in previous reports to the Committee, policymakers can respond to these less favorable circumstances by adopting strategies that either minimize the likelihood of a binding zero lower bound, or mitigate the costs imposed by the zero lower bound. The most basic of these strategies is to raise the Committee's objective for the average rate of inflation. Although a detailed analysis of this issue is beyond the scope of this memo, preliminary staff research suggests that even a significant rise in macroeconomic variability might merit only a modest increase in the target rate of inflation. For example, if policymakers were comfortable with a 1½ percent inflation objective conditional on variability similar to that seen over the past 40 years, then they might wish to raise the objective ½ percentage point or so if they decided variability was instead going to be 50 percent greater than in the past. In addition, staff work also suggests that a large shift in the Committee's inflation objective—say, on the order of 1 or 2 percentage points— would do little to increase the effectiveness of conventional monetary policy in an economic downturn as severe as that we now face.
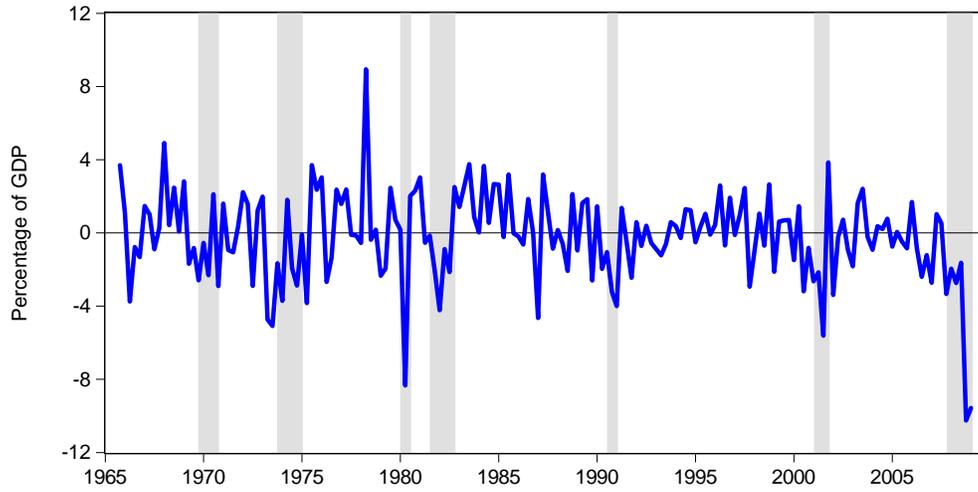
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Figure 1: June 2007 projection and actual outcomes

■■ June 2007 projection ----- Actual outcomes

Real GDP

4–quarter percent change

90 percent interval
from June 2007 GB

70 percent interval
from June 2007 GB

Unemployment Rate

Percent

PCE Prices excluding Food and Energy

4–quarter percent change

Federal Funds Rate

Percent

Figure 2: FRB/US residuals

a) Aggregate spending

b) Consumer Prices
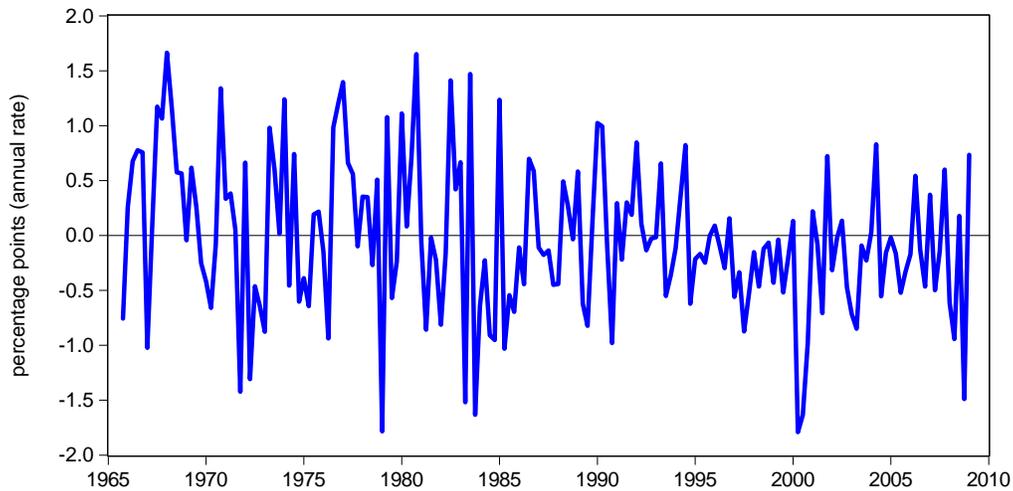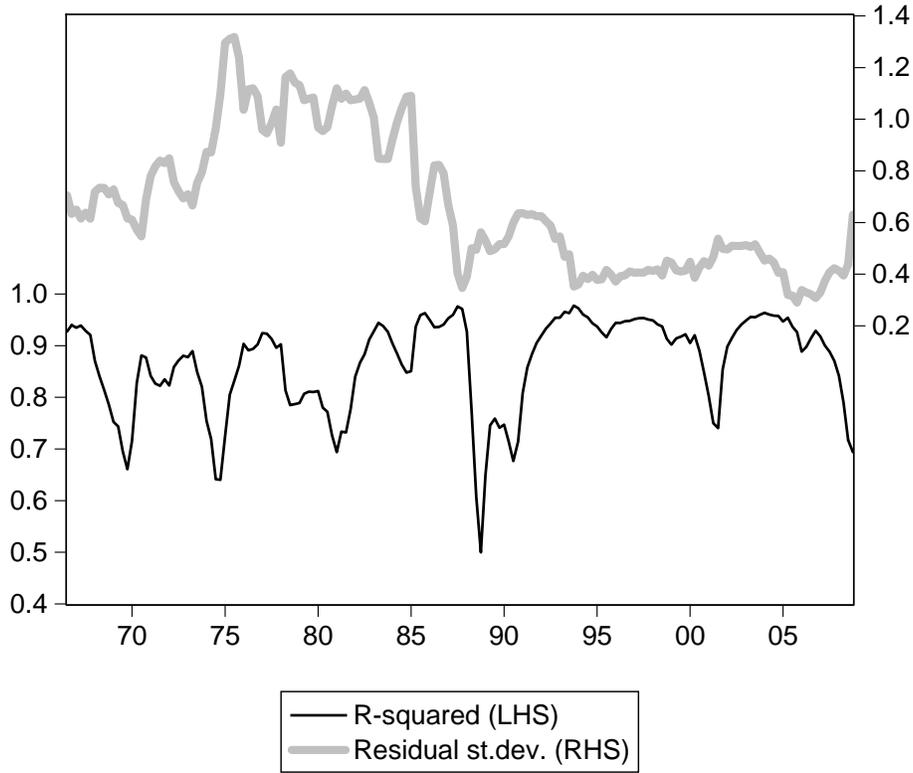

c) Baa bond premium
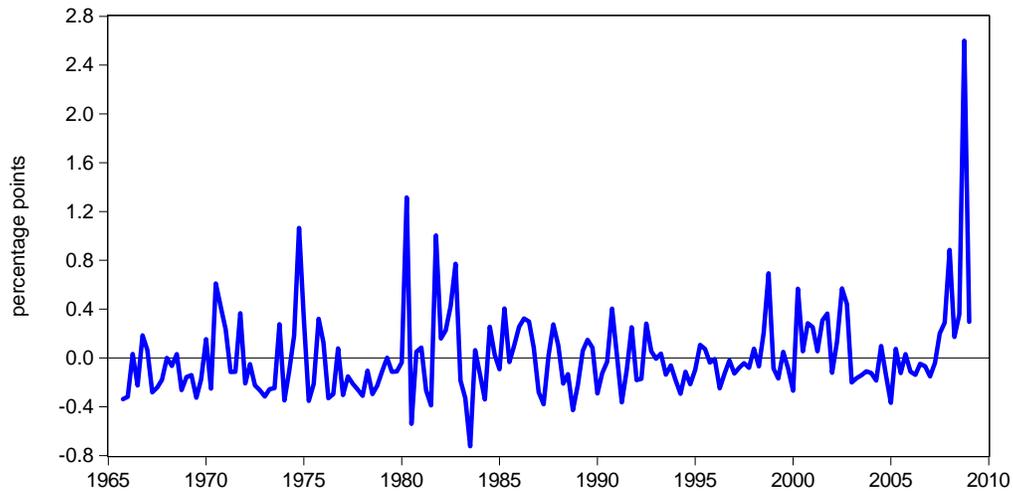
Figure 3: Output gap and inflation; rolling 5-year estimates
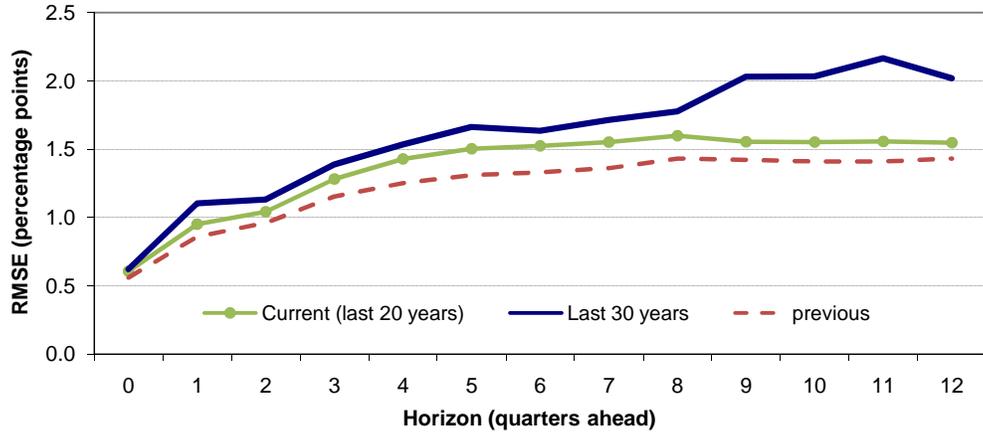
a) Output gap equation

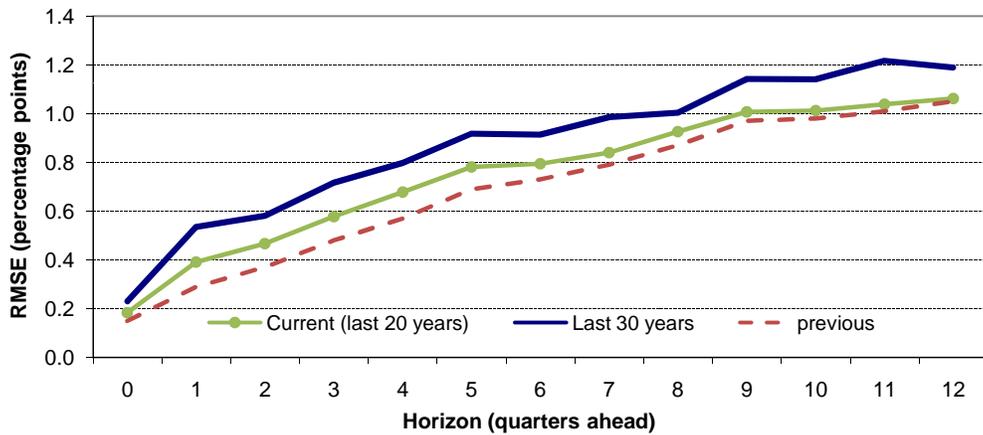### b) Inflation equation

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Figure 4

Average Root Mean Squared Forecast Errors

GDP, q4/q4 change

Unemployment Rate, q4 level

CPI, q4/q4 change